

Report for Webb Henderson – Public version

Review of the efficiency and
prudence of NBN Co's fibre, wireless
and satellite network design

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Contents

1	Executive summary	1
1.1	Efficiency and prudence of NBN Co's fibre network	2
1.2	Efficiency and prudence of NBN Co's fixed wireless network	6
1.3	Efficiency and prudence of NBN Co's satellite network	9
2	Introduction	13
2.1	Background	13
2.2	Question addressed in this report and scope of our review	13
2.3	Our approach	15
2.4	Documents reviewed in the preparation of this report	17
2.5	Structure of this report	18
3	Technical overview of FTTP networks	20
3.1	Introduction	20
3.2	Overview of FTTP technology options	20
3.3	TDM PON standards and architecture options	22
3.4	P2P network standards and architecture	27
3.5	Worldwide deployments	29
3.6	Technology roadmaps for GPON and P2P	30
3.7	Ability of GPON and P2P to meet evolving bandwidth demand	36
3.8	Operational considerations for technology upgrades	41
3.9	Conclusion	42
4	Technical overview of fixed wireless networks	43
4.1	Introduction	43
4.2	Overview of wireless technology options	43
4.3	Overview of 3GPP LTE technology standards	46
4.4	Overview of IEEE WiMAX technology standards	50
4.5	LTE and WiMAX comparison	54
5	Technical overview of satellite networks	56
5.1	Introduction	56
5.2	Overview of satellite technology options	56
5.3	Worldwide satellite broadband deployments	61
5.4	Technology roadmaps for broadband satellites	64
5.5	Ability of satellite broadband networks to meet evolving bandwidth demand	64
5.6	Conclusion	65
6	Review of the efficiency and prudence of NBN Co's fibre network design	66
6.1	Introduction	66

6.2	Fibre technology assessment	69
6.3	Fibre network architecture assessment	70
6.4	Fibre network infrastructure assessment	80
6.5	Conclusion	118
7	Review of the efficiency and prudence of NBN Co's wireless network design	123
7.1	Introduction	123
7.2	Wireless technology assessment	125
7.3	Wireless network architecture assessment	129
7.4	Wireless network infrastructure assessment	135
7.5	Conclusion	152
8	Review of the efficiency and prudence of NBN Co's satellite network design	156
8.1	Introduction	156
8.2	Satellite technology assessment	158
8.3	Satellite network architecture and regulatory assessment	161
8.4	Satellite network infrastructure assessment	170
8.5	Conclusion	178
Annex A	FTTP network benchmarking	
Annex B	Analysys Mason LTE link budgets	
Annex C	Description of the NBN Co satellite payload	
Annex D	Principal authors	
Annex E	Declaration	
Annex F	Glossary	

Acknowledgement

I have read, understood and complied with the contents of the 'Practice Note CM 7: Expert Witnesses in proceedings in the Federal Court of Australia' supplied to me by Webb Henderson. I agree to comply with the terms of the Practice Note.

Amrish Kacker for Analysys Mason Pte Ltd

A handwritten signature in black ink, appearing to read 'Amrish Kacker', with a long horizontal stroke extending to the right.

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26 September 2012

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1 Executive summary

NBN Co Limited (NBN Co) has submitted a Special Access Undertaking (SAU) under section 152CBA of the Competition and Consumer Act 2010 (CCA) to the Australian Competition and Consumer Commission (ACCC) for approval.

As part of the SAU process, Webb Henderson has commissioned Analysys Mason (hereinafter referred to as 'Analysys Mason' or 'we') to provide an expert opinion on whether, and the extent to which, NBN Co's design for its fibre, fixed wireless and satellite networks reflects an efficient and prudent network design.

To answer the above question with regard to the fibre and fixed wireless networks proposed by NBN Co, we first carried out a technical overview of fibre to the premises (FTTP) and fixed wireless technology used throughout the world by different operators, and where reasonable to do so, we have sought to benchmark NBN Co's approach to that adopted by overseas operators for the purposes of determining the efficiency and prudence of NBN Co's design. To answer the above question with regard to the satellite network we have benchmarked NBN Co's approach against existing satellite operators.

In preparing this report, we have used the following framework for analysis:¹

- in reviewing the 'prudence' of network design decisions made by NBN Co, we have had regard to whether those decisions have been made with care and thought for the future based on various factors, such as scalability, resilience and flexibility of the relevant element of the network design
- in reviewing the 'efficiency' of the network design decisions made by NBN Co, we have had regard to whether those decisions are likely to achieve the maximum result with minimum wasted effort or expense in the circumstances.

Our analysis of NBN Co's fibre, fixed wireless and satellite network designs has focussed on the following areas, which we consider to be key to an assessment of efficiency and prudence:

- technology choices
- architectural choices
- infrastructure choices.

In preparing our responses to the question put to us, we considered multiple sources of information that were provided by NBN Co that capture or explain the key decisions that have been made to date in respect of the design of NBN Co's fibre, fixed wireless and satellite networks. These have included:

¹

Due to the subject matter or nature of some of the decisions associated with developing a network design, it is not practically possible to evaluate all design decisions from both a prudence and efficiency perspective. In practice, this has meant that our analysis of some design decisions has, depending on the subject matter, focused on the prudence or efficiency of the particular choice, but not both. Accordingly, where an assessment in our report only refers to the efficiency or the prudence of the relevant design decision, but not to both, this should be taken to mean that Analysys Mason has only evaluated that particular decision by reference to the relevant specified factor.

- the Network Design Rules, which serve as the basis for establishing the efficiency and prudence of NBN Co's initial network design during the SAU approval process and which provide the baseline for the operation of the prudence provisions in Schedule 1E of the SAU
- other publicly available NBN Co documents, as further described in Section 2.4²
- various internal NBN Co documents that record key design decisions and the basis for those decisions.

This report does not examine the merits of the specifications given by the Australian Government to NBN Co at a policy level that impact on the design of the NBN. Rather, this report examines the key choices or decisions that have been made by NBN Co in the design of its network within the overall parameters that have been established by the Australian Government at a policy level through its *Statement of Expectations*.

Our findings in response to the specific question put forward by Webb Henderson are set out below:

“Please advise whether, and the extent to which, NBN Co's design for its fibre, wireless and satellite networks reflects an efficient and prudent network design.”

Analysys Mason advises that NBN Co's design of its fibre, wireless and satellite networks reflects an efficient and prudent network design for the reasons set out below.

1.1 Efficiency and prudence of NBN Co's fibre network

Analysys Mason considers that NBN Co's design of its FTTP network reflects an efficient and prudent network design.

In particular:

► *Technology decisions*

- NBN Co's decision to implement Gigabit passive optical network (GPON) for the mass-market segment prudently implements the requirements of the Australian Government under its *Statement of Expectations*.
- NBN Co's decision to use point-to-point (P2P) technology for the delivery of services to the enterprise and government segment is a prudent design choice for the supply of higher-bandwidth and symmetrical services to large government and enterprise customers, and represents international best practice.
- NBN Co's choice of Ethernet as a Layer 2 protocol is both efficient and prudent, as the choice of Ethernet aligns with global standards and is a proven technology, and will facilitate competitive vendor pricing and minimises technology risk/risk of stranded assets.

²

Available at <http://www.nbnco.com.au/our-network/industry-consultation.html>.

► *Architecture-related decisions*

- NBN Co's adoption of a centralised GPON architecture is both efficient and prudent, as it represents the best choice of architecture from a long-term cost-management perspective and from a network scalability and flexibility perspective.
- NBN Co's network design is prudent from a resiliency perspective for the following reasons:
 - the design of NBN Co's distribution fibre network is based on a ring topology, which provides path diversity from the fibre access node (FAN) to every fibre distribution hub (FDH) and will prevent any single fibre cut within the distribution fibre network from being service affecting
 - NBN Co could implement all standardised GPON protection option types, if required, using its proposed architecture
 - NBN Co plans to have at least two independent entry/exit locations in each FAN, which represents best practice and will ensure that each segment of the rings is diversely routed
 - a centralised architecture provides greater flexibility in the implementation of protection in the FDH as it is easier to design a ring topology around fewer sites hosting splitters.
- NBN Co's choice of ribbon technology for fibre cables is both efficient and prudent for the following reasons:
 - ribbon technology is modular and can provide adequate fibre counts for all parts of the network, standardising cable size and associated deployment processes
 - ribbon technology minimises operational expenditure (opex) as it allows the operational team to deal with bundled fibres simultaneously rather than as single individual fibres
 - each fibre in a ribbon is colour-coded, which mitigates against human connection errors, thereby minimising opex
 - fibre ribbon suits the pre-connectorised system being used by NBN Co as part of its fibre network roll-out
 - fibre ribbon cable is also better suited for aerial deployment (where required) because it weighs 60% less than a traditional stranded fibre cable, maximising the number of existing poles that can be potentially used for FTTP deployment
 - fibre ribbon cable is extensively deployed by leading FTTP operators internationally, including Verizon, NTT and Korea Telecom.
- NBN Co's proposed end-to-end service availability target of 99.9% is prudent from a network design perspective, having regard to the geography of Australia and specifically due to the significantly longer fibre runs in Australia compared to most overseas jurisdictions.

► *Infrastructure-related design decisions generally*

- As NBN Co has a mandate to provide services to 100% of the Australian population through a combination of FTTP, fixed wireless and next generation satellite technology, it is important that a prudence and efficiency analysis has regard to this fact. Analysys Mason considers that

the methodology used by NBN Co to determine the boundary between the FTTP network and the fixed wireless network is both prudent and efficient, as it will ensure that a maximum number of end users are covered by the FTTP network, while at the same time not resulting in NBN Co incurring disproportionate costs in the relevant circumstances. In particular, based on NBN Co's estimate of FTTP coverage of 92.3% for existing premises and 93% of existing and future premises (taking account of population growth), NBN Co will meet the Australian Government's minimum fibre coverage obligation of 90% and its objective of connecting 93% of premises with fibre. In other words, NBN Co's decision to set the reach of the fibre network at 92.3% for existing premises (and at 93% when taking account of both existing and future premises) serves as an efficient breakpoint for determining the boundary of the fixed and wireless network footprints.

- NBN Co's decision to re-use Telstra's infrastructure is prudent from an operational perspective. There are strong operational reasons to use underground infrastructure wherever it exists and is fit for purpose. The re-use of Telstra's existing infrastructure will provide more certainty (and therefore reduce risks) in a number of areas, including significantly reducing the need for NBN Co to construct its own duct infrastructure (which would increase NBN Co's construction costs and delay the roll-out of its fibre network). It will also overcome some of the downside that may be associated with aerial deployments, such as lower levels of reliability and higher associated opex. We also welcome the provide-or-pay (PoP) provisions contemplated in the NBN Co–Telstra deal, which will further increase the certainty of the available infrastructure.
- *Infrastructure-related design decisions at the end-user premises and the local fibre network*
- NBN Co's design of the local fibre network is prudent, as it uses a standard design for FTTP with a centralised architecture.
 - NBN Co's approach to the architecture and features provided on the network termination device (NTD) in areas served by fibre infrastructure is prudent, as it will allow simultaneous delivery of multiple applications and services by multiple service providers (SPs) and is consistent with industry best practice.
 - NBN Co's decision to provision a single fibre in the local fibre network for the initial service connection to the premises, along with a second fibre to meet future capacity requirements in respect of the relevant premises (e.g. to take account of subdivision of the relevant property), is both efficient and prudent, as we would recommend a strict minimum of two fibres per premises in the local fibre network for operational, growth and potential protection reasons. While the number of fibres that are needed in the local fibre network to cover non-addressable premises is challenging to evaluate at this point, we consider that NBN Co's overall provisioning of fibre in the local fibre network is prudent.
 - NBN Co's decision to pre-build the final drop is efficient and prudent, having regard to current levels of broadband penetration in Australia and the deal between NBN Co and Telstra, which provides for the migration of end users from the public switched telephone network (PSTN)

and hybrid fibre coaxial (HFC) network to the national broadband network (NBN). It is reasonable for NBN Co to assume a take-up profile of 70%³ in light of these factors and a decision to pre-build the final drop is the most cost-effective approach.

- NBN Co's decision to implement FDHs using street cabinets is a prudent choice, as it provides greater levels of flexibility over time than underground splitter enclosures and is also consistent with the approach that is implemented by the majority of operators using centralised GPON architectures worldwide.
- ▶ *Infrastructure-related design decisions in relation to the fibre distribution network*
- NBN Co's design of the distribution network is prudent, as it allows for different levels of protection to be implemented in the FTTP network, which will ensure high levels of resiliency.
- NBN Co's decision to re-use existing Telstra local exchanges for the FAN is both efficient and prudent, particularly in the context of NBN Co's deal with Telstra. As all ducts in Telstra's distribution network come back to local exchanges, the use of local exchanges as FAN sites will minimise additional civil works that would otherwise be required as part of the roll-out, resulting in cost savings relative to a situation where NBN Co was constructing its own facilities.
- NBN Co's approach to defining the size of fibre serving areas (FSAs) (which sets a maximum size of 38 500 geocoded national address files or GNAFs) is prudent, having regard to NBN Co's deal with Telstra and NBN Co's decision to use Telstra's exchanges as FAN sites and the geographical reach of GPON and P2P technology.
- NBN Co's decision to use an optical fibre distribution frame at FAN sites to connect to the FDH is prudent, as it will provide a higher level of flexibility than an optical consolidation rack.
- ▶ *Infrastructure-related design decisions in the fibre transit network*
- NBN Co's design and architecture for the transit network is prudent for the following reasons:
 - use of wavelength division multiplexing (WDM) technology is prudent as it is a mature technology, which has been adopted by most operators in their core networks throughout the world to minimise the number of fibres to be deployed
 - a single dark fibre pair leased from Telstra will be sufficient to carry traffic in different sections of the transit network for the medium and long term, thereby minimising opex
 - NBN Co has adopted a ring topology, which adequately addresses the requirements for a resilient transit network and provides an optimal solution for linking the points of interconnection (PoIs) and the FANs
 - NBN Co's implementation of an overlapping physical ring topology is also prudent as this makes the most efficient use of available infrastructure without compromising the resiliency of the network.

³ The expected penetration of 70% does not take into account the agreement between NBN Co and Optus which should increase the penetration further.

- NBN Co's intention to dimension each TC_4 AVC to a minimum of 150kbps is prudent, particularly in light of the forecast average fixed download volume for NBN Co services up to 2013. Our own analysis of busy hour estimates provide that the bandwidth per TC_4 AVC should be around 166kbps, which suggests NBN Co's own initial dimensioning is broadly consistent with our own calculations.
 - NBN Co's implementation of a semi-distributed PoI architecture is consistent with the requirements of the Australian Government in its *Statement of Expectations* and has been prudently implemented by having regard to the availability of competitive backhaul in accordance with the ACCC's 'competition criteria' and by having regard to duct space, power and cooling.
- *Future-proofing of NBN Co's fibre network*
- NBN Co's network design is likely to have a sufficient upgrade path to meet the reasonably anticipated requirements of access seekers and end users for bandwidth over the next 30 years.
 - In terms of bandwidth evolution, the GPON standard has a clear evolution path as the downlink bandwidth can be upgraded from 2.5Gbps to 10Gbps.
 - While it is difficult to predict how the technology will evolve in the next 30 years, we have not found any bottlenecks in the choice of the technology or design of the physical network that would mean the network cannot be upgraded in terms of bandwidth or functionality for the fibre network. In 2010, on behalf of Ofcom, Analysys Mason undertook a large-scale study regarding the capacity limitations in fibre access networks.⁴ In that study, we concluded that we did not believe that capacity will be the main limiting factor in GPON fibre access networks, and we do not foresee a situation where supply is unable to meet the growing demand of users. Instead, the study suggests that the bottlenecks in the access network may be in the operational upgrade of one generation of FTTP technology to the next, but we are confident these issues will be resolved in time.
 - The proposed GPON architecture is future-proof, especially regarding the dimensioning of the local fibre.

1.2 Efficiency and prudence of NBN Co's fixed wireless network

Analysys Mason considers that NBN Co's design of its fixed wireless network reflects an efficient and prudent network design.

In particular:

⁴ See <http://stakeholders.ofcom.org.uk/binaries/research/technology-research/fibre.pdf>.

► *Technology decisions*

- NBN Co's decision to deploy TD-LTE is efficient and prudent, as its adoption by major operators, such as China Mobile and Reliance Infotel, will create economies of scale, and so reduce the overall cost of the solution.
- Layer 2 wholesale services have not previously been implemented on TD-LTE networks, so this choice represents a technology risk, but this risk is mitigated by the fact that NBN Co reports that current trials to deliver these products are currently performing according to specification.

► *Architecture-related decisions*

- As NBN Co is using a standardised 3GPP architecture for its fixed wireless network, we consider that its approach to network architecture is prudent.
- Each area that is served by a wireless network will be associated with an FSA, therefore avoiding infrastructure duplication. We therefore believe that this is a prudent architecture design choice.
- From our past experience, an end-to-end service availability target of 99.9% is prudent for providing residential services with fixed wireless networks. Evidence produced by NBN Co indicates that the wireless network architecture will be able to deliver services that meet their availability target of 99.9%.

► *Coverage of wireless network*

- As mentioned before, in terms of overall coverage, Analysys Mason considers that the methodology used by NBN Co to determine the boundary limits between premises served by the fibre network and those served by the fixed wireless network is both prudent and efficient, as it will ensure that a maximum number of end users are covered by the FTTP network, while at the same time not resulting in NBN Co incurring disproportionate costs in the relevant circumstances. We consider this overall approach provides an efficient basis for determining where the fibre footprint stops and where the fixed wireless footprint starts. Using this process, NBN Co has derived lower and upper bounds for fixed wireless coverage of the 94th and 97th percentiles, which are fully in line with the Australian Government's *Statement of Expectations*.

► *Infrastructure-related design decisions at the end-user premises and the wireless access network*

- NBN Co is using NTDs with four data ports within the wireless footprint. This is a prudent decision, as it will allow simultaneous delivery of multiple applications and services by multiple service providers and is consistent with industry best practice.
- NBN Co has followed a rigorous and best-practice planning methodology to design the wireless access network, with test results showing that the estimated cell ranges are prudent. We also believe that the implementation of six 'first release' sites across Australia during 2012

is a prudent step to help further fine-tune the planning parameters (as well as systems and processes) before mass deployment.

► *Infrastructure-related design decisions in the wireless core network*

- NBN Co's development of a core wireless network based on 3GPP standards is prudent, as this will ensure that different network elements from several vendors inter-operate. Adopting a standardised approach is also efficient, as it will minimise costs because of the large volumes that are generated worldwide.
- We also note that:
 - NBN Co's decision to use the same PoIs for both the fibre footprint and the fixed wireless footprint will reduce duplication in infrastructure and will therefore be more efficient than using separate PoIs for the fibre and fixed wireless footprint. The same argument is valid for the transit network, which will be used for both the fibre footprint and the fixed wireless footprint
 - NBN Co's approach to core network scalability is efficient and prudent; the 'modular' packet data network gateway (PDN-GW) will enable NBN Co to invest in line with traffic demand and will also avoid over-investment
 - the use of redundant 1+1 PDN-GWs at every PoI site is prudent. Also, the duplication of wireless network elements (MME, HSS, EIR, PCRF, DNS/DHCP, etc.) in Sydney and Melbourne will also be vital in achieving the target availability set out by NBN Co.

► *Infrastructure-related design decisions in the backhaul network*

- For 'last mile' backhaul, the use of microwave technology is prudent for the short to medium term, as it represents the best choice in consideration of bandwidth requirements and costs (compared with fibre). We also believe that the dimensioning of the last-mile microwave link will not only support the minimum average busy-hour throughput (ABHT) bandwidth requirement for each premises, but will also provide support for all three sectors of a particular site to operate at or near their peak throughput.
- For 'mid mile' backhaul, NBN Co is planning to use microwave technology to aggregate traffic from a number of eNodeBs on a single link. This will range from two eNodeBs to up to eight eNodeBs on a single link (although we note that NBN Co intends to keep the number of eNodeBs on a single link to a minimum). When 3 or more eNodeBs need to be aggregated, we consider that the use of fibre in the mid mile would be a more prudent option for implementing mid-mile backhaul in terms of resiliency and bandwidth scalability but also note that the proposed microwave backhaul option provides the benefit of easier deployment within the proposed build timeframes for the fixed wireless network, which are unlikely to be met with a fibre based deployment in the mid mile.
- NBN Co's decision to generally use fibre for the last backhaul link before reaching the FAN is a prudent decision.

► *Future-proofing of NBN Co's fixed wireless network*

- We believe that NBN Co's fixed wireless network design is future-proof for the following reasons:
 - TD-LTE is a standardised technology and 3GPP has a clearly defined LTE roadmap to provide higher data rates in the future
 - the technology is supported by major mobile network operators worldwide, including China Mobile, Reliance Infotel and Softbank, which will ensure the existence of LTE for a long time in the future
 - TD-LTE is also backed by most equipment vendors, creating the high economies of scale for network and customer premises equipment that will benefit both operators and end users
 - devices will be able to support both time division duplexing (TDD) and frequency division duplexing (FDD) in the future
 - the wireless core network is based on fibre technology, which provides sufficient scalability in terms of capacity to accommodate increased end-user demands in the future.

1.3 Efficiency and prudence of NBN Co's satellite network

Analysys Mason considers that NBN Co's design of its satellite network reflects an efficient and prudent network design.

In particular:

► *Technology decisions*

- NBN Co's decision to procure high-throughput satellites rather than conventional FSS satellites is efficient given the amount of capacity required to meet the Government's expectation that the satellite network should be capable of providing service to 3% of Australian premises at a peak speed of at least 12Mbps, and prudent given the track record of the commercial high-throughput satellites in orbit.
- Given the amount of capacity required, it is efficient for NBN Co to procure Ka-band satellites and NBN Co appears to have been prudent in the way it has allowed for the increased level of rain fade that occurs in the Ka band.
- NBN Co's choice of Ethernet as a Layer 2 protocol is both efficient and prudent, as the choice of Ethernet aligns with global standards and the Layer 2 protocol to be used on NBN Co's fibre and fixed wireless networks.

► *Architecture-related and regulatory decisions*

- Given the bandwidth likely to be required to achieve the target overall capacity and peak throughput per user of at least 12Mbps, we believe that it is efficient and prudent for NBN Co to strive to make use of additional spectrum for CPE links beyond the two 500MHz bands allocated exclusively for FSS use by the ITU.

- Given that the expected number of users in certain spotbeams exceeds the capacity that could be provided by a single satellite, we believe that it is efficient for NBN Co to procure two satellites. A network based on two satellites is also more prudent than use of a single satellite since, in the unlikely event of the single satellite failing, service would be lost for an extended period (possibly several years).
- Having decided to order two satellites, it is efficient to place them in separate orbital positions as this doubles the capacity that can be obtained from a given amount of spectrum. This decision means that in the event of one satellite failing totally, it will be necessary to re-point half of the user terminals. Given the expected number of users this would clearly be a significant undertaking but we consider that the time required would be far less than the lead time for a replacement satellite. Consequently, we believe that this approach is prudent.
- NBN Co has prudently made four applications for orbital positions in case problems arise in co-ordinating the use of the two preferred positions. NBN Co appears to have proceeded efficiently with co-ordination activities to date.
- Analysys Mason believes that NBN Co's beam coverage plan, involving a combination of small and large beams, is efficient. The total number of beams specified is at the high end of the industry's proven capability, but we believe that this is manageable for an experienced satellite manufacturer so the decision should be regarded as prudent.
- While the size of the reflector necessary to produce the smaller beams is slightly larger than on previous high-throughput satellites, larger diameter reflectors of this type have flight heritage, and this is an area of continuing progress through industrial research and development. Analysys Mason therefore considers that this development is manageable following standard industry developments and qualification practice.
- Given the capacity requirement we believe that it is efficient and prudent to construct nine primary gateway locations with a tenth gateway location for disaster recovery. We believe that adjusting the amount of bandwidth allocated to each of the smaller beams to match the expected level of demand is efficient since it should increase the proportion of installed capacity that is ultimately usable. The approach is also prudent since there is some margin to manage uncertainties in the predictions and to implement the channel plan in the satellite network.
- NBN Co has adopted a centralised approach to the architecture for data processing centres (DPCs) required to support the satellite network. Although we have not seen detailed calculations showing the relative cost of a centralised versus a distributed DPC architecture, it seems intuitively reasonable that a centralised architecture would be more cost-efficient and would simplify maintenance, making it a prudent approach as well.
- We believe that the arrangements for connecting the gateways and the DPCs to the NBN Co fibre network using dual redundant links are prudent and efficient. We also believe that it is prudent to transport the data traffic in a separate virtual private network from the management

and control traffic since this minimises the risk of a fault condition on the data network affecting the management and control network, and vice versa.

- If the satellite network were being used as a back-up for NBN Co's terrestrial services, then it may have been prudent to use a different fibre transit network altogether to carry the traffic from the satellite network. However, since it is intended that different users should either have satellite or terrestrial service, we see no particular benefit in terms of prudence (but a significant loss of efficiency) by carrying the satellite traffic separately.

► *Infrastructure-related decisions*

- In our opinion, the CPE design is efficient in terms of the trade-off it provides between cost, performance and ease of installation. NBN Co's selection of ViaSat as its CPE provider is prudent since ViaSat is one of the leading suppliers of Ka-band satellite CPE.
- We believe it is efficient and prudent for NBN Co to choose a single supplier for both gateways and CPE given that there is a lesser degree of standardisation in satellite terminals and gateways than in the terminals and network equipment for fibre and terrestrial wireless networks.
- Analysys Mason believes that the complex decision on the location of gateways has proceeded efficiently and prudently. It is a complex trade across technologies, commercial and external factors.
- We believe that the improvement in link performance and availability associated with NBN Co's decision to choose the largest gateway antenna available, combined with the limited cost differential and low risk associated with the development, is a prudent and efficient choice.
- Based on Space Systems/Loral's track record of supplying high-throughput satellites, we believe that NBN Co's choice of manufacturer is prudent. We have not had access to the evaluation of the different proposals received, but have no reason to doubt that Space Systems/Loral was chosen on the grounds that it offered the most efficient approach.
- **[C-I-C]**
- We consider that NBN Co has been prudent to retain compatibility with three launch vehicles at this stage in the design process. However, we recognise that it may be more efficient from a technical perspective to allow the satellite mass to grow and restrict the choice of launch vehicles to two.
- We believe that NBN Co's approach to dimensioning the terrestrial links is efficient and prudent and that the initial capacities proposed are reasonable.

► *Degree of future-proofing in the satellite network*

- Once launched the total amount of capacity in each spotbeam provided by the satellites will essentially be fixed. Some marginal improvement may be possible by adjusting the transmission parameters. It may also be possible to increase the maximum speed for individual users by upgrading their CPE (for example, by installing a larger or more powerful outdoor unit or a higher-speed indoor unit).
- Nevertheless, since the satellite network is being used as one component of a national broadband network then it should be possible to meet evolving bandwidth demand by substituting terrestrial capacity for satellite capacity – for instance, if clusters of satellite broadband users are causing congestion in a particular spotbeam, it may be possible to serve some of the clusters with a new terrestrial wireless base station instead, freeing up satellite bandwidth to continue serving the most remote users.
- We also note that the spacecraft are being designed for a 15-year working life (the standard approach in the satellite industry) while other components of NBN Co's network are being designed for a 30-year working life. Consequently, there is an opportunity to revisit the requirement for the satellite network, and potentially implement a significant upgrade, approximately half way through the working life envisaged for the network as a whole.

2 Introduction

2.1 Background

NBN Co Limited (NBN Co) was established in April 2009 to design, build and operate a national broadband network (NBN) to deliver high-speed broadband and telephony services across Australia. NBN Co is a wholly owned Commonwealth company that has been prescribed as a Government Business Enterprise (GBE). The company has two 'Shareholder Ministers' – the Minister for Broadband, Communications and the Digital Economy, and the Minister of Finance and Deregulation.

NBN Co's remit is to design, build and operate a wholesale-only, super-fast broadband network that will initially provide downlink speeds of up to 100Mbps to 93% of premises in Australia using fibre (with a minimum fibre coverage obligation of 90%), and speeds of up to 12Mbps to remaining premises using wireless and satellite technologies. NBN Co is proposing to complete the construction of the entire NBN in approximately nine and a half years, by 2021, with on-going incremental investment to meet the needs of new housing growth, as well as technology upgrades to active equipment over time to increase the speed and/or capabilities of the network.

Under section 152CBA of the Competition and Consumer Act 2010 (CCA), an entity that is (or expects to be) a carrier or a carriage service provider of a listed carriage service, such as NBN Co, may submit a Special Access Undertaking (SAU) to the Australian Competition and Consumer Commission (ACCC) for approval.

As part of the SAU process, Webb Henderson has commissioned Analysys Mason to provide expert advice on the efficiency and prudence of NBN Co's design of its fibre, wireless and permanent satellite networks. Our terms of reference did not include any expert advice in respect of NBN Co's interim satellite network.⁵ For this reason, the interim satellite network is not considered further in this report and we refer to the NBN Co permanent satellite network simply as the satellite network.

2.2 Question addressed in this report and scope of our review

This report presents Analysys Mason's expert opinion on the following question that has been put to us by Webb Henderson:

“Please advise whether, and the extent to which, NBN Co's design for its fibre, wireless and satellite networks reflects an efficient and prudent network design.”

With regard to the satellite network, we were asked to advise in particular whether:

⁵ The terms 'NBN Co Permanent Satellite Network' and 'NBN Co Interim Satellite Network' are defined in the NBN Co SAU.

- NBN Co's decision to build and deploy two Ka-band satellites to deliver broadband to remote regions of Australia is both efficient and prudent. In undertaking our analysis, we were asked to take account of the need:
 - for NBN Co to meet future demand for satellite broadband capacity, and
 - to enable broadband satellite coverage with peak speeds of at least 12Mbps.
- NBN Co's infrastructure-related decisions regarding the design of the terrestrial elements of its Long Term Satellite Service (such as associated telemetry, gateways, data centres and tracking & command systems) are both efficient and prudent.
- NBN Co's approach to securing orbital slots for NBN Co's two Ka-band satellites is efficient and prudent, having regard to the approval process typically undertaken for a satellite deployment of this nature.

Webb Henderson's instructions specifically state that, in undertaking our assessment of whether, and the extent to which, NBN Co's design for its fibre, wireless and satellite networks reflects an efficient and prudent network design, Analysys Mason does not need to assess policy decisions that have been made by the Australian Government in its *Statement of Expectations*, including:

- the objective of connecting 93% of Australian homes, schools and businesses with fibre-to-the-premises (FTTP) technology providing broadband speeds of up to 100Mbps, with a minimum fibre coverage obligation of 90% of Australian premises
- the requirement for all remaining premises to be served by a combination of next-generation fixed wireless and satellite technologies providing peak speeds of at least 12Mbps
- the requirement for NBN Co to supply services to access seekers on a wholesale only, open access basis, via Layer 2 services
- the expectation that NBN Co will use existing infrastructure where it is efficient and economical to do so
- that NBN Co should proceed with network planning and construction of the roll-out on the basis of a Gigabit passive optical network (GPON) architecture, and
- the requirement for NBN Co to implement a semi-distributed points of interconnection (PoI) architecture, as a consequence of which NBN Co will establish 121 initial PoIs throughout Australia.

Therefore, in accordance with Webb Henderson's instructions, this report does not examine the merits of the specifications given by the Australian Government to NBN Co at a policy level that impact upon the design of the NBN. Rather, this report examines the key choices or decisions that have been made by NBN Co in the design of its network within the overall parameters that have been established by the Australian Government at a policy level through its *Statement of Expectations*.

As elements of NBN Co's network design have been specified at a policy level, Analysys Mason has sought to explicitly identify the relevant elements in its analysis, and either:

- not assessed them (where NBN Co has had to make no substantive design decision in fulfilling that policy requirement); or
- limited the assessment to determining whether any substantive design decision made by NBN Co as part of the implementation of that policy requirement is efficient and prudent (where NBN Co has had to make a substantive design decision in fulfilling that policy requirement).

For each major decision that NBN Co has had to make in respect of the design of NBN Co's satellite network, we:

- identify the design choice that had to be made (and where relevant, identify whether that decision was specified by the Australian Government at a policy level in its *Statement of Expectations*)
- provide some background discussion on the potential issues related to the design decision to be made
- state what NBN Co's position is in relation to the decision
- provide Analysys Mason's assessment of the decision from a prudence and/or efficiency perspective.

2.3 Our approach

Analysys Mason considers that the key decisions that influence the efficiency and prudence of a network design include:

- technology choices, which mainly relate to the technology being used to supply services
- architectural choices, which mainly relate to the topology of the network
- infrastructure choices, which relate to the physical implementation of different sections and nodes of the network.

It is in these specific areas of NBN Co's design of its fibre, wireless and satellite networks that we have focused our analysis.

In performing our analysis, we have had regard to, and have considered whether, NBN Co's design decisions are consistent with international approaches to date in the deployment of FTTP, fixed wireless and satellite broadband networks in other leading jurisdictions.

In undertaking our analysis and forming our conclusions, we have used the following framework for analysis:

- in reviewing the 'prudence' of network design decisions made by NBN Co, we have had regard to whether those decisions have been made with care and thought for the future based on various factors, such as scalability, resilience and flexibility of the relevant element of the network design
- in reviewing the 'efficiency' of the network design decisions made by NBN Co, we have had regard to whether those decisions are likely to achieve the maximum result with minimum wasted effort or expense in the circumstances.

Therefore, in developing this report, we have referred to the concepts of prudence and efficiency separately, using the plain English meaning attributed above. Due to the subject matter or nature of some of the decisions associated with developing a network design, we note that it is not always necessary or, indeed, practically possible to evaluate all design decisions from both a prudence and efficiency perspective. In practice, this has meant that our analysis of some design decisions has, depending on the subject matter, focused on the prudence or efficiency of the particular choice, but not both. Accordingly, where an assessment in our report only refers to the efficiency or the prudence of the relevant design decision, but not to both, this should be taken to mean that Analysys Mason has only evaluated that particular decision by reference to the relevant specified factor.

As part of our prudence analysis, we have sought to analyse whether, and the extent to which, NBN Co's design decisions establish a sufficient upgrade path to meet the reasonably anticipated requirements of access seekers and end users for bandwidth over the next thirty years (fifteen years in the case of the satellite network, since this is the expected working life of the two satellites proposed by NBN Co). The purpose behind this line of inquiry is to ensure that our analysis of NBN Co's key technology decisions is not static or 'frozen at a point in time', but that consideration is also given to the extent to which key technology decisions made by NBN Co today allow NBN Co to readily upgrade its network over time to meet the evolving demand from access seekers and end users (e.g. for additional bandwidth). This reflects, in our view, a key element of considering the prudence of NBN Co's design decisions, as described above.

It is also important to note that many decisions have to be made as part of the development of an efficient and prudent network design. Our analysis has sought to consider, from an efficiency and prudence perspective, many of the key individual design choices that have been made by NBN Co. However, it is the combination of these individual design choices and decisions that together determine whether the NBN Co fibre, fixed wireless or satellite network, as a whole, is efficient and prudent from a design perspective. Therefore, while we have made individual assessments of the efficiency and prudence of individual design choices and decisions, our overall conclusion on the question of whether, and the extent to which, NBN Co's design for its fibre, fixed wireless and satellite networks reflects an efficient and prudent network design, is based on Analysys Mason taking a view on NBN Co's design of each network in its totality.

Finally, our analysis has also considered the prudence and efficiency of NBN Co's design of its fibre, fixed wireless and satellite networks in a collective sense. As NBN Co has a mandate to provide services to 100% of the Australian population through a combination of FTTP, fixed wireless and next-generation satellite technology, it is important that a prudence and efficiency analysis have regard to this fact. For example, while an operator may deploy a fibre, fixed wireless or satellite network on a standalone basis (and the efficiency of that network design would be appropriately considered on a standalone basis), as NBN Co is utilising three different technologies to deploy the NBN, NBN Co's design decisions for its fixed wireless and satellite networks would need to be reviewed in light of how that network interacts with, and utilises, elements of NBN Co's FTTP infrastructure (such as PoIs and fibre backhaul). The absence of such analysis would mean that the efficiencies that would be gained by designing NBN Co's fibre, fixed

wireless and satellite networks in an integrated manner would not otherwise be considered. This would result in a situation where NBN Co's network design would be held to a lower prudence and efficiency standard than should be the case in the applicable circumstances. Accordingly, we have sought to apply our analysis of NBN Co's fibre, fixed wireless and satellite networks in a collective manner, where relevant.

2.4 Documents reviewed in the preparation of this report

In undertaking our assessment of the efficiency and prudence of NBN Co's design of its fibre and wireless networks, we considered multiple sources of information that were provided by NBN Co that capture or explain the key decisions that have been made to date in respect of the design of NBN Co's fibre and wireless networks.

Some of the key documents that have underpinned our review include:

- *Statement of Expectations* from Senator the Hon Penny Wong, Minister for Finance and Deregulation, and Senator the Hon Stephen Conroy, Minister for Broadband, Communications and the Digital Economy (dated 17 December 2010)⁶
- NBN Co's Network Design Rules, which serve as the baseline for the network design contemplated within the prudence provisions in Schedule 1E of the SAU
- NBN Co Special Access Undertaking given to the ACCC in accordance with Part XIC of the Competition and Consumer Act 2010 (Cth)
- NBN Co's Product and Pricing Overview for Service Providers, dated December 2011 (and the preceding version)⁷
- NBN Co's Consultation Paper: Proposed Business and Enterprise Fibre Access Services, dated 23 December 2011⁸
- NBN Co's Network Availability Discussion Paper⁹
- NBN Co's Network-Network Interface Discussion Paper¹⁰
- NBN Co's Traffic Class Performance Paper for the NBN Co Fibre Access Service¹¹
- NBN Co's Wholesale Broadband Agreement¹²

⁶ http://www.dbcde.gov.au/__data/assets/pdf_file/0003/132069/Statement_of_Expectations.pdf

⁷ <http://www.nbnco.com.au/assets/documents/product-and-pricing-overview-dec-11.pdf>

⁸ <http://www.nbnco.com.au/our-network/industry-consultation/proposed-business-and-enterprise-fibre-access-services.html>

⁹ <http://www.nbnco.com.au/our-network/industry-consultation/network-availability-discussion-paper.html>

¹⁰ <http://www.nbnco.com.au/assets/documents/nni-whitepaper-dec-2011.pdf>

¹¹ <http://www.nbnco.com.au/our-network/industry-consultation/traffic-class-performance-discussion-paper.html>

- NBN Co's Facilities Access Product overview paper¹³
- NBN Co's Multicast: Feature, Technology and Pricing overview for multicast over fibre¹⁴
- NBN Co's Fair Use Policy¹⁵
- NBN Co Points of Interconnect documentation on the ACCC website.¹⁶
- Requests for co-ordination in respect of AUS-NBN-2, AUS-NBN-3, AUS-NBN-4 and AUS-NBN-5 (dated 6 September 2011).

We have also reviewed some internal documents provided by NBN Co, such as consultation papers being prepared for public release and internal (confidential) planning documents that record key network design decisions and the basis for those decisions. We have also taken into account the written and verbal answers received from NBN Co to a number of questions posed by Analysys Mason.

Our assessment reflects the documentation and position taken by NBN Co as at 26 September 2012. Any modifications (if any) to the architecture, product roadmap or product construct made by NBN Co after 26 September 2012 may not be reflected in this report.

2.5 Structure of this report

The remainder of this report is laid out as follows:

- **Section 3** presents a technical overview of FTTP networks; it is designed as a reference point for all fibre-related products and architecture discussed in the rest of the report
- **Section 4** provides a technical overview of fixed wireless network technology that is suitable for the provision of broadband services; it is designed as a reference point for all fixed wireless-related products and architecture discussed in the rest of the report
- **Section 5** presents a technical overview of broadband satellite networks; it is designed as a reference point for the discussion of the efficiency and prudence of NBN Co's satellite network design.
- **Section 6** presents our analysis and conclusions in respect of whether, and the extent to which, NBN Co's design for its fibre network reflects an efficient and prudent network design

¹² <http://www.nbnco.com.au/getting-connected/service-providers/wba.html>

¹³ <http://www.nbnco.com.au/assets/documents/facilities-access.pdf>.

¹⁴ <http://www.nbnco.com.au/our-network/industry-consultation/nfas-technical-discussion-paper-multicast.html>.

¹⁵ <http://www.nbnco.com.au/assets/documents/fair-use-policy-30-nov-11.pdf>.

¹⁶ <http://www.accc.gov.au/content/index.phtml/itemId/952292>.

- **Section 7** presents our analysis and conclusions in respect of whether, and the extent to which, NBN Co's design for its fixed wireless network reflects an efficient and prudent network design.
- **Section 8** presents our analysis and conclusions in respect of whether, and to what extent, NBN Co's design for its satellite network reflects an efficient and prudent network design.

In addition, a number of annexes are included which contain the following supporting documentation:

- **Annex A** presents six case studies of FTTP deployments around the world to allow us to benchmark the technical solution adopted by NBN Co for the NBN against the solutions adopted for the deployment of other national broadband networks
- **Annex B** includes the Long Term Evolution (LTE) link budgets used by Analysys Mason to evaluate the prudence of NBN Co's fixed wireless network design
- **Annex C** describes the payload of the proposed NBN Co satellites.
- **Annex D** describes the expertise and experience of the principal authors of this report
- **Annex E** includes declarations from Analysys Mason as per the requirements of *Practice Note CM 7: Expert Witnesses in proceedings in the Federal Court of Australia* supplied by Webb Henderson
- **Annex F** provides an explanatory list of the acronyms used throughout this report.

3 Technical overview of FTTP networks

3.1 Introduction

This section presents a technical overview of FTTP technologies, and is designed as a reference point for the rest of this report. It is structured as follows:

- Section 3.2 describes the technical options available for deploying an FTTP network – namely passive optical network (PON) and point-to-point (P2P) network architecture
- Sections 3.3 and 3.4 describe PON and P2P networks respectively in terms of their standards, possible architectures and key network elements
- Section 3.5 provides an overview of the key worldwide deployments of GPON and P2P technologies
- Section 3.6 includes a technology roadmap for the next 25 years for both PON and P2P technologies, to show the expected evolution of bandwidth and reach for each technology
- Section 3.7 presents a simple demand model scenario, which evolves over time, to assess whether PON and P2P technology roadmaps will be able to meet the expected demand in the future, and more generally, if these technologies are future-proof
- Section 3.8 provides insight into key operational issues associated with technology upgrades and migration for both PON and P2P networks.

Supplementary reference material can be found in the Analysys Mason report for Ofcom entitled *Fibre Capacity Limitations in Access Networks, January 2010* (hereinafter referred to as ‘the Analysys Mason report on access networks for Ofcom’).¹⁷

3.2 Overview of FTTP technology options

Infrastructure providers seeking to deploy an FTTP network have two options for the physical topology:

- PON topology
- P2P topology.

Each option is described in more detail below.

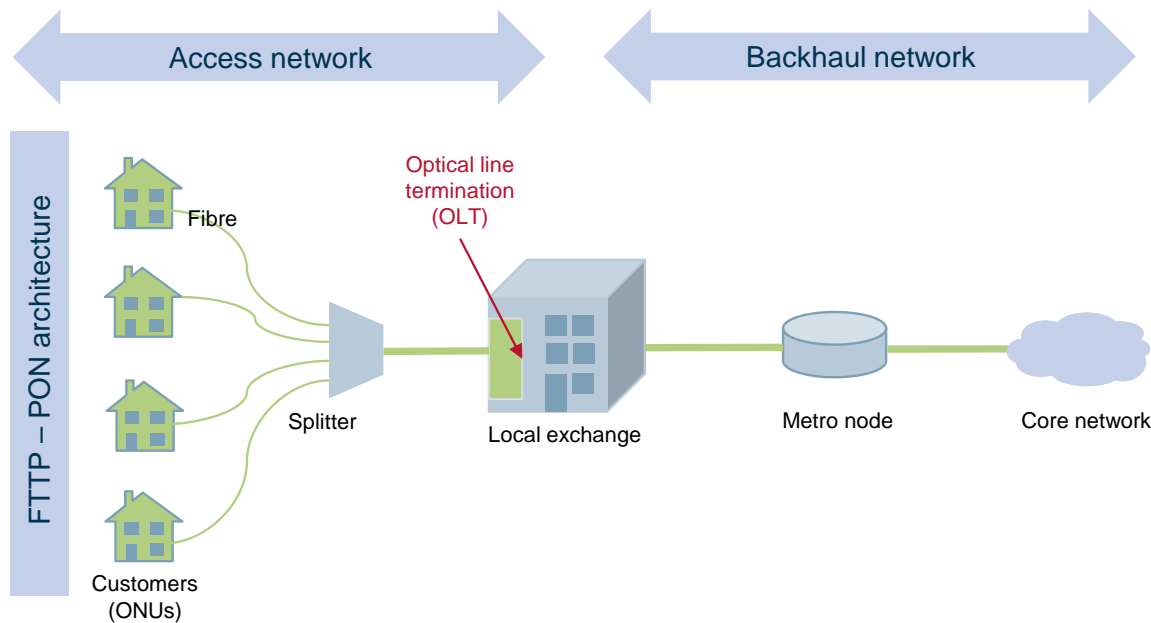
To better understand FTTP technology, it is important to understand the evolution of different FTTP technologies. Here, we describe how FTTP technology has evolved over time. It should be highlighted that NBN Co will primarily provide GPON-based fibre services, complemented by some P2P-based services to meet the specific requirements of the enterprise and government segment.

¹⁷ Analysys Mason for Ofcom (2009), *Fibre Capacity Limitations in Access Networks*. Available at: http://www.ofcom.org.uk/research/technology/research/emer_tech/fibre/.

3.2.1 PON architecture

A PON is a point-to-multipoint, FTTP-based architecture in which unpowered (passive) optical splitters are used to enable a single optical fibre to serve a number of subscribers (typically 32 or 64). Other PON components include the optical line terminal (OLT) at the infrastructure provider's local exchange and the optical network units (ONUs), also referred to as network termination devices (NTDs), located with the end users. These components are illustrated in Figure 3.1 below.

Figure 3.1: PON architecture [Source: Analysys Mason]



In a PON, the single fibre between the OLT and the passive splitter is shared by all customers connected to the PON, which significantly reduces the number of fibres required in the network.

The active layer is defined as all electronic components in the network. There are three principal options for implementing the active layer for a PON:

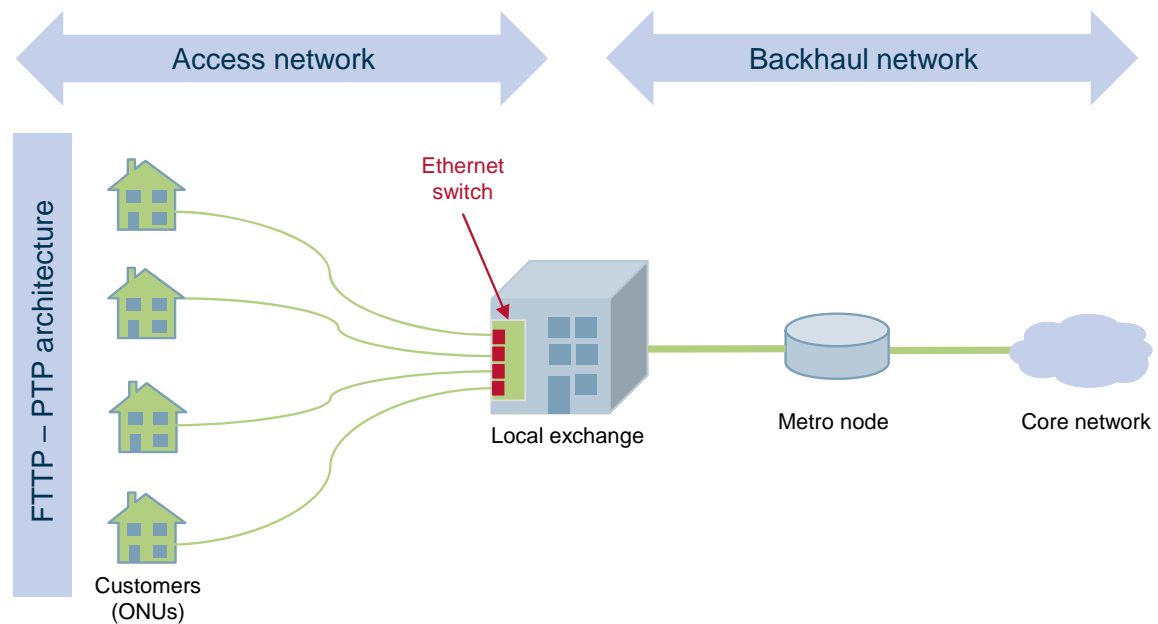
- **Ethernet PON (EPON)** is an IEEE/EFM standard for using Ethernet in the last mile (IEEE 802.3ah). EPON is applicable for data-centric networks, as well as full-service voice, data and video networks. It is less popular in Europe and the USA than in Japan and South Korea, where it dominates. The current download/upload speed of EPON is 1Gbps.
- **Gigabit PON (GPON)** is an evolution of the broadband PON (BPON) standard, and its standardisation is supported by the International Telecommunication Union (ITU) and the Full Services Access Network (FSAN) Group. GPON can provide asymmetrical bandwidth (2.5Gbps downstream and 1.25Gbps upstream), shared by all subscribers on the same fibre.
- **Wavelength division multiplexing PON (WDM PON)** consists of dedicating a wavelength and associated bandwidth to every user connected to a PON, providing dedicated bandwidth over a shared infrastructure. The WDM PON standardisation body is the FSAN Group. It should be noted that this **technology has not yet been standardised**, although some operators have already deployed proprietary solutions from leading vendors.

EPON and GPON systems are collectively referred to as **TDM PON** architecture because they both rely on time division multiplexing (TDM) technology. This is in contrast to **WDM PON** systems, which use frequency to separate users' signals. WDM PON is not discussed in detail in this document as it has not yet been standardised and does not represent a feasible deployment option for NBN Co.

3.2.2 P2P architecture

P2P architecture is based on existing **Ethernet** technology, whereby a dedicated fibre with dedicated capacity is deployed from the local exchange to the premises for each individual user. A typical P2P architecture is illustrated in Figure 3.2.

Figure 3.2: P2P architecture [Source: Analysys Mason]



3.3 TDM PON standards and architecture options

3.3.1 TDM PON standards and associated timescales

GPON standards

The FSAN Group, which is led by operators, defined a series of PON technologies that have now been implemented as ITU Recommendations. These Recommendations include APON (ATM PON), BPON and GPON, which provide 2.5Gbps downstream and 1.25Gbps upstream for a maximum of 64 optical network terminations (users, in the case of FTTP). The ITU Recommendation for GPON is the ITU G.984 standards series, which was first approved in 2003.

In June 2010, the FSAN Group and the ITU standardised next-generation GPON (XG PON),¹⁸ which provides 10Gbps downstream and 2.5Gbps upstream (four times the download speed of the previous generation of GPON).

¹⁸ ITU-T G.987.x standard series.

It is expected that a symmetrical version of 10G GPON (10Gbps downstream and upstream) will be standardised under the XG PON 2 programme, towards the end of 2012.

EPON standards

In June 2004, the IEEE approved an EPON standard with a 1Gbps symmetrical bitrate – known as **Ethernet in the last mile** (IEEE 802.3ah). The first EPON deployment took place in 2004/2005, with Japan leading the market. At the end of 2011, we estimated that 40 million EPON¹⁹ ports have been deployed worldwide.

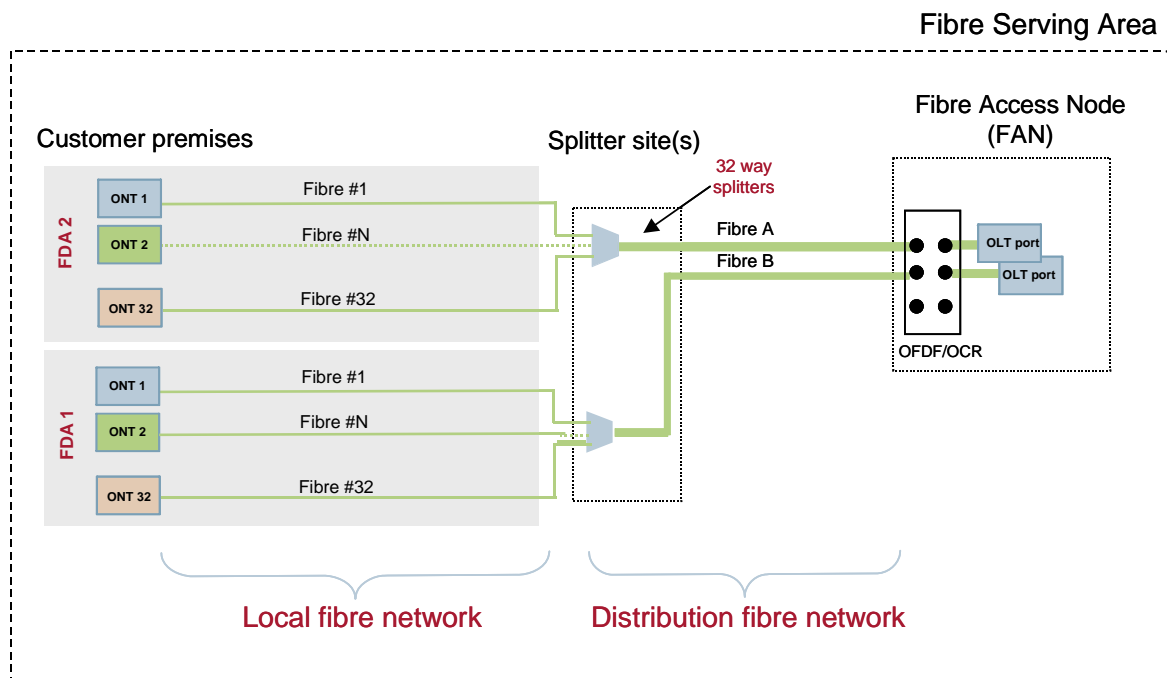
The next generation of the IEEE family of PON is the 10 GEPON (Gigabit Ethernet PON). This was standardised by the IEEE P802.3av task force in September 2009 and is backwards-compatible with IEEE 802.3ah EPON.

3.3.2 TDM PON architecture and deployment options

Reference model and definition of terms

Figure 3.3 below shows a reference GPON architecture. We note that the architecture principles are equally applicable to EPON, but for clarity we consider the components discussed below in the context of GPON only.

Figure 3.3: Reference GPON architecture [Source: Analysys Mason]



For the purposes of this report, we define the following terms in relation to Figure 3.3:

¹⁹ Analysys Mason FTTx Forecast, 2011.

- **Fibre access node (FAN)** – a FAN contains active GPON electronics. It houses the OLT, which has typically three shelves to house typically eight GPON line cards, and each of which contains typically four or eight line-card ports. Each line-card port drives a single PON, which leaves the FAN as a single distribution fibre. The optical fibre distribution frame (OFDF) or optical connection rack (OCR) within the FAN acts as a fibre management node and sits between the OLT and the incoming fibres from the distribution fibre network. There are two types of fibre management equipment: an optical distribution frame (ODF), which contains connectors, and an optical connection rack (OCR), which contains fusion-splice based connections. The OCR option is less flexible, but also less prone to faults.
- **Optical splitters** – optical splitters are passive elements that split the incoming optical signal N ways. In Figure 3.3, there are 32-way splitters. Splitters are typically hosted in underground enclosures, street cabinets or in overhead enclosures (mounted on a pole).
- **Fibre distribution hub (FDH)** – an FDH is usually defined as a site where several optical splitters are hosted. Therefore, an FDH represents a consolidation point for splitters and so is used in the context of a centralised architecture.
- **Fibre distribution area (FDA)** – an FDA is defined as the geographical area served by an FDH (i.e. all customers attached to a particular FDH).
- **Distribution fibre network (DFN)** – a DFN comprises the fibre network between the FAN and the splitter sites. The DFN connects each splitter to an OLT port using a dedicated fibre.
- **Local fibre network (LFN)** – an LFN represents the fibre network between the splitter sites and the end users. In a local fibre network, each fibre is dedicated to a particular customer. It should be noted that an LFN can include a number of network access points (NAPs), which are generally used as access points to connect individual end users.
- **Fibre serving area (FSA)** – as illustrated in Figure 3.3, the FSA is defined as the geographical area and associated users served by a FAN. In other words, an FSA is defined as the aggregate area served by all FDAs associated with a FAN.

GPON deployment options

In GPON, three main splitter architectures are currently used in the industry:

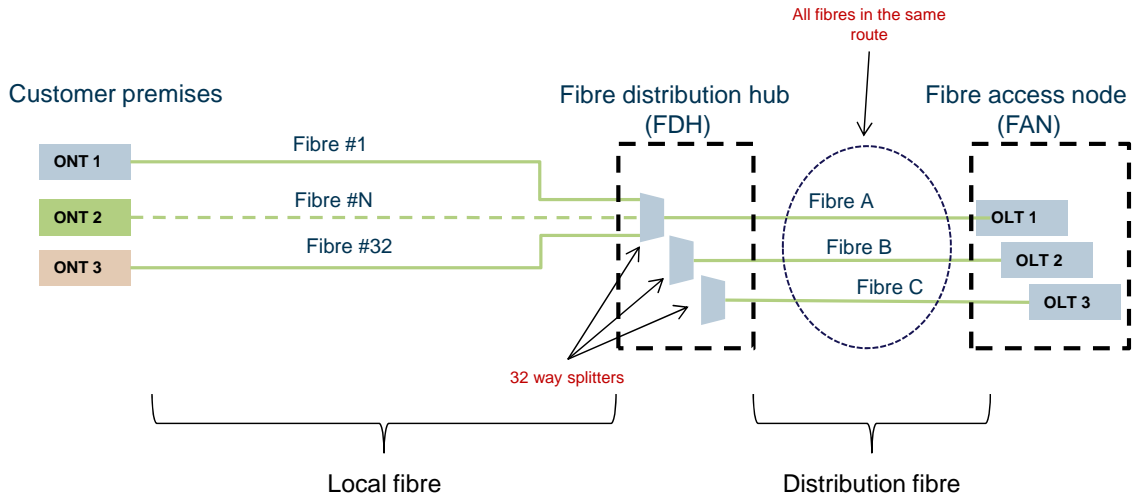
- centralised architecture
- distributed architecture
- cascaded architecture.

The chosen architecture usually depends on the distribution of the end-user premises within the FSA. The three architectures are discussed further below.

► *Centralised architecture*

Figure 3.4 shows the centralised splitter architecture.²⁰

Figure 3.4: Centralised splitter architecture [Source: Analysys Mason]



A centralised splitter architecture uses a single level of split (a 1×32 splitting scheme is illustrated in Figure 3.5 with all of the splitters co-located in a single location). This location is often referred to as an FDH. The FDH can be physically implemented either in the form of a street cabinet or in the form of an underground enclosure, as illustrated in Figure 3.5 below.

Figure 3.5: Underground enclosure (left) and street cabinet (right) for splitters [Source: Analysys Mason]



The use of a centralised architecture has the advantage of providing an aggregation point for splitters, which in a low-penetration scenario can save OLT cards. Also, the fact that splitters are aggregated in a

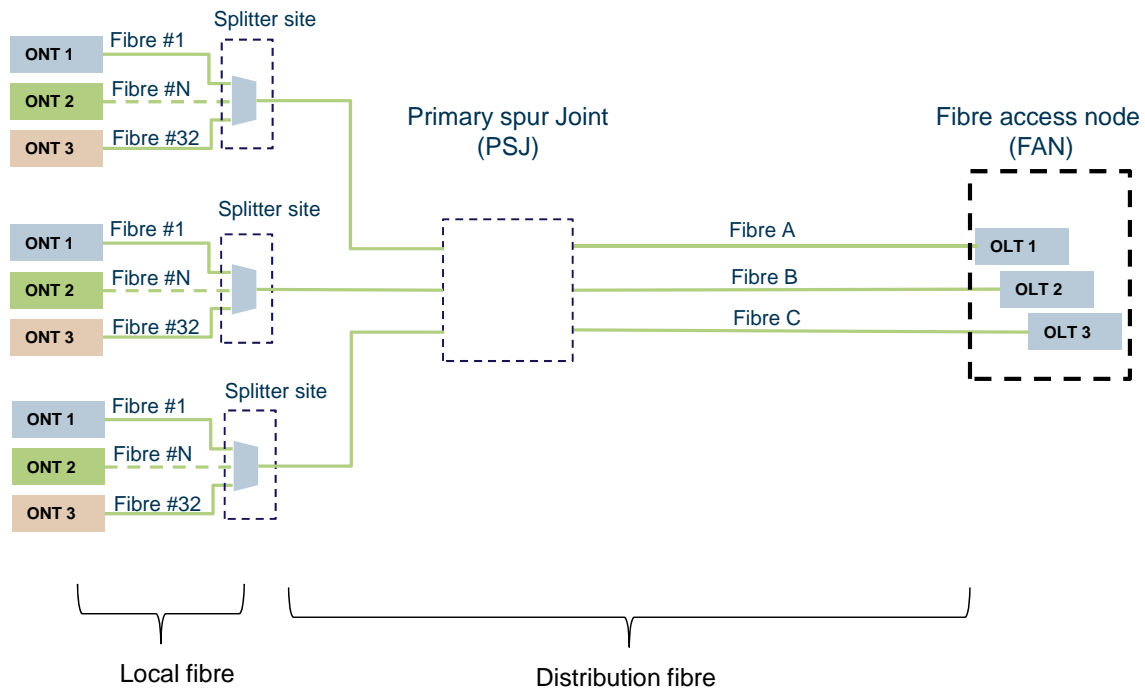
²⁰ Please note that, in this report, a centralised architecture does not refer to the case where all splitters are hosted in the FAN site, but refers to an architecture where all splitters are centrally located in a remote cabinet.

central location means that, in a centralised architecture, fewer splitter sites will be required, which reduces the number of footboxes/manholes required when compared with a distributed architecture.

► *Distributed architecture*

Figure 3.6 shows an example of a distributed splitter architecture.

Figure 3.6: Distributed splitter architecture [Source: Analysys Mason]

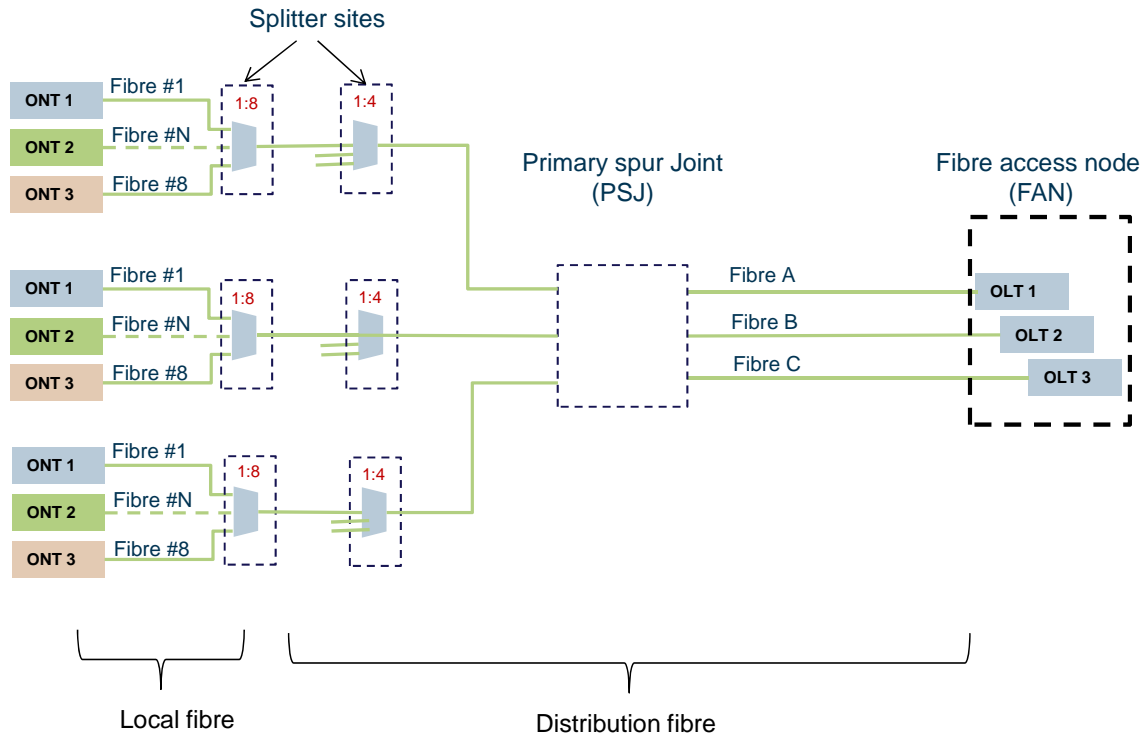


A distributed architecture uses a single level of split (a 1×32 splitting scheme is illustrated above) with the splitters distributed in the field, closer to the end users. In a distributed architecture, splitters are usually located in either underground footboxes/manholes or in enclosures on poles (in the case of aerial local fibre). This architecture maximises the length of the distribution fibre and so is often referred to as a duct and fibre lean architecture, which provides an opportunity to save significant capex in civil works, as existing infrastructure can be re-used.

► Cascaded architecture

Figure 3.7 shows the cascaded splitter architecture.

Figure 3.7: Cascaded splitter architecture [Source: Analysys Mason]



In contrast to the centralised and distributed architectures, a cascaded architecture uses multiple levels of split (commonly two) as illustrated in Figure 3.7, which shows a 1×4 splitter followed by a 1×8 splitter to achieve a total 32-way split. In this example, all splitters are located in the external plant environment. However, it should be noted that the first splitter can also be located within the FAN.

A cascaded architecture is a good choice where discrete clusters of end users exist. For example, in the case of a cluster of four multi-dwelling units (MDUs), with eight dwelling units in each MDU, the best configuration is to have one 8-way splitter facing each MDU, with an additional 4-way splitter downstream.

3.4 P2P network standards and architecture

3.4.1 P2P standards

P2P technology has been standardised as Ethernet in the first mile and is based on the IEEE 802.3ah standard. The IEEE 802.3ah working group was established in 2001 in order to enable Ethernet penetration into access networks. In parallel, the EFM Alliance (EFMA) was formed by the participating vendors, to promote Ethernet subscriber access technology and support the IEEE standard effort. The EFM standard was approved in June 2004 and published in September 2004 as IEEE 802.3ah-2004. The EFMA was absorbed by the Metro Ethernet Forum.

Central to P2P standardisation is the standardisation of bi-directional optics that can operate in a full duplex mode, where upstream and downstream operate along the same fibre. These standardisations are:

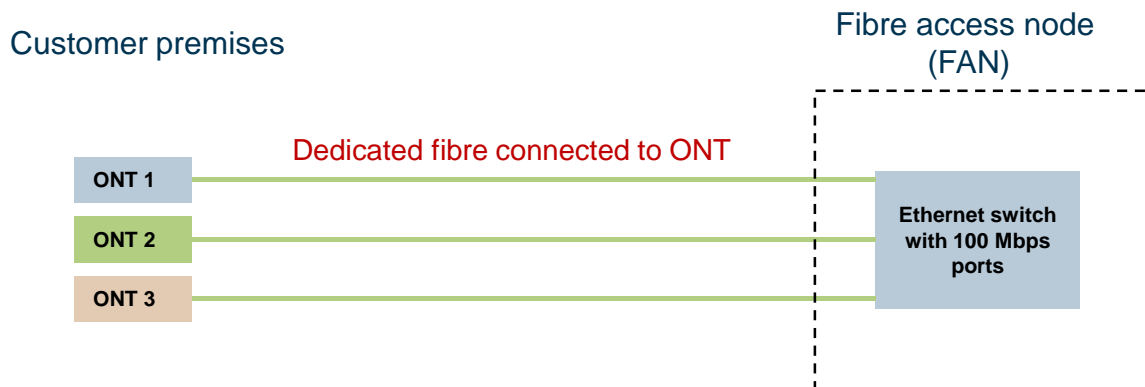
- **100BASE-BX10**, a version of Fast Ethernet over a single strand of optical fibre, where a special multiplexer splits the signal into transmit and receive wavelengths. The two wavelengths used for transmitting and receiving are either 1310/1550nm or 1310/1490nm. This is specified for use over distances of 10km.
- **1000BASE-BX10**, the Gigabit Ethernet equivalent of 100BASE-BX10, also specified to operate over 10km.

The 10G Ethernet interface 10GBASE-BX is also available, but this is not currently used in P2P systems because such capacity is not required, especially for residential applications.

3.4.2 P2P architecture

As illustrated in Figure 3.8, the P2P architecture is relatively simple, consisting of dedicated fibres between the central office and each end user.

Figure 3.8: Reference P2P architecture [Source: Analysys Mason]



In a P2P system, the capacity on each fibre is dedicated to a single user, making this solution scalable in terms of bandwidth and therefore appropriate for users who require a high capacity (e.g. medium and large businesses). However, the main disadvantage of P2P is the number of fibres required for deployment, which may mean there is insufficient space in the existing infrastructure to deploy these fibres and so there may be a need for additional civil works when compared to a PON-based solution. Additionally, due to the amount of fibre that needs to be managed and maintained, a P2P solution involves higher operational expenditure (opex) for an operator than a PON-based solution.

3.5 Worldwide deployments

According to IDATE,²¹ EPON technology is used to provide services to around 60% of FTTP/FTTB subscribers worldwide. It should be noted that EPON is mainly deployed in Asia,²² in early-adopting countries such as Japan and South Korea (as explained further in Annex A). However, the current trend among operators that choose TDM PON technology is to move away from EPON and deploy GPON, as is currently being done by South Korean incumbent, KT. The transition to GPON is mainly happening because GPON can offer twice as much bandwidth on the downlink as EPON, and also because the next generation of EPON will provide a 10Gbps symmetrical service, which will impose significant technology and cost constraints on the NTD. For these reasons, EPON no longer represents a viable choice of FTTP technology.

For countries that have decided to deploy FTTP/FTTB infrastructure more recently, GPON is the technology of choice among incumbent operators for delivering broadband services to residential and small business customers. For example, as discussed in Annex A, Verizon is currently deploying its FiOS network using GPON technology. In June 2011, Verizon's GPON-based FiOS network passed 15.7 million homes and had 4.5 million connected customers, representing a subscriber penetration of approximately 30%.²³ Furthermore, Verizon trialled an XG PON 2 service in October 2010, and achieved 10Gbps both upstream and downstream.²⁴

GPON is currently the FTTP technology of choice for large operators in a number of countries. For example, France (France Telecom), Germany (Deutsche Telekom), the UK (British Telecom/Openreach), Singapore (OpenNet/Nucleus Connect), Canada (Bell Canada) and Spain (Orange) have all adopted GPON technology for delivering FTTP/FTTB services to residential and SME customers.

It is also important to note that P2P technology has a significant footprint in Europe. For example, operators and/or municipalities in the Netherlands, Switzerland,²⁵ Slovenia and Norway have deployed P2P networks, as described in Annex A. In fact, as of June 2011, 71% of European FTTP/FTTB subscribers were connected through a P2P network and only 29% through a GPON solution.²⁶ However, this trend is slowly changing now that many European incumbents are starting to heavily invest in GPON technology to address the residential market.

²¹ IDATE, *FTTH Global Panorama*, FTTH Submit 2010, London, June 2010.

²² In June 2011, Asia represented 73% of FTTP/FTTB subscribers worldwide.

²³ Analysys Mason NGA Tracker, 2011.

²⁴ Analysys Mason NGA Tracker, 2011.

²⁵ Swisscom's PTP network is being installed with multiple fibres to each user/site with the potential for a GPON configuration to evolve.

²⁶ FTTH Council Europe, Press Conference BBWF, 27 September 2011.

3.6 Technology roadmaps for GPON and P2P

Below we outline the potential evolution of GPON and P2P networks over the next 25 years, in order to understand likely changes in network capacity. We first provide a timeline for anticipated developments in both technologies, and then examine their evolution in terms of three timeframes:

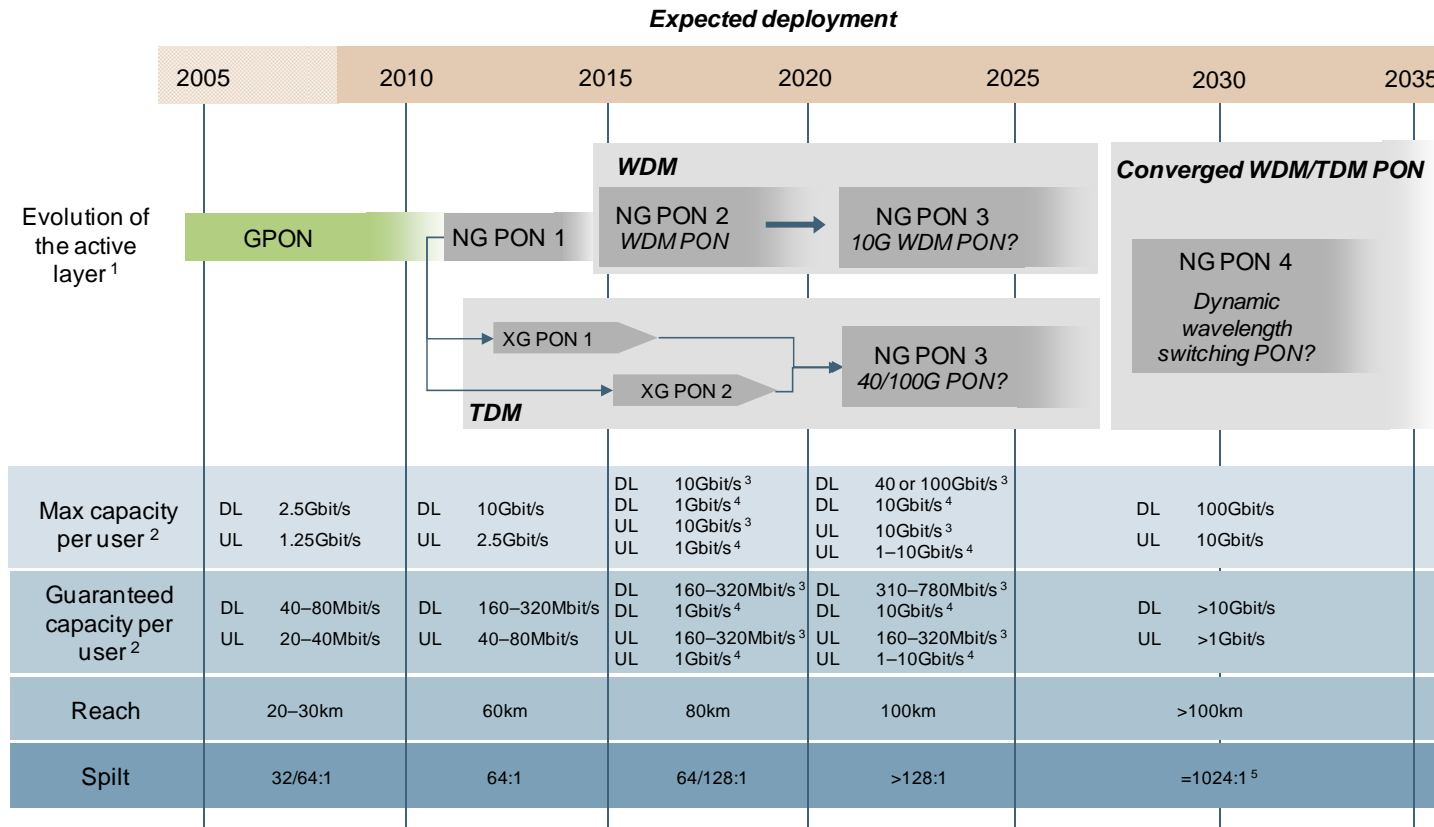
- 2011 to 2015
- 2015 to 2025
- beyond 2025.

It is important to note that developments beyond 2015 are difficult to predict with any certainty and should therefore be considered as indicative only.

3.6.1 PON technology roadmap

The anticipated evolution of PON in terms of maximum capacity per user, guaranteed capacity per user, reach and split is illustrated in Figure 3.9 below.

Figure 3.9: Possible evolution of PON [Source: Analysys Mason]



Key

DL = downlink
UL = uplink

XG = 10th generation
10G = 10 gigabit



The shaded boxes indicate the expected start year of deployment, with an approximate end year/s. Green indicates standardisation has taken place and the technology deployed. Grey indicates standardisation and deployment have not yet happened.

¹ Deployment plans are based on information issued by the ITU and FSAN
² Note these are indicative values only based on Analysys Mason's estimates
³ Applicable to TDM GPON
⁴ Applicable to WDM GPON
⁵ Please note that a maximum of 32 users per wavelength will be allocated

PON development – 2011 to 2015

The FSAN Group is currently working on the next generation of PON phase 2 (XG PON 2) standards and these standards are expected to have a major impact on PON development over the next five years. As explained previously, the FSAN Group has split its work into two different workstreams, called NG PON 1 and NG PON 2, as follows:

► *NG PON 1 (or 10G PON)*

This will comprise two variants:

- **Asymmetric** 10G PON (called XG PON 1),²⁷ i.e. 10Gbps downstream, 2.5Gbps upstream. **Approval of this standard was reached in Geneva in June 2010.**
- **Symmetric** 10G PON (called XG PON 2), i.e. 10Gbps downstream, 10Gbps upstream. **Approval of this standard is expected towards the end of 2012.**

This evolution is indicated in the roadmap in Figure 3.9 above. Note that both of these standards will have extended reach options.

► *NG PON 2 (or WDM PON)*

This is a longer-term initiative that will include the standardisation of WDM PON, but its scope has not yet been agreed by the FSAN. Please refer to Section 7.1.1 of the Analysys Mason report on access networks for Ofcom for a detailed discussion of NG PON 2 and WDM PON.

PON development – 2015 to 2025

The standardisation bodies have not announced any plans beyond 2013, which makes it difficult to predict how these PON will evolve. However, we believe that NG PON 3 might comprise two developments:

- 40G/100G PON (TDM)
- 10G WDM PON.

Please refer to Section 7.1.2 of the Analysys Mason report on access networks for Ofcom for a detailed discussion on 40G/100G PON and 10G WDM PON.

PON development – beyond 2025

It is not possible to predict accurately how PON will develop beyond 2025 as many components are not yet available, even in research labs, to make this evolution happen. However, we believe that PON may rely on dynamic wavelength allocation, based on hybrid WDM/TDM technology. We refer to this evolution as NG PON 4 in Figure 3.9 above.

²⁷ Where XG PON is synonymous with 10G PON.

Please refer to Section 7.1.3 of the Analysys Mason report on access networks for Ofcom for a detailed discussion on NG PON 4.

Potential barriers to PON evolution

There will be an increasing level of technology risk associated with successive generations of PON technology (i.e. NG PON 1 through to 4). For example, new modulation, coding, transmitter, receiver and multiplexing products will have to be developed. Although most of these are already available for long-haul applications, different products need to be developed to meet mass-market price points.

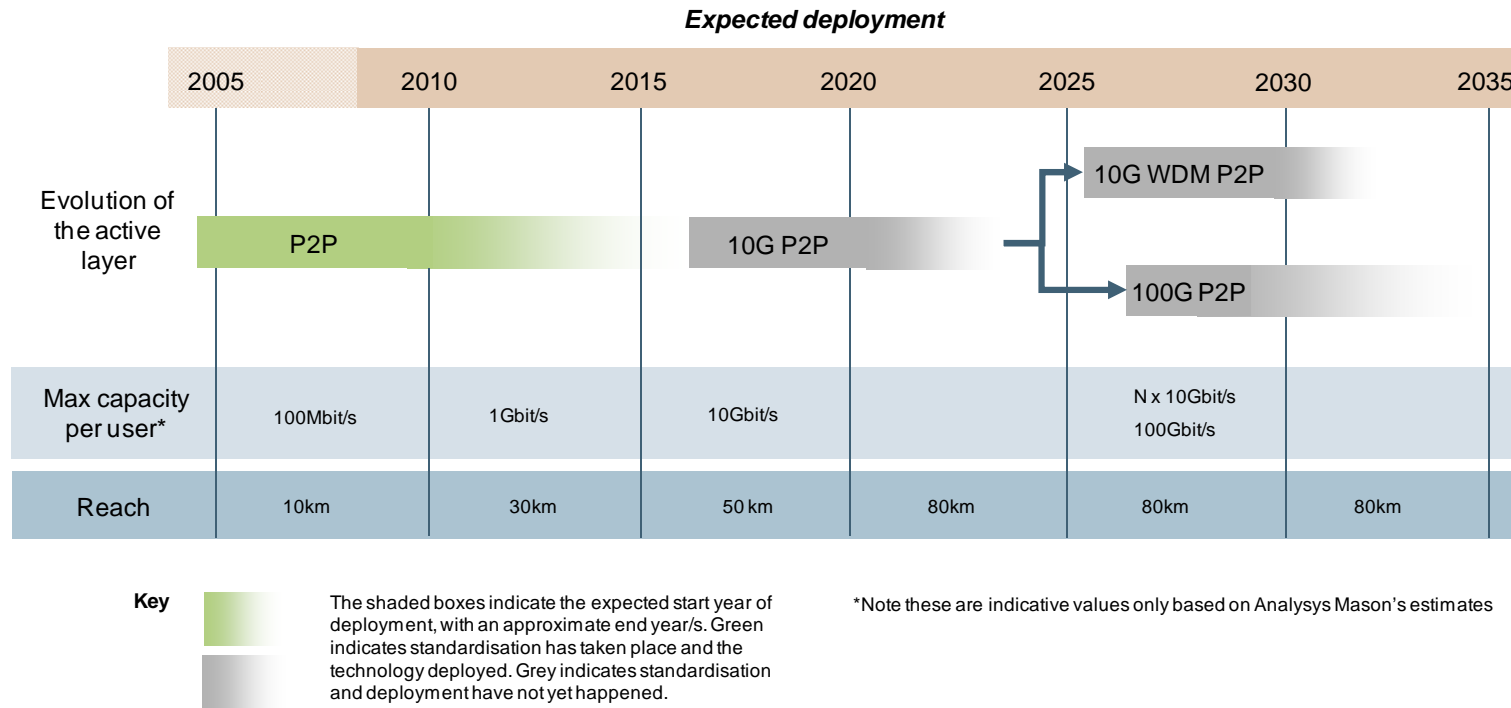
Please refer to Section 7.2.4 of the Analysys Mason report on access networks for Ofcom for a detailed discussion on the barriers to PON evolution.

3.6.2 P2P

The evolution of P2P networks is easier to predict than that of GPON mainly due to the fact that the underlying architecture provides a direct fibre link between the OLT and end users. We note that our long-term predictions (beyond 2015) should still be treated as indicative, due to the many uncertainties involved.

Figure 3.10 below shows how we anticipate that P2P networks might evolve.

Figure 3.10: Possible evolution of P2P networks [Source: Analysys Mason]



P2P development – 2011 to 2015

Current P2P systems can offer 100Mbps or 1Gbps of symmetrical bandwidth to each user. We believe that these systems will continue to be deployed in 2015–2020 (with a bias towards 1Gbps) as they can address the bandwidth requirements of both residential and small business users. The evolution of demand in terms of bandwidth is discussed in Section 3.7 below.

The only anticipated evolution in the short term is in the reach of these systems, currently specified to 10km by the IEEE standards.²⁸ It is likely that the IEEE will soon specify longer distances to extend the reach of current systems, but it has not yet made any announcements regarding standardisation.

Please refer to Section 7.2.1 of the Analysys Mason report on access networks for Ofcom for a detailed discussion on P2P evolution.

P2P development – 2015 to 2025

We expect P2P systems to evolve to 10G Ethernet, which we expect to be deployed from 2015. Current 10G Ethernet (10G Base-BX) interfaces are already available from equipment vendors but pricing is currently a barrier to their deployment for residential mass-market applications. However, as the integration density of microchips continues to increase, microchip prices are expected to fall significantly by 2015, which will make their use more affordable. Also, by that time, there could be a higher level of demand for 10Gbps per user.

We also believe that there will be a case for extending the reach of P2P systems, in an attempt to consolidate OLT sites (local exchanges). Given the maturity of 10G Ethernet interfaces, we expect that a low-cost 10G interface, achieving a 50km reach, may also be commercially available by around 2015–2017.

P2P development – beyond 2025

It is very difficult to predict what technologies will be available or even deployed beyond 2025, and so the expectations we set out here are purely indicative.

There are two candidate developments for P2P networks that might occur:

- **WDM P2P** – involves the allocation of several wavelengths in each dedicated fibre to a single user. We expect that dedicated 10G P2P should be sufficient to provide bandwidth to end users up to 2025. After that, we may see 10G CWDM systems emerging to provide up to eight Ethernet channels of 10Gbps each per user.

²⁸ Depending on the quality of the fibre, these systems could achieve in excess of 30km.

- **100G P2P** – alternatively, we may see the deployment of 100Gbps technology in the access network beyond 2025. It should be noted that this would not be feasible with the current technology, which does not provide a 100Gbps interface for any commercial systems.

Please refer to Section 7.2.3 of the Analysys Mason report on access networks for Ofcom for a detailed discussion on the evolution of P2P.

3.7 Ability of GPON and P2P to meet evolving bandwidth demand

3.7.1 Current and future evolution of demand

Changing social habits and advancements in technology have led to the emergence of a variety of digital services for residential and business customers, as well as for public organisations. These services can be categorised as follows:

- **e-government services** – e-government initiatives are focused on increasing operational efficiencies, primarily through the use of centralised information storage and networked activities. Thus, public servants located in different geographical areas or offices can access information without that information having to be stored at each local office. This not only reduces cost, but increases the efficiency with which their daily activities are performed. Internet connectivity is also increasingly being viewed as an essential driver for digital inclusion initiatives, as it enables previously unconnected citizens to communicate with others (using voice, video and other innovative applications), and can be beneficial in many aspects of their lives (e.g. education and employment).
- **e-health services** – The provision of e-health care services, particularly to meet primary medical requirements, has become popular around the world and has also generated additional demand for broadband networks. Patients can participate in virtual medical consultations with their doctors via videoconferencing. In addition, prescriptions and treatments can be recorded using an online system, providing ubiquitous and efficient access by authorised personnel to patients' medical history. Again, geographical boundaries are removed. e-health services enable patients to be monitored remotely, which reduces the need for physical hospital facilities. This translates into significant cost savings and is particularly convenient for elderly citizens, whose quality of life can be greatly enhanced. One country where e-health services have been implemented is in Japan, where sensors have been installed in elderly patients' homes to detect unusual patterns of behaviour, such as a lack of activity. For example, sensors connected to a kettle can alert the health authorities if the kettle has not been used for a day. The health authorities then send a representative to check that the patient is well.
- **e-learning services** – The e-learning facility is also creating significant consumer demand for broadband. e-learning allows individuals to attend classes and lectures that are given in a remote location from their home. This is achieved through videoconferencing and the use of virtual environment software such as Second Life, and again reduces the requirement for physical infrastructure (e.g. schools, classrooms), potentially saving both investment and maintenance costs for the educational institutions.

- **e-business services** – These types of applications such as e-shopping (Amazon) and online auctions (eBay) have become highly popular. Traditional small and medium businesses also flourish, as higher-bandwidth connections allow individuals to establish their own businesses anywhere, with worldwide connectivity for sourcing, marketing and selling their products. In recent years, the e-business experience has been extended to tele-working, which significantly reduces employers' overhead costs (and hence increases their profitability) and at the same time can improve the quality of life of employees.
- **e-homes services** – Additional demand for broadband can also be expected in future with the evolution of virtual environments in the home. These e-homes will be fully connected and equipped with automatic sensors and relays that can undertake tasks such as monitoring and filling grocery supplies, enabling remote access to security systems and fire alarms, and facilitating remote monitoring of children and other residents through surveillance cameras, for example. In terms of entertainment, the use of advanced and content-rich entertainment services is a trend that is expected to persist, with ever-increasing bandwidth requirements. For example, residential broadband consumers make extensive use of online video content and TV, online gaming and video calls to families.

Finally, the growth of cloud computing is likely to escalate the demand for high-speed broadband, as information and other resources will increasingly be located 'in the cloud'. Therefore, it will be vital that the access network does not become a bottleneck for bandwidth to make use of these services.

While the kinds of services described here can facilitate social inclusion and provide socio-economic value for citizens, it is widely acknowledged that the most significant drivers of demand for bandwidth are currently (and will continue to be) two main upstream and downstream services:

- IPTV (downstream)
- social networking and user-content generated websites (upstream).

High-definition TV delivered over IPTV requires high downstream bandwidths. At the same time, the increase in user-generated content (typically video) has created demand for greater upstream bandwidth. As a result, it is increasingly challenging to meet demand for bandwidth over traditional, asymmetrical copper access networks.

► *IPTV*

Video can be delivered over the Internet using several kinds of delivery mechanism. These can be classified as:

- download-and-store
- streamed to a PC or TV using an 'open' platform, often referred to as over-the-top (OTT) services
- streamed to a TV using a 'closed' (proprietary) IPTV platform.

Each type is summarised in Figure 3.11.

	Download-and-store video	Streamed video (open)	Streamed video (closed IPTV)
Mode	Non-linear	Non-linear VoD	Linear and non-linear VoD
User interface	PC (TV*)	PC (TV*)	TV
Relative video quality	Medium	Low	High
Relative bandwidth requirement	Low	Medium	High
Examples	4oD, iPlayer, Sky Anytime	YouTube, iPlayer	Tiscali, BT Vision, Virgin Media

Figure 3.11: Simple classification of different types of mechanism for delivering video content over the Internet [Source: Analysys Mason]

*Indicates a transition from PC to TV that is already starting, enabled by in-home technologies

► *Social networking and user-generated content*

As the use of social networking sites and the uploading of user-generated content is now commonplace, the bandwidth requirement for upstream traffic is increasing. Websites such as Facebook and YouTube encourage the sharing of user-generated media, such as photographs and videos, via the Internet. For example, the number of uploads to YouTube has been increasing dramatically, as illustrated in Figure 3.12.

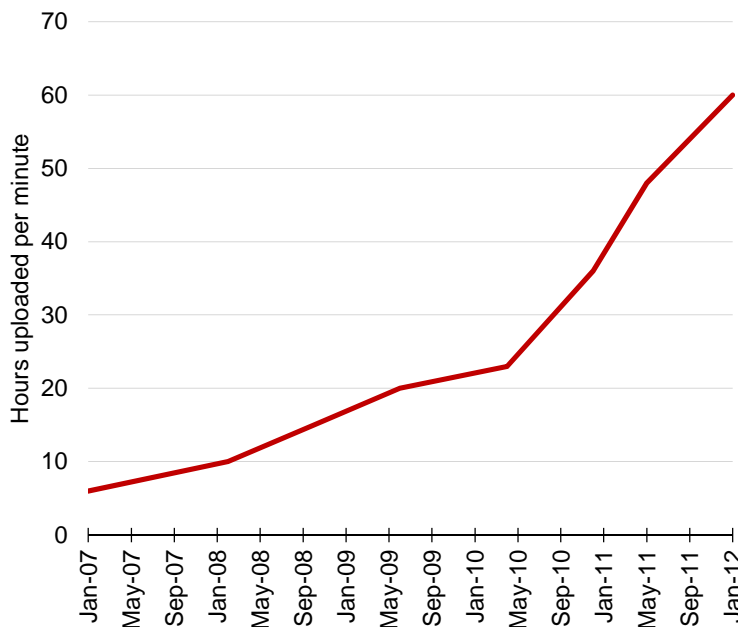


Figure 3.12: Hours of video uploaded to YouTube every minute [Source: YouTube]

► *Estimated overall increase in demand to 2035*

In the Analysys Mason report on access networks for Ofcom, we estimated the evolution of residential demand for bandwidth for both uplink and downlink traffic, based on various scenarios

of the number of simultaneous IPTV channels. This estimation was based on an extensive research programme, involving consultation with a large number of different stakeholders (operators, equipment vendors, Internet service providers (ISPs), regulators and academics). The expected evolution of downlink and uplink demand is shown in Figure 3.13 and Figure 3.14 respectively.

Figure 3.13: Downstream demand assumptions for residential customers [Source: Analysys Mason]

Timescale	Services	Total downstream bandwidth requirements
2015	2×3DTV channel and 30Mbps Internet	90Mbps
2025	2×HD 3DTV channel and 100Mbps Internet	300Mbps
2035	2×ultra-HD 3DTV channel and 300Mbps Internet	900Mbps ²⁹

Figure 3.14: Upstream demand scenario assumptions [Source: Analysys Mason]

Timescale	Upload type	Upstream bandwidth requirements
2015	<ul style="list-style-type: none"> • Upload 3D video • Upload large file (50MB in 1 minute) 	<ul style="list-style-type: none"> • 30Mbps • 10Mbps
2025	<ul style="list-style-type: none"> • Upload HD 3D video • Upload large file (300MB in 20 seconds) 	<ul style="list-style-type: none"> • 100Mbps • 120Mbps
2035	<ul style="list-style-type: none"> • Upload ultra-HD 3D video • Upload large file (1GB in 20 seconds) 	<ul style="list-style-type: none"> • 300Mbps • 400Mbps

From this analysis, it can be seen that a ten-fold increase in demand is expected between 2015 and 2035. It should be noted that these predictions are only indicative, but provide robust assumptions to determine the risks associated with the technology roadmaps.

3.7.2 Comparison of demand and technology roadmap

Based on the technology roadmaps for GPON and P2P (Figure 3.9 and Figure 3.10 respectively) and the demand scenarios shown in Figure 3.13 and Figure 3.14, it is possible to compare the evolution of bandwidth **demand** and bandwidth **supply** for both GPON and P2P technologies.

Figure 3.15 and Figure 3.16 below show the downlink and uplink bandwidth requirements.

²⁹ The significant increase in bandwidth between HD 3DTV and ultra HDTV is due to the fact that in ultra HDTV many different channels will need to be superimposed to allow the user to watch 3DTV from many different angles on auto-stereoscopic screens.

Figure 3.15: Downlink bandwidth requirements vs. technology bandwidth [Source: Analysys Mason]

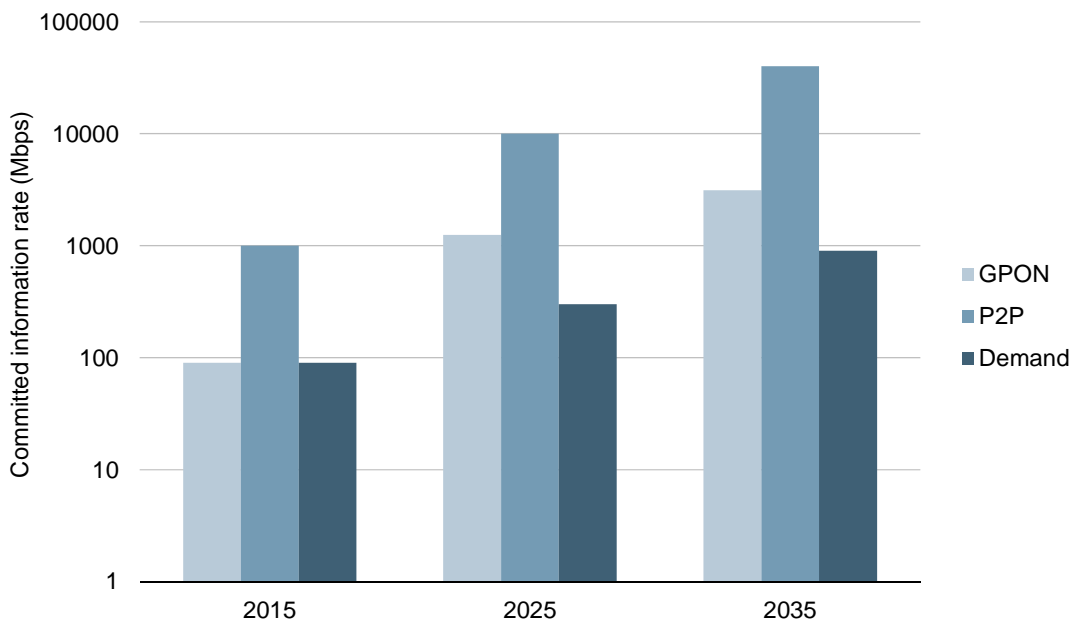
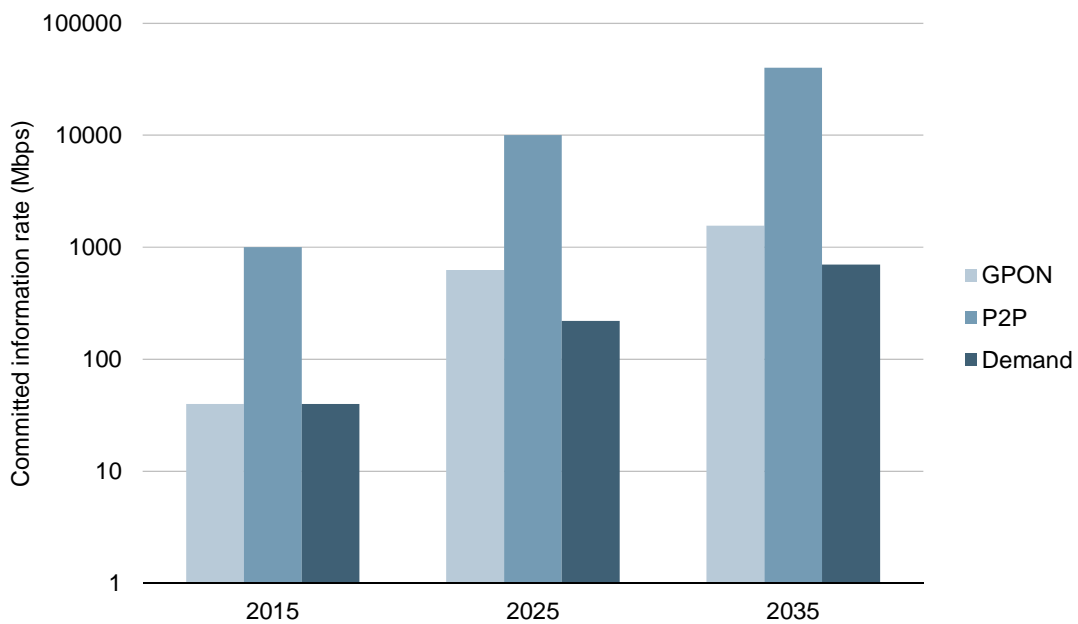


Figure 3.16: Uplink bandwidth requirements vs. technology bandwidth [Source: Analysys Mason]



From Figure 3.15 and Figure 3.16, it can be seen that both P2P and GPON will meet both downstream and upstream demand up to 2035. Figure 3.16 also illustrates that, by 2035, P2P technologies may provide an order of magnitude more bandwidth than GPON.

From this, we conclude that:

- P2P networks will remain more scalable than GPON in terms of bandwidth
- the roadmap for GPON evolution will still be able to meet future demand from the mass-market, even though GPON will always offer less bandwidth to users than P2P.

We therefore believe that both GPON and P2P should be able to meet future demand from the residential and business segment and the enterprise and government segment, respectively.

3.8 Operational considerations for technology upgrades

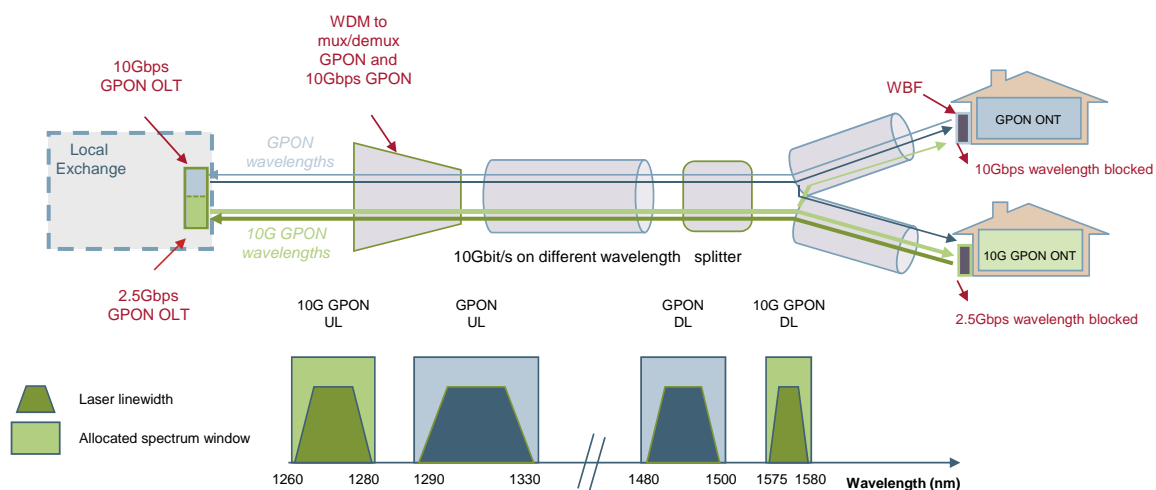
3.8.1 P2P upgrades

As demonstrated in Figure 3.10, P2P provides an easy upgrade path to higher bandwidth, as the operator would only have to change the NTD at the customer premises and connect the fibre in the exchange to a higher-bandwidth port on the OLT. Therefore, we believe that there is very limited risk associated with the upgrade of a P2P network. It should be noted that in a P2P network, an increase in bandwidth for one user has no impact on any other users in the network, due to the dedicated bandwidth characteristics of P2P.

3.8.2 GPON upgrades

According to the ITU-T G.987 standard, NG PON 1 will be supported *in parallel* to current 2.5Gbps GPON, by using different upstream and downstream wavelengths from 2.5Gbps GPON, as illustrated in Figure 3.17. This will allow an operator to support both 2.5Gbps users and 10Gbps users on the same underlying PON infrastructure. However, the major drawback associated with such a solution is that existing NTDs will need to be retro-fitted with wavelength blocking filters (WBFs) to filter out the NG PON 1 wavelength. Also, if a combined GPON/NG PON system is implemented (as illustrated in Figure 3.17 below), a wavelength multiplexer will be required in the FAN to multiplex GPON and NG PON wavelengths into the same fibre. This may cause a minor service outage, since the GPON line card will have to be disconnected from the OFDF to install the wavelength multiplexer.

Figure 3.17: Co-existence of GPON and 10G GPON in the same infrastructure [Source: Analysys Mason]



Alternatively, to overcome these operational issues, NG PON can be deployed using a dedicated PON, i.e. independent of the network used to serve GPON customers. This would remove the need

for a WBF retro-fit on existing NTDs. We understand that several operators in the world are considering this approach, including Verizon in the USA.

3.9 Conclusion

In summary, there are two main types of FTTP technologies that can be used to address residential and business customers: GPON and P2P. Both technologies have been standardised and have a clear technology roadmap for the next five years. In terms of bandwidth evolution, the GPON standard has a clear evolution path as the downlink bandwidth can be upgraded from 2.5Gbps to 10Gbps.

GPON and P2P technologies are both therefore likely to have a sufficient upgrade path to meet the reasonably anticipated requirements of access seekers and end users for bandwidth over the next 30 years. They are both, therefore, considered to be future-proof technologies. In terms of deployment, GPON is currently the FTTP technology of choice for large operators in a number of countries for offering ultra-fast broadband services to the residential segment. This is because GPON is considered to have a lower total cost of ownership compared to P2P technology.

However, due to the high bandwidth requirement and the need for symmetry in the uplink and downlink, P2P is generally better suited to offer services to large enterprises.

4 Technical overview of fixed wireless networks

4.1 Introduction

This section provides a technical overview of fixed wireless network technology that is suitable for the provision of broadband services. It is structured as follows:

- Section 4.2 describes the evolution of wireless standards over the past two decades
- Sections 4.3 and 4.4 present overviews of 3GPP LTE and IEEE WiMAX technology standards respectively, describing the market and technical features for each technology
- Section 4.5 provides a comparison between LTE and WiMAX.

4.2 Overview of wireless technology options

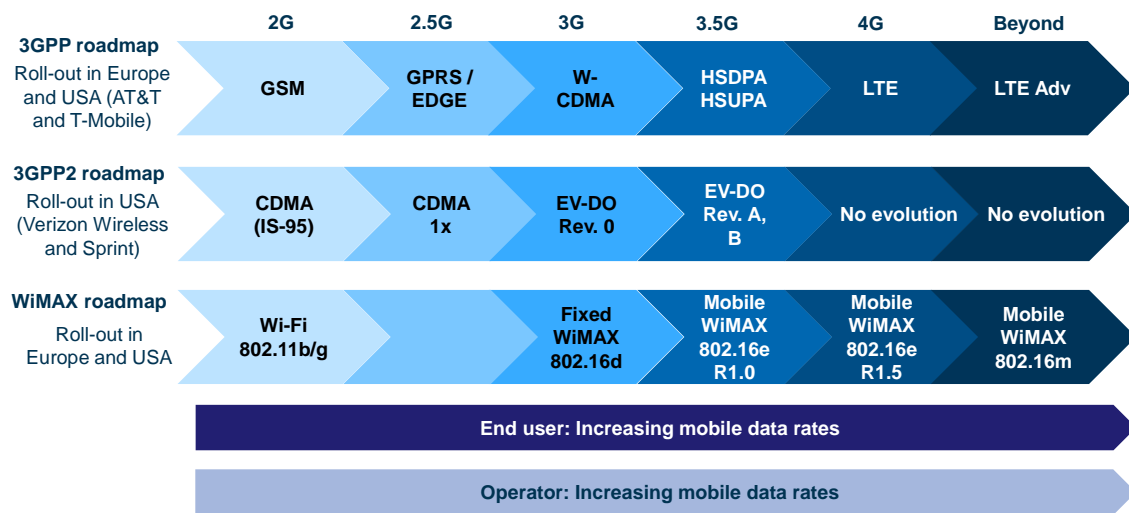
Fixed wireless access networks are becoming increasingly popular to connect end users. This is especially the case in emerging economies where wireline access infrastructure is not well developed, and also in the rural areas of developed countries where it is very costly to roll out this kind of infrastructure. In this context, NBN Co plans to provide fixed wireless wholesale services in more rural areas where it does not make economic sense to provide fibre wholesale services. In order to better understand fixed wireless technology, it is important to understand the evolution of different wireless standards used by mobile operators, as fixed wireless technology represents an evolution of these standards. Below we describe how wireless standards have evolved over the past two decades. We also describe mobile technology to provide some context to the wireless standards, but it should be highlighted that NBN Co is planning to only provide fixed wireless wholesale services, with no roaming or mobility features.

Wireless technologies have evolved in response to changing customer requirements. In the past ten years, wireless technologies have focused on improving the delivery of mobile data in order to meet the increasing consumer demand for mobile data traffic and the emergence of new mobile applications.

In the past, harmonisation of frequency bands was not common and different parts of the world adopted different technologies in the same frequency bands. For example, Europe uses the GSM standard, while the USA predominantly uses code division multiple access (CDMA) as its 2G mobile technology, which poses a number of challenges for international roaming. Nowadays, regulators, operators and equipment vendors are in favour of the harmonisation of frequency bands as a way of facilitating roaming and developing cheaper end-user devices on a large scale.

There are currently three families of mobile access technology: GSM, CDMA and worldwide interoperability for microwave access (WiMAX). The evolution of these technologies is illustrated in Figure 4.1 below.

Figure 4.1: Wireless access technology roadmap [Source: Analysys Mason]



These mobile access technologies are discussed in turn below:

- **GSM** and its associated family of standards are the most popular standards for mobile telephone access in the world; according to the GSM Association, as of mid-2009 there were over 3.5 billion mobile GSM subscribers in over 200 countries, representing a global market share of 89.5%. The development of these standards is supported by the Third-Generation Partnership Project (3GPP), which emerged from the collaboration of different groups of telecoms associations throughout the world.
- **CDMA** and its family of standards originated from the Interim Standard 95 (IS-95), which was developed by Qualcomm. CDMA2000 was the first CDMA-based digital cellular system, and is therefore a second-generation (2G) mobile system. Supporting the development of these standards is the 3GPP2, which emerged from the collaboration of associations in Japan, China, North America and South Korea.
- **WiMAX** is a wireless broadband standard based on the 802.16 family of standards developed by the IEEE. There are two versions of WiMAX technology, fixed and mobile, with separate standards namely 802.16d and 802.16e respectively.

As shown in Figure 4.1, the 3GPP and WiMAX standards are still both evolving and will both provide a fourth generation of devices and networks. However, the CDMA family of standards is not future-proof as its development has been stopped in favour of LTE, a technology belonging to the 3GPP family.

Spectrum requirements and performance

In wireless access systems, efficient use of spectrum is crucial, as it is a finite resource that is highly valuable. The increase in bandwidth that can be provided using wireless technologies has mainly been achieved by maximising the spectrum efficiency of the technologies (i.e. increasing the number of Mbps that can be carried in each MHz of spectrum).

Figure 4.2 provides an indication of the spectrum requirements for each of the three wireless technology standards (3GPP, 3GPP2 and WiMAX).

Figure 4.2: Wireless technology bandwidth and spectrum requirements [Source: Analysys Mason]

Wireless broadband technology	Theoretical download peak rate	Theoretical upload peak rate	Channel width	Frequency duplex	Commercial availability
3GPP (GSM/UMTS)					
W-CDMA (R99)	384kbps	128kbps	5MHz	FDD	Available
HSDPA+	28Mbps	N/A*	5MHz	FDD	Available
HSUPA (cat 6)	N/A	5.7Mbps	5MHz	FDD	Available
LTE	>300Mbps	>80Mbps	20MHz	FDD/TDD	Available
LTE Advanced	100/1000Mbps	50/500Mbps	20MHz – 100 MHz	FDD/TDD	Not standardised
3GPP 2 (CDMA2000)					
EV-DO (Rev 0)	2.4Mbps	153kbps	1.25MHz	FDD	Available
EV-DO (Rev A)	3.1Mbps	1.8Mbps	1.25MHz	FDD	Available
EV-DO (Rev B)	4.9Mbps	1.8Mbps	1.25MHz	FDD	Available
IEEE 802.16 (WiMAX)					
IEEE 802.16d	6.55Mbps	2.5Mbps	1.75MHz	FDD/TDD	Available
IEEE 802.16e	46/32Mbps	8/14Mbps	10MHz	FDD/TDD	Available
IEEE 802.16m	100/1000Mbps	50/500Mbps	20MHz – 100 MHz	FDD/TDD	Not standardised

N/A = Not available

The choice of technology dictates the frequency duplexing access to be used. Frequency duplexing relates to how the downlink and the uplink of a full duplex communication are separated in frequency. There are two main full-duplex access schemes:

- **Frequency division duplexing (FDD)** – uses different spectrum bands for the uplink and downlink, separating them in frequency.
- **Time division duplexing (TDD)** – separates uplink and downlink signals in time, using the same spectrum band.

TDD has a strong advantage over FDD in cases where there is asymmetry between uplink and downlink data traffic. As the amount of uplink data increases, more communication capacity can dynamically be allocated in this direction, and as the demand shrinks capacity can be taken away. The same is true for the downlink traffic. In the case of FDD, however, high utilisation in any of the separated bands cannot be compensated for by dynamically allocating more spectrum from the band with lower utilisation, and so FDD is more suited for symmetric traffic flows such as those associated with voice traffic, which by nature is balanced in both directions. As illustrated in Figure 4.2, 3GPP- and 3GPP2-based standards were traditionally based on FDD, whereas WiMAX 802.16e and

802.16m³⁰ use both FDD and TDD. One of the most important developments in 3GPP standards is that LTE is standardised for both FDD and TDD, which makes spectrum management significantly more straightforward, as TDD spectrum can be the duplex methodology for both WiMAX and 3GPP.

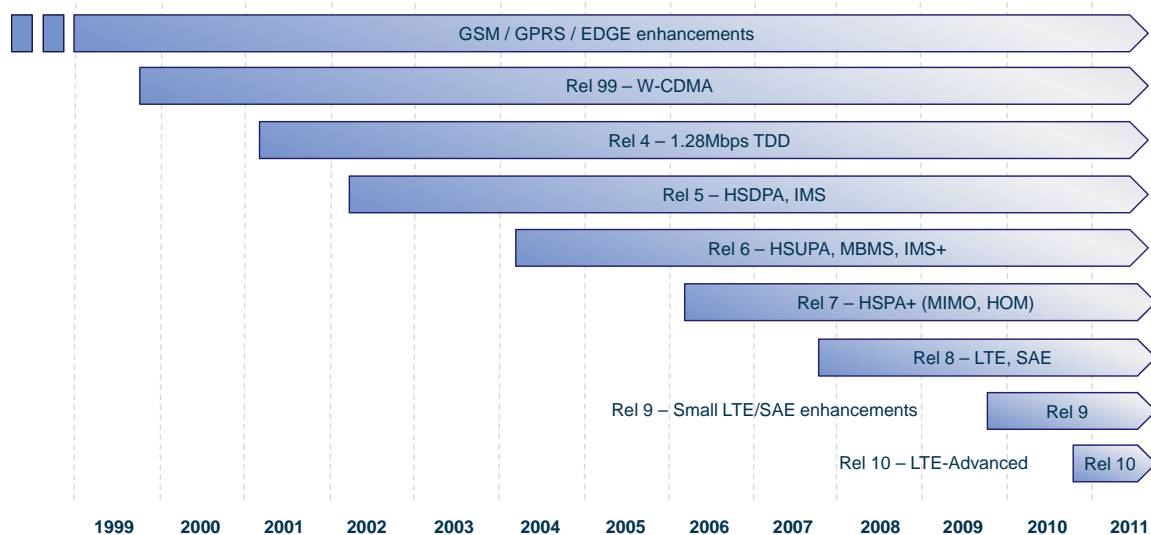
4.3 Overview of 3GPP LTE technology standards

LTE, also known as Enhanced-UTRA, was proposed as the next phase in the 3GPP migration path in 2004. Its specification requirements were initially defined in 3GPP Rel-8 in 2008, with further enhancements in 3GPP Rel-9 in 2009. LTE employs OFDMA in the downlink and single carrier frequency division multiple access (SC-FDMA) in the uplink, whereas the previous 3GPP technology employs CDMA in both the downlink and uplink. LTE is based on an all-IP network architecture and can provide high-speed mobile broadband. LTE can operate in both FDD (FD-LTE) and TDD (TD-LTE) modes, and user equipment is targeted by manufacturers to be operable in these dual modes.

3GPP partners formally submitted LTE Release 10 (Rel-10) to the ITU in September 2009, as a proposed candidate for IMT-Advanced. The LTE-Advanced standard is currently being developed by the 3GPP group and is expected to be completed in late 2012. The aim of the LTE-Advanced standard is to meet or exceed the requirements of IMT-Advanced.³¹ It is expected that the multiple access schemes in the downlink and uplink will be the same as LTE Rel-9.

The 3GPP specifications release is summarised in Figure 4.3.

Figure 4.3: Timeline for release of 3GPP specifications [Source: 3GPP]



Although LTE Rel-8 specifications were released at the end of 2007, the first commercial launch of LTE Rel-8 was in July 2011, by SK Telecom in South Korea.

³⁰ 802.16m (Advanced Air Interface) is a successor to Mobile WiMAX and is generally referred to as Mobile WiMAX Release 2. It aims to increase the speeds available with 802.16e.

³¹ www.itu.int/md/R07-IMT.ADV-C-0001/en.

Most of the major operators have confirmed that their strategy is to move to LTE immediately or in the near future, and this has given equipment vendors confidence to manufacture devices on a large scale.

Because LTE is all-IP in both the core and access sub-networks, this has the following advantages:

- it offers significant performance improvements compared with legacy networks
- it has the backing of the mobile industry
- it can offer significant savings on capex and opex
- it enables more flexible use of spectrum compared with legacy networks.

4.3.1 Market overview

LTE Rel-8 (with some enhancements in Rel-9) is the standard that is being deployed, as it is well understood by all the stakeholders involved. End-user demand for data is expected to continue growing and so it is likely that LTE Rel-10 (which is likely to be standardised in the near future) will be implemented to meet this demand.

There are currently 34 operational LTE data networks, of which 32 are FD-LTE networks. FD-LTE is currently more popular because it was standardised first, and most of the operators support FDD because 3GPP technologies have been mainly based on FDD. The majority of these LTE networks have been deployed in Scandinavian countries, home to equipment manufacturers Nokia and Ericsson, which use these networks as test beds. Figure 4.4 summarises the status of current FD-LTE networks around the world.

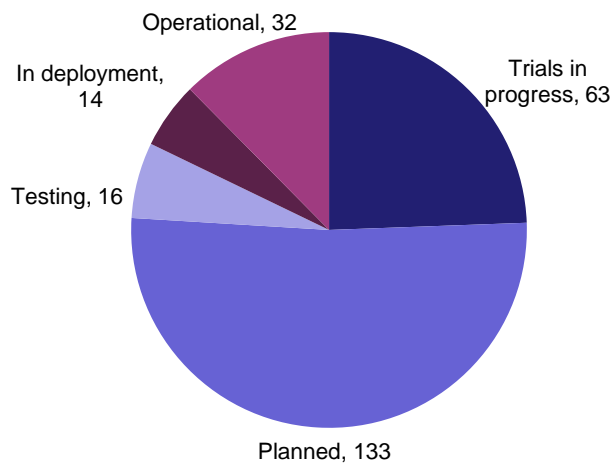


Figure 4.4: Network status of FD-LTE
[Source: Analysys Mason]

The high number of 'planned' and 'trials in progress' FD-LTE networks shows the high degree of confidence that mobile operators have in LTE technology. In other words, most mobile operators have adopted LTE as their 4G technology.

Currently, only two TD-LTE networks have been launched – by SK Telecom in South Korea (in July 2011) and Mobily in Saudi Arabia (in September 2011). Despite the lack of operational TD-

LTE networks, there has been significant momentum behind TD-LTE lately because of the asymmetrical demand for bandwidth from end users. Indeed, two of the largest operators (China Mobile and Reliance Infotel) are currently trialling TD-LTE and intend to deploy it in early 2012. Given the very large customer bases of these two operators, end-user devices for TD-LTE are likely to be available at more competitive prices.

Figure 4.5 provides a summary of the status of current TD-LTE networks around the world.

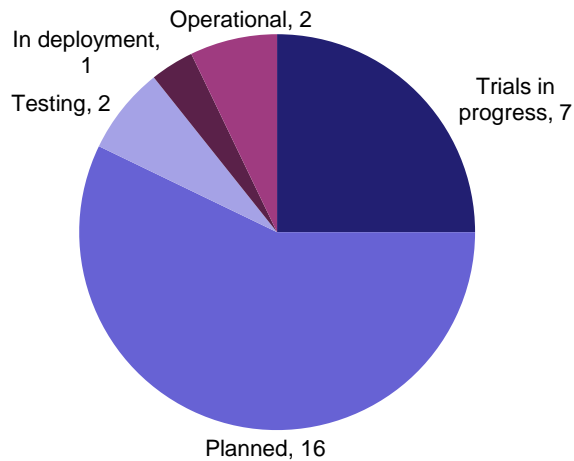


Figure 4.5: Network status of TD-LTE
[Source: Analysys Mason]

The number of 'planned' and 'trials in progress' TD-LTE networks shows that the TD-LTE ecosystem is growing and hence market confidence in the technology is increasing.

In summary, there seem to be three main benefits of TD-LTE:

- global backing for the standard – unlike TD-SCDMA, large global operators such as Vodafone, Airtel and Softbank are supporting trials of TD-LTE
- strong commercial drivers – there is an increasing need for China Mobile and Reliance Infotel to have a strong technology in competitive markets
- creation of a mainstream mobile ecosystem – devices will be mainstream; for example, Apple is expected to support TD-LTE devices.

4.3.2 Technical overview

A number of discrete spectrum bands have been allocated for LTE in order to increase the harmonisation of bands worldwide, as shown in Figure 4.6.

Figure 4.6: LTE operating bands [Source: 3GPP]

E-UTRAN band	Uplink		Downlink		Duplex mode (MHz)
	$F_{ul\ Low}$ (MHz)	$F_{ul\ High}$ (MHz)	$F_{dl\ Low}$ (MHz)	$F_{dl\ High}$ (MHz)	
1	1920	1980	2110	2170	FDD
2	1850	1910	1930	1990	FDD
3	1710	1785	1805	1880	FDD
4	1710	1785	1805	1880	FDD
5	824	849	869	894	FDD
6	830	840	875	885	FDD
7	2500	2570	2620	2690	FDD
8	880	915	925	960	FDD
9	1749.9	1784.9	1844.9	1879.9	FDD
10	1710	1770	2110	2170	FDD
11	1427.9	1447.9	1475.9	1495.9	FDD
12	698	716	728	746	FDD
13	777	787	746	756	FDD
14	788	798	758	768	FDD
15	Reserved	-	-	-	FDD
16	Reserved				FDD
17	704	716	734	746	FDD
18	815	830	860	875	FDD
19	830	845	875	890	FDD
20	832	862	791	821	FDD
21	1447.9	1462.9	1495.9	1510.9	FDD
...
33	1900	1920	1900	1920	TDD
34	2010	2025	2010	2025	TDD
35	1850	1910	1850	1910	TDD
36	1930	1990	1930	1990	TDD
37	1910	1930	1910	1930	TDD
38	2570	2620	2570	2620	TDD
39	1880	1920	1880	1920	TDD
40	2300	2400	2300	2400	TDD

The key technical parameters for LTE Rel-8/Rel-9 are summarised in Figure 4.7.

Figure 4.7: Key technical parameters of LTE (3GPP Rel-8/Rel-9) [Source: Analysys Mason]

Parameter	LTE (3GPP R8/9)
Standards body	3GPP
Network equipment availability	2009
Handset availability	2010
Duplexing	FDD & TDD
Frequency bands	700, 850, 900, 1800, 1900, 2100, 2300, 2500MHz
Channel bandwidth	1.25, 3, 5, 10, 15, 20MHz
Advanced antenna support	DL: 2x2, 2x4, 4x2, 4x4 UL: 1x2, 1x4, 2x2, 2x4
MIMO models	Spatial multiplexing Transmit diversity (Alamouti, CDD) UE specific beam-forming
Sector throughput (capacity) (10MHz)	15.7Mbps (2x2) ³²
Downlink air interface	OFDMA
Uplink air interface	SC-FDMA
Mobility	Up to 350km/hr
Adaptive modulation schemes	QPSK, 16 QAM, 64 QAM
Error correction rates	1/2, 2/3, 3/4, 5/6
Frame size	1ms
Link layer latency	< 5ms
Handoff latency	< 30ms

4.4 Overview of IEEE WiMAX technology standards

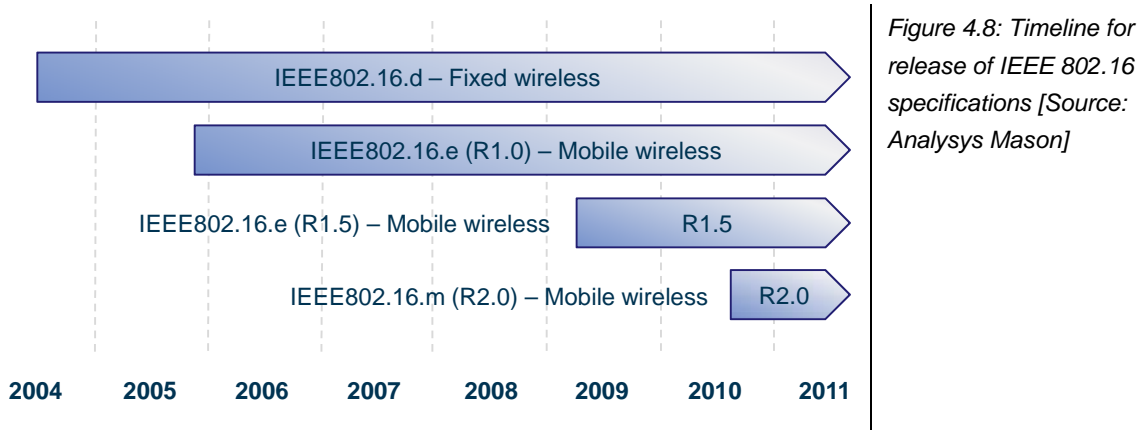
In 2005, the IEEE 802.16 working group standardised IEEE 802.16e, which is an amendment of the IEEE 802.16d air interface to support mobility and so it is most commonly known as mobile WiMAX Release 1.0 (R1.0). WiMAX R1.0 operates in TDD and uses OFDMA based on an all-IP flat core network, which provides reduced latency services. Mobile WiMAX has been designed to provide a high-speed mobile broadband service. In 2009, another release of 802.16e (Release 1.5, R1.5) was published by IEEE with contributions from the WiMAX Forum. R1.5 includes new spectrum allocations for most countries and incorporates an FDD operating mode to make its deployment more flexible in some countries with regulatory constraints.

The IEEE 802.16 working group obtained approval to develop IEEE 802.16m (Release 2.0, R2.0) in December 2006, and development is ongoing. The goal of Release 2.0 is to meet or exceed the requirements of IMT-Advanced. The WiMAX Forum is working on the development of the mobile WiMAX R2.0 system profile, and shortly after finalisation of IEEE 802.16m by the 802.16 working group, the WiMAX Forum will be able to certify WiMAX R2.0 products.

³² See <http://business.motorola.com/experiencelte/lte-depth.html>.

IEEE 802.16d has not evolved since 2004, whereas IEEE 802.16e has undergone two stages of evolution (R1.5 in 2009 and R2.0 in 2010).

Figure 4.8 summarises the evolution of the specification of IEEE 802.16.



4.4.1 Market overview

WiMAX has gained a strong foothold in emerging markets that have poor fixed-line infrastructure, where it is used for backhaul and mobile broadband services.

At the time of writing this report there were 428 operational WiMAX networks (284 fixed WiMAX and 144 mobile WiMAX) worldwide. The WiMAX ecosystem is already well established, and devices and network equipment are available in the market to support a wide range of services – from backhaul provision to various outdoor applications that require high-speed nomadic coverage. Although there are many operational networks, most of them are niche networks and only a few provide nationwide coverage, such as MobIsle Comm in Malta and OneMax in the Dominican Republic.

The status of WiMAX networks worldwide is shown in Figure 4.9 (fixed WiMAX) and Figure 4.10 (mobile WiMAX) below.

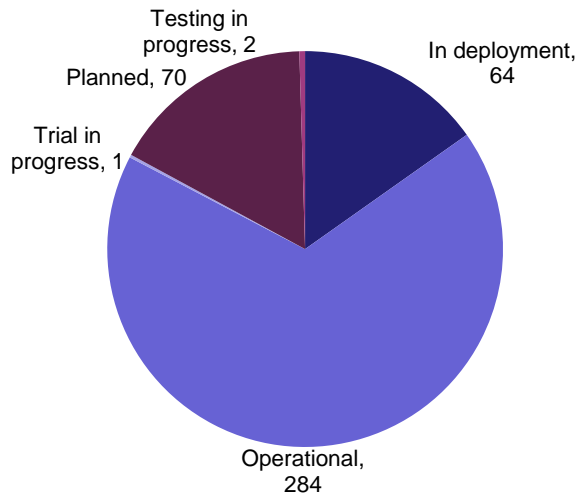


Figure 4.9: Status of fixed WiMAX networks
[Source: Analysys Mason]

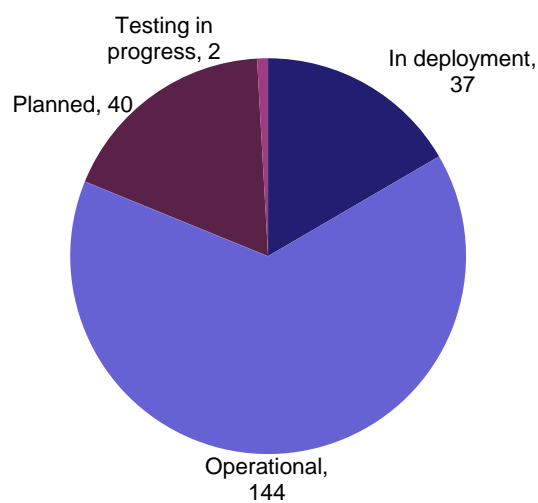


Figure 4.10: Status of mobile WiMAX networks
[Source: Analysys Mason]

Although the number of operational WiMAX networks is high, the number of 'planned' and 'testing in progress' WiMAX networks is relatively low. This indicates a lack of confidence among network operators to support WiMAX technology. The fact that the number of WiMAX operational networks is much higher than that for LTE reflects that WiMAX was standardised almost four years earlier.

It should also be noted that all the major Tier-1 WiMAX vendors such as Motorola and Huawei (both vendors are also investing in the FDD and TDD variants of LTE) are still investing in WiMAX. Ericsson and Alcatel-Lucent are now solely developing (and in the case of Ericsson deploying) commercial LTE network equipment, and Cisco has recently withdrawn from the WiMAX market. Alvarion, which maintains about 20% of the remaining mobile WiMAX market share, has already conducted successful TD-LTE trials in 2011.

4.4.2 Technical overview

A number of discrete spectrum bands have been allocated for WiMAX in order to increase the worldwide harmonisation of bands, as shown in Figure 4.11 below.

Figure 4.11: WiMAX profile bands [Source: WiMAX Forum]

Profile name	Frequency (GHz)	Channel bandwidth (MHz)	Technology	Duplexing
ET01	3.4–3.6	3.5	Fixed WiMAX	TDD
ET02	3.4–3.6	3.5	Fixed WiMAX	FDD
ET03	5.725–5.850	10	Fixed WiMAX	TDD
MP01	2.3–2.4	8.75	Mobile WiMAX	TDD
MP02	2.3–2.4	5 and 10	Mobile WiMAX	TDD
MP05	2.496–2.690	5 and 10	Mobile WiMAX	TDD
MP06	3.3–3.4	5	Mobile WiMAX	TDD
MP07	3.3–3.4	7	Mobile WiMAX	TDD
MP08	3.4–3.8	5	Mobile WiMAX	TDD
MP09	3.4–3.6	5	Mobile WiMAX	TDD
MP10	3.4–3.6	10	Mobile WiMAX	TDD
MP11	3.4–3.8	10	Mobile WiMAX	TDD
MP12	3.4–3.6	10	Mobile WiMAX	TDD

The key technical parameters for WiMAX R1.0 and R1.5 are summarised in Figure 4.12.

Figure 4.12: Key technical parameters of WiMAX 802.16e R1.0 and R1.5 [Source: Analysys Mason]

Parameter	WiMAX 802.16e (R1.0)	WiMAX 802.16e (R1.5)
Standards body	IEEE and WiMAX Forum	IEEE and WiMAX Forum
Network equipment availability	2007	2009
Handset availability	2008	2010
Duplexing	TDD	TDD & FDD
Frequency bands	2300, 2500, 3300, 3500, 3700MHz	700, 1700, 2300, 2500, 3300, 3500, 3700MHz
Channel bandwidth	1.25, 3.5, 5, 7, 8.75, 10MHz	1.25, 3.5, 5, 7, 8.75, 10, 20MHz
Advanced antenna support	DL: 2x2, 2x4, 4x2, 4x4 UL: 1x2, 1x4, 2x2, 2x4	DL: 2x2, 2x4, 4x2, 4x4 UL: 1x2, 1x4, 2x2, 2x4
MIMO models	Spatial multiplexing Transmit diversity (Alamouti) UE specific beam-forming Collaborative UL SLM	Spatial multiplexing Transmit diversity (Alamouti, CDD) UE specific beam-forming Collaborative UL SLM
Sector throughput (capacity) (10MHz)	14.2Mbps (2x2 and 3:1 downlink uplink ratio) ³³	
Downlink air interface	OFDMA	OFDMA
Uplink air interface	OFDMA	OFDMA
Mobility	Up to 120km/hr	Up to 120km/hr
Adaptive modulation schemes	BPSK, QPSK, 16 QAM, 64 QAM	BPSK, QPSK, 16 QAM, 64 QAM
Error correction rates	1/2, 2/3, 3/4, 5/6	1/2, 2/3, 3/4, 5/6
Frame size	5ms	5ms
Link layer latency	~20ms	~20ms

³³ Mobile WiMAX: A Performance and Comparative Summary, Doug Gray, September 2006, WiMAX Forum; and Comparing Mobile WiMAX, 3G and Beyond – A technical comparison of mobile WiMAX and third generation mobile technologies, Alvarion.

Parameter	WiMAX 802.16e (R1.0)	WiMAX 802.16e (R1.5)
Handoff latency	< 50ms	< 50ms

4.5 LTE and WiMAX comparison

4.5.1 Comparison of LTE Rel-8 and WiMAX 802.16e

There are a lot of commonalities between LTE Rel-8 and WiMAX, but there are some notable differences. For example:

- LTE uses SC-FDMA for the uplink, whereas mobile WiMAX uses OFDMA. LTE user equipment (SC-FDMA) has a lower peak-to-average-power ratio when compared to mobile WiMAX user equipment (OFDMA), which translates into longer battery life for LTE user equipment
- LTE networks can provide communication services at a higher mobility (up to 350km/hr) than mobile WiMAX (up to 120km/hr)
- interworking between W-CDMA and LTE or between HSPA and LTE is easier than with mobile WiMAX.

4.5.2 Comparison of LTE-Advanced and WiMAX 802.16m

The aim of LTE-Advanced and IEEE 802.16m WiMAX (R2.0) is to meet or exceed the IMT-Advanced requirements. Some key features of IMT-Advanced are worldwide roaming, compatibility of services, interworking with other radio access systems and enhanced peak data rates. The shared channel downlink peak rate is expected to be 1000Mbps and 100Mbps in low- and high-mobility scenarios, respectively. It is expected that WiMAX R2.0 and LTE-Advanced will be deployed in late 2012 at the earliest. WiMAX R2.0 could potentially be deployed first, as work on IEEE 802.16m started earlier than LTE-Advanced.

At this stage, it is not possible to make a comprehensive comparison of these technologies, because the standards have not yet been finalised. However, the differences between LTE-Advanced and 802.16m WiMAX are most likely to be the same as the previous releases.

4.5.3 FD-LTE and TD-LTE

Traditional 3GPP mobile network operators have generally accepted FD-LTE as their evolution path towards 4G because the existing 3GPP infrastructure is based on FDD mode. This explains why the current FD-LTE ecosystem is bigger than that of TD-LTE.

China Mobile has adopted TD-LTE as its 4G technology because of its unique evolution path in the industry from GSM to TD-SCDMA and then to TD-LTE, which means that China Mobile's existing network infrastructure already operates in TDD mode. Following this announcement, other mobile network operators have considered TD-LTE as a viable option for their 4G strategies.

Greenfield and existing WiMAX operators are also giving more attention to TD-LTE than to FD-LTE. The potential cost-effective equipment, and the greater availability and lower cost of TDD

spectrum make TD-LTE an attractive option for greenfield operators. Current WiMAX spectrum bands and the ability to provide a smooth migration from existing WiMAX infrastructure to TD-LTE also make TD-LTE an attractive option for existing WiMAX operators. Existing WiMAX operators such as P1 in Malaysia and Yota in Russia have announced plans for migration to TD-LTE. In India, despite having had 2.3GHz spectrum for almost 18 months, the operators are understood to be preparing to launch TD-LTE rather than WiMAX. Increasingly, traditional 3GPP operators are also considering TD-LTE; for example, E-Plus in Germany and Hi3G in Denmark and Sweden have been considering whether to use unpaired spectrum to deploy TD-LTE.

4.5.4 Conclusion

There are more similarities than differences between WiMAX and LTE technologies. However, there is a general consensus among the major mobile operators that WiMAX is a more complex technology to implement than LTE. For example, the subcarrier spacing option for LTE is fixed and for WiMAX it is variable, which makes the latter more complex to design and implement.

Due to the stronger backing of LTE by operators, the volume of end-user devices is expected to be much higher for LTE than for WiMAX. LTE is regarded as the natural evolution path for all mobile networks employing 3GPP technologies. Another factor that favours LTE over WiMAX is the roaming issue between WiMAX devices and 3GPP networks (GSM, W-CDMA and HSPA) and vice-versa. This is evidenced by a number of WiMAX service providers and vendors that have started to buy into the potential benefits of the economies of scale offered by LTE. Yota, a WiMAX operator in Russia, announced its intention in May 2010 to commence roll-out of an LTE network, citing the global shift towards LTE by operators and vendors as its reason for the switch to LTE and adding that its delay in deploying LTE had been due to the immaturity of the technology.

LTE has also gained support in the USA. For example, Clearwire conducted TD-LTE trials from late 2010 to early 2011. The operator had previously been technology agnostic, and initially deployed WiMAX to meet the immediate subscriber demand for ubiquitous and affordable mobile broadband services. Clearwire has also restated its commitment to WiMAX, stating that it is “conducting LTE technical trials to determine how it could potentially add LTE technology to coexist with WiMAX”.

In summary, both LTE and WiMAX are future-proofed technologies. However, mobile network operators have shown more confidence in LTE, and particularly TD-LTE, because it provides asymmetrical mobile broadband, which is better aligned to end-user expectations.

5 Technical overview of satellite networks

5.1 Introduction

This section presents a technical overview of broadband satellite networks, and is designed as a reference point for the discussion of the efficiency and prudence of NBN Co's satellite network design. It is structured as follows:

- Section 5.2 describes the technical options available for deploying a satellite network
- Section 5.3 provides an overview of the key worldwide deployments of satellite broadband networks
- Section 5.4 contains some comments on the technology roadmaps for broadband satellites for the next ten to twenty years which may increase the capacity of future satellites
- Section 5.5 assesses whether broadband satellite technology will be able to meet the expected demand in the future, and more generally, if this technology is future-proof
- Section 5.6 presents the conclusions from our technical review of broadband satellite networks.

5.2 Overview of satellite technology options

The history of artificial satellites dates back to 1957 when the Soviet Union launched Sputnik 1. This had a mass of less than 100kg, orbited relatively close to the Earth's surface (the height of the orbit varied from 215km to 939km) and transmitted radio signals which could be picked up on the ground for 22 days before its batteries ran out. Over the course of the last 55 years considerable technical progress has been made and today a communications satellite may have a mass of up to seven tonnes, will typically orbit at a height of 35 786km above the equator and has a useful working life of around 15 years.

Choice of orbit

The choice of orbit is crucially important and in practice it determines the maximum mass of the satellite which in turn tends to determine the working life. The laws of physics dictate that the further away from the Earth a satellite orbits, the longer it takes to complete each orbit. At a height of 35 786km above the equator, known as a geostationary or geosynchronous orbit, the period of each orbit is 24 hours, which means that to an observer based on the ground the satellite appears to remain motionless at a fixed position in the sky. Consequently, communication can be maintained with the satellite using a simple fixed antenna, whereas tracking satellites in other orbits involves the use of motorised antennas and many more satellites. This feature of a geostationary orbit means that it is by far the most popular choice of orbit for communications satellites and there is excess demand for the limited number of orbital 'slots' available.

Applications for geostationary orbital slots are co-ordinated globally by the International Telecommunications Union (ITU), which interfaces directly only with national authorities. In

Australia, this is the Australian Communications and Media Authority (ACMA). All Australian satellite operators have to apply to the ITU via ACMA, which also administers any necessary applications for domestic licences.

The key disadvantage of using a geostationary orbit is that the distance involved introduces a significant delay of around 120ms to signals sent in each direction. Broadband satellite networks need to be designed to take account of, and mitigate the effects of, this latency, and satellite broadband service may be unsuitable for some latency-intolerant broadband applications.

Choice of launch vehicle

To place a satellite into geostationary orbit a powerful rocket (referred to as the launch vehicle) lifts it to the right height. The maximum mass and size of the satellite are therefore determined by the lifting capacity and maximum permissible payload dimensions of the chosen launch vehicle. Today, the most powerful launch vehicles available into geostationary transfer orbit (GTO) are the European Ariane-5, the Sea Launch Zenit 3SL and the Russian Proton-M. All three of these launch vehicles are being considered by NBN Co. Mitsubishi is also claiming equivalent performance, although it has yet to demonstrate its full GTO capability with the H2A and H2B launch vehicles.

Design of a satellite bus

To reduce manufacturing costs and improve reliability, communications satellites are typically built around a standard design, known as a satellite bus. The bus supports the communications equipment on board the satellite, known as the satellite payload.

Once a communications satellite is in the correct orbital location, the satellite bus will typically fully deploy two large solar panel arrays. At geostationary height there are no hours of darkness, but in spring and autumn the Earth eclipses the satellite for up to about 55 minutes each day. The solar arrays power the payload and simultaneously recharge a set of lithium-ion batteries to maintain power to the payload during the eclipse seasons. The solar arrays can be seen clearly in the illustration of the proposed NBN Co satellite design in Figure 5.1 below.

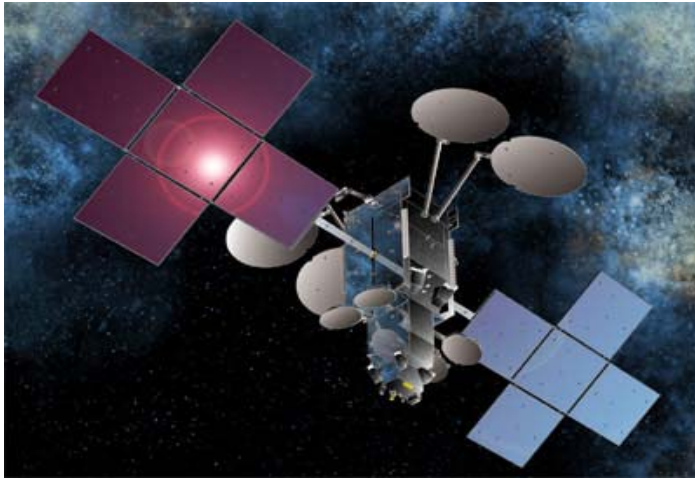


Figure 5.1: Illustration of the satellite proposed by NBN Co [Source: Space Systems Loral, 2012]

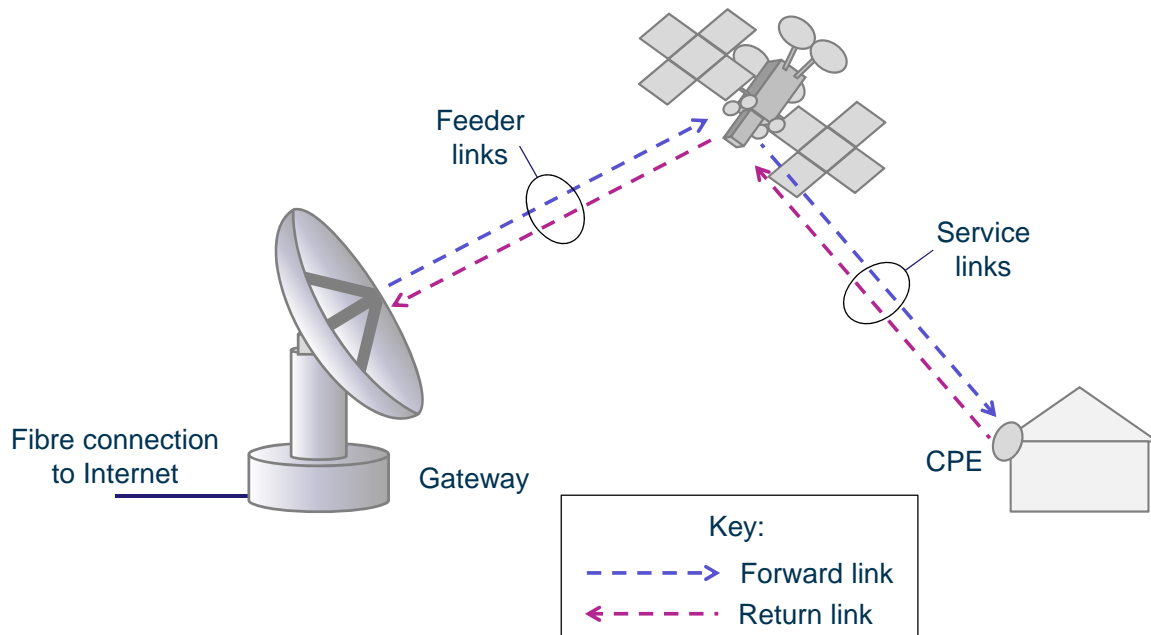
Maintaining a satellite in geostationary orbit can be compared to a person trying to stay in one place on a unicycle: just as the rider needs to make a series of small movements to stay upright and approximately stationary, so the satellite bus needs to keep firing a set of on-board thruster motors to minimise rotation and drift. On most communications satellites in use today these thruster motors are small chemically-powered rocket motors. It is the amount of chemical fuel that can be carried on board which typically limits the working life of a satellite (although failure of other equipment can result in the working life ending prematurely). Some more recent communications satellites use electrically-powered ion thrusters to replace some of the chemical thrusters. Ion thrusters still require the satellite bus to carry a chemical source of ions, but this approach is more weight-efficient; with the result that the working life can be extended by carrying more fuel or, alternatively, that the payload can be made heavier.

Network architecture

A broadband satellite network is usually designed to provide a radio link between a large central earth station, known as a gateway, which is linked to the Internet via fibre, and a much more compact set of customer premises equipment (CPE) comprising an outdoor unit (dish antenna plus associated radio frequency electronics) and an indoor unit (satellite modem) (see Figure 5.2 below).

The uplink from the gateway to the satellite and the downlink from the satellite to the gateway are collectively referred to as the *feeder links*, while the uplink from the CPE to the satellite and the downlink from the satellite to the CPE are collectively referred to as the *service links*. In addition the uplink from the gateway to the satellite and the downlink from the satellite to the CPE are collectively referred to as the *forward link* while the uplink from the CPE to the satellite and the downlink from the satellite to the gateway are collectively referred to as the *return link*.

Figure 5.2: Overview of the network architecture for two-way satellite broadband [Source: Analysys Mason, 2012]



Choice of frequency bands

The frequency bands used to provide satellite services are named using a rather arcane system of letters. The bands commonly used to provide commercial fixed satellite services are often known as:

- C-band: 3.4–6.725GHz
- Ku-band: 10.7–18.1GHz
- Ka-band: 17.7–30.0GHz.

Certain parts of these bands are designated by the ITU for earth-to-space communication (i.e. uplinks) while other parts are designated for space-to-earth (i.e. downlinks). There is some overlap between the Ku-band feeder uplink frequencies and the Ka-band service downlink frequencies.

The advantages of using the higher frequency bands are:

- they are less congested with other users and it is therefore generally easier to secure a large allocation of spectrum
- the diameter of the antenna required to achieve a given gain is smaller; this results in CPE which is less obtrusive and less expensive to manufacture and install.

The disadvantage of using the higher frequency bands is that they are more susceptible to a phenomenon known as ‘rain fade’ – attenuation of the satellite signal by atmospheric moisture – which can lead to impairment or loss of service in wet weather. Modern broadband satellite networks mitigate against rain fade through the use of adaptive coding algorithms (which provide reduced speeds during wet weather) and site diversity at the gateways (i.e. having two or more

gateways sufficiently far apart that it is unlikely that both would be affected simultaneously by the same storm). Consequently, they should only ever lose service locally and during the most extreme storms.

Design of payload

The payload on a communications satellite comprises the electronic equipment and a set of antennas which transmit beams of radio signals to equipment on the ground and also receive signals from the ground equipment (the reflectors forming part of service link antennas on the proposed NBN Co satellites are the large grey elliptical objects clearly visible in Figure 5.1). A conventional payload for a fixed satellite services (FSS) communications satellite provides a fairly small number of service beams, each of which covers a wide area. For example, the Optus D3 satellite, launched in 2009, has four distinct beams including one which is shaped to cover the whole of Australia for direct-to-home (DTH) satellite broadcasting.

More recently, the so-called high-throughput satellites have come into commercial use. In this type of satellite the payload is designed to provide a much larger number of small spotbeams, each being typically a few hundred kilometres across. The two satellites proposed by NBN Co are high-throughput satellites, each providing a total of 101 service spotbeams (75 small spotbeams covering the more densely populated parts of Australia and 26 large spotbeams covering the less densely populated parts) plus 10 gateway beams. Figure 5.3 shows the proposed beam configuration.

Figure 5.3: Proposed spotbeam configuration for NBN Co's satellite 1A [Source: NBN Co, 2012]



The advantage of the spotbeam approach is that the spectrum available to the satellite can be re-used across multiple spotbeams, increasing the overall capacity of the satellite (hence the high-throughput designation) and, in doing so, reducing the overall cost per Mbps of throughput provided. By contrast, the disadvantage of this approach is that the design of high-throughput satellites to meet geographically varying traffic demand is more complicated and the technology is less mature than for conventional satellites. Four separate reflectors are required to provide a 'carpet' of spot beams of the same size. In particular, to produce smaller-diameter spotbeams larger antenna reflectors are required – in Figure 5.1 the four smaller reflectors on the top of the satellite produce the larger beams, whilst the four larger reflectors (two on either side) produce the smaller beams.

Choice of CPE

As previously discussed, the CPE for satellite broadband comprises an outdoor unit which consists of two elements: a dish antenna with associated radio frequency electronics to transmit data to, and receive data from, the satellite; and an indoor unit which consists of a small desktop modem which is typically mains powered. The outdoor unit is connected to the indoor unit by one or more coaxial cables.

The outdoor unit needs to be installed in a position with a clear line of sight to the satellite, pointed accurately at the satellite and mounted rigidly to avoid movement: since a satellite broadband antenna transmits as well as receives (unlike a DTH satellite TV antenna which is receive-only), any mis-pointing will not only affect the performance of the CPE in question, but may also cause interference to adjacent satellites.

The design of satellite modems is generally less standardised than the design of CPE for fibre and terrestrial wireless networks. They are amenable to mass production but have only recently exceeded the first million shipments. Although there is an international standard for two-way satellite modems, known as digital video broadcasting-return channel via satellite or (return channel over system) (DVB-RCS), many satellite operators (including NBN Co) have selected proprietary equipment instead.

5.3 Worldwide satellite broadband deployments

At the time of writing we are aware of nine commercial high-throughput satellites in orbit, launched between July 2004 and August 2012, out of a total of around 300 commercial communications satellites in orbit.³⁴ Three of these high-throughput satellites were built by NBN Co's chosen contractor, Space Systems/Loral. Of those, the Viasat-1 and EchoStar XVII / Jupiter 1 satellites were built using the satellite bus which NBN Co proposes to use. Of the remaining high-throughput satellites, Astrium – a subsidiary of European Aeronautic Defence and Space (EADS) – built two (plus a third one in conjunction with the Indian Space Research Organisation), Boeing built two and Orbital Sciences Corporation built one. Despite the relative

³⁴ Estimate from Boeing, see: http://www.boeing.com/defense-space/space/bss/launch/980031_001.pdf.

immaturity of the technology, all the commercial high-throughput satellites launched to date have been deployed and brought into commercial service without any reported difficulties, and none had failed in orbit as of August 2012.

Details of each satellite are provided in Figure 5.4 below.

Figure 5.4: Commercial high-throughput satellites in orbit [Source: Analysys Mason, August 2012]

Name of satellite (and owner)	Supplier (and bus)	Launch date	Frequency band used for HTS operation (and number of spotbeams)	Total throughput	Notes
Anik F2 (Telesat)	Boeing (702)	Jul 2004	Ka-band (45)	Not stated	Covers the USA and most of Canada. Supports Wildblue broadband service. Suffered temporary anomaly on 6 October 2011, which resulted in service outage lasting approximately 24 hours
Thaicom 4 / IPSTAR (Thaicom)	Space Systems/ Loral (FS-1300L)	Aug 2005	Ku-band (84) Ka-band (10)	45Gbps	Covers India, Japan, Malaysia, the Philippines, Thailand, Singapore and parts of Australia, China and Indonesia
Spaceway 3 (Hughes Network Systems)	Boeing (702)	Aug 2007	Ka-band (104)	c.10Gbps	Covers the USA and southern Canada. Supports HughesNet broadband service
HYLAS-1 (Avanti Communications)	EADS Astrium/ ISRO (I-2K)	Nov 2010	Ka-band (8)	Not stated	Covers UK and Ireland, Spain and Portugal, Austria, Germany, Greece, Italy, Switzerland and most of Central and Eastern Europe
KA-SAT (Eutelsat)	EADS Astrium (Eurostar E3000)	Dec 2010	Ka-band (82)	Over 70Gbps	Covers most of Europe and Turkey plus parts of North Africa and the Middle East
ViaSat-1 (ViaSat)	Space Systems/ Loral (LS-1300)	Oct 2011	Ka-band (72)	130Gbps	Covers the USA and southern Canada. Supports WildBlue broadband service
Yahsat 1B (AI Yah Satellite Communications)	EADS Astrium (Eurostar E3000)	Apr 2012	Ka-band (61)	Not stated	Mixed government and commercial use. Supports YahClick broadband service. Covers Angola, Egypt, Nigeria, North and South Sudan, South Africa, Turkey, East Africa, most of the Middle East, parts of Central Asia
Echostar XVII / Jupiter 1 (Hughes Network Systems)	Space Systems/ Loral (LS-1300)	July 2012	Ka-band (60)	Over 100Gbps	Covers North America. Supports HughesNet broadband service
HYLAS-2 (Avanti Communications)	Orbital Sciences Corporation (STAR)	Aug 2012	Ka-band (24)	Not stated	Covers most of Europe, Afghanistan, Botswana, South Africa, Turkey, East Africa and parts of the Middle East

5.4 Technology roadmaps for broadband satellites

It can be seen from Figure 5.4 that the early high-throughput satellites had a total throughput of less than 50Gbps, while some of the latest ones have a total throughput in excess of 100Gbps. Broadband satellites with higher throughput generally deliver a lower cost per Mbps than those with lesser throughput, hence there is ongoing research to develop satellites with even higher throughput (for example, the European Space Agency's TERASAT project, which is considering the enabling technologies that would be needed to construct a satellite with 1Tbps total throughput by 2020).³⁵

We consider that the two biggest technical challenges involved in designing a terabit satellite are:

- **Commercialisation of Q- or V-band feeder links** – To avoid problems with interference, a satellite's feeder links need to operate at different frequencies from the service links. In today's largest high-throughput satellites, both sets of links operate in the Ka-band, but the amount of spectrum available for the service links (and thus the total throughput) could be increased if the feeder links operated in a different band. Given the level of international demand for spectrum in the lower-frequency satellite bands, this would in practice mean a move to a higher band such as the Q-band (33–50GHz) or the V-band (50–75GHz). The technology to build equipment to operate in these bands is evolving, but it is not yet sufficiently mature to be deployed on a satellite which is expected to operate for 15 years or more with no maintenance.
- **Development of larger antenna reflectors** – Due to limits on the total amount of spectrum available (even taking into account the potential to operate the feeder links in the Q- or V-bands) the design of a terabit satellite would almost certainly incorporate more spotbeams than the one hundred or so that represents the current state of the art. As explained previously, this would in practice entail the development of larger antenna reflectors. The proposed NBN Co satellites have rigid antenna reflectors which are close to the maximum diameter that today's satellites can accommodate. Some commercial communications satellites, such as the three Inmarsat-4 satellites, Skyterra 1 and Terrestar-1, have successfully deployed larger reflectors based on unfurlable designs (which work rather like a folding umbrella). Unfurlable reflectors have, however, tended to be less reliable than their fixed counterparts (there were initial problems in deploying Skyterra 1's reflector, and another large unfurlable reflector on Eutelsat's W2A satellite failed to deploy correctly). Further research and development is therefore required to make unfurlable reflectors as reliable as fixed ones and then to develop the necessary industrial capacity.

5.5 Ability of satellite broadband networks to meet evolving bandwidth demand

On a high-throughput satellite there is usually limited, if any, capability to reallocate capacity between spotbeams to cope with variations in bandwidth demand across the coverage footprint.

³⁵ The project homepage can be found at: <http://telecom.esa.int/telecom/www/object/index.cfm?fobjectid=31254>.

Such flexibility, if implemented, would increase the mass of the satellite at the expense of total capacity. Moreover, once a satellite has been launched into geostationary orbit, there is no opportunity to upgrade it or perform physical maintenance on it.

Depending on the configuration of the satellite, it may be possible to obtain some incremental improvement in performance during the lifetime of the satellite through the implementation of new modulation and coding techniques if and when they are developed. It may also be possible to increase the maximum speed for individual users by upgrading their CPE (for example, by installing a larger or more powerful outdoor unit or a higher-speed indoor unit).

Nevertheless, when a satellite network is being used as one component of a national broadband network, as NBN Co intends, then it may be possible to meet evolving bandwidth demand by substituting terrestrial capacity for satellite capacity – for instance, if clusters of satellite broadband users are causing congestion in a particular spotbeam, it may be possible to serve some of the clusters with a new terrestrial wireless base station instead, freeing up satellite bandwidth to continue serving the most remote users.

We also note that the spacecraft are being designed for a 15-year working life (the standard approach in the satellite industry) while other components of NBN Co's network are being designed for a 30-year working life. Consequently, there is an opportunity to revisit the requirement for the satellite network, and potentially implement a significant upgrade, approximately half way through the term of the SAU.

5.6 Conclusion

Satellite networks are a proven technology for delivering broadband services in remote areas. Although high-throughput satellite technology is less mature than that for conventional communications satellites, a number of high-throughput Ka-band satellites similar in concept to the satellites proposed by NBN Co are already being used to deliver commercial broadband services in various regions of the world, including North America, Europe, and the Middle East & North Africa. To date, the launch, deployment and subsequent operation of these satellites has been largely free of problems.

6 Review of the efficiency and prudence of NBN Co's fibre network design

6.1 Introduction

In this section, Analysys Mason sets out its assessment and conclusions in respect of whether, and the extent to which, NBN Co's design for its fibre network reflects an efficient and prudent network design.

Many decisions have to be made as part of the development of an efficient and prudent FTTP network architecture and associated infrastructure. We consider that the key decisions that influence that efficiency and prudence of a network design include:

- technology choices, which mainly relate to the fibre technology being used to supply services (e.g. GPON), as well as related choices such as the choice of Layer 2 protocol (e.g. Ethernet)
- architectural choices, which mainly relate to the topology of the network
- infrastructure choices, which relate to the physical implementation of different sections and nodes of the network.

In particular, we consider that the following decisions will have the most impact on the efficiency and prudence of the design of FTTP networks:

- technology:
 - GPON³⁶ or P2P technology, or a combination of both
 - Layer 2 protocol³⁷
- architecture:
 - centralised architecture versus distributed architecture in terms of network scalability, flexibility and cost
 - approach to network resilience (i.e. end-to-end service availability) and protection options
 - fibre cable options, including the number of fibres in cables, the overall diameter of cables and cable design and protection specifications
- infrastructure:
 - approach to fibre dimensioning
 - the extent of re-use of existing passive infrastructure³⁸

³⁶ This design choice has been specified by the Australian Government in the *Statement of Expectations*, which provides that NBN Co "should proceed with network planning and construction of the rollout on the basis of GPON architecture".

³⁷ The Australian Government has specified in the *Statement of Expectations* that NBN Co is to supply "open and equivalent access to wholesale services...via Layer 2 bitstream services". Therefore, this decision relates to the protocol to be used by NBN Co in supplying Layer 2 bitstream services.

³⁸ The *Statement of Expectations* provides that the Australian Government "requests NBN Co to provide this network and expects NBN Co to use existing infrastructure in providing this service, where efficient and economic to do so".

- customer premises, including the number of fibres to each premises, the demarcation point for the wholesale service and number of UNI ports on the NTD³⁹
- local fibre network, including coverage requirements, infrastructure options (e.g. overhead versus underground), local fibre network dimensioning and architecture, final drop provisioning
- fibre distribution hub (i.e. splitter location), being either street cabinets or underground splitter enclosures
- distribution fibre network, including distribution network architecture and resilience of the distribution network
- fibre access node and fibre serving area, including the FAN location, the size of each FSA and the use of an optical fibre distribution frame at the FAN site
- transit network, including architecture and technology choices, bandwidth dimensioning and PoI architecture.⁴⁰

These are the design choices on which we have focused our efficiency and prudence analysis below.

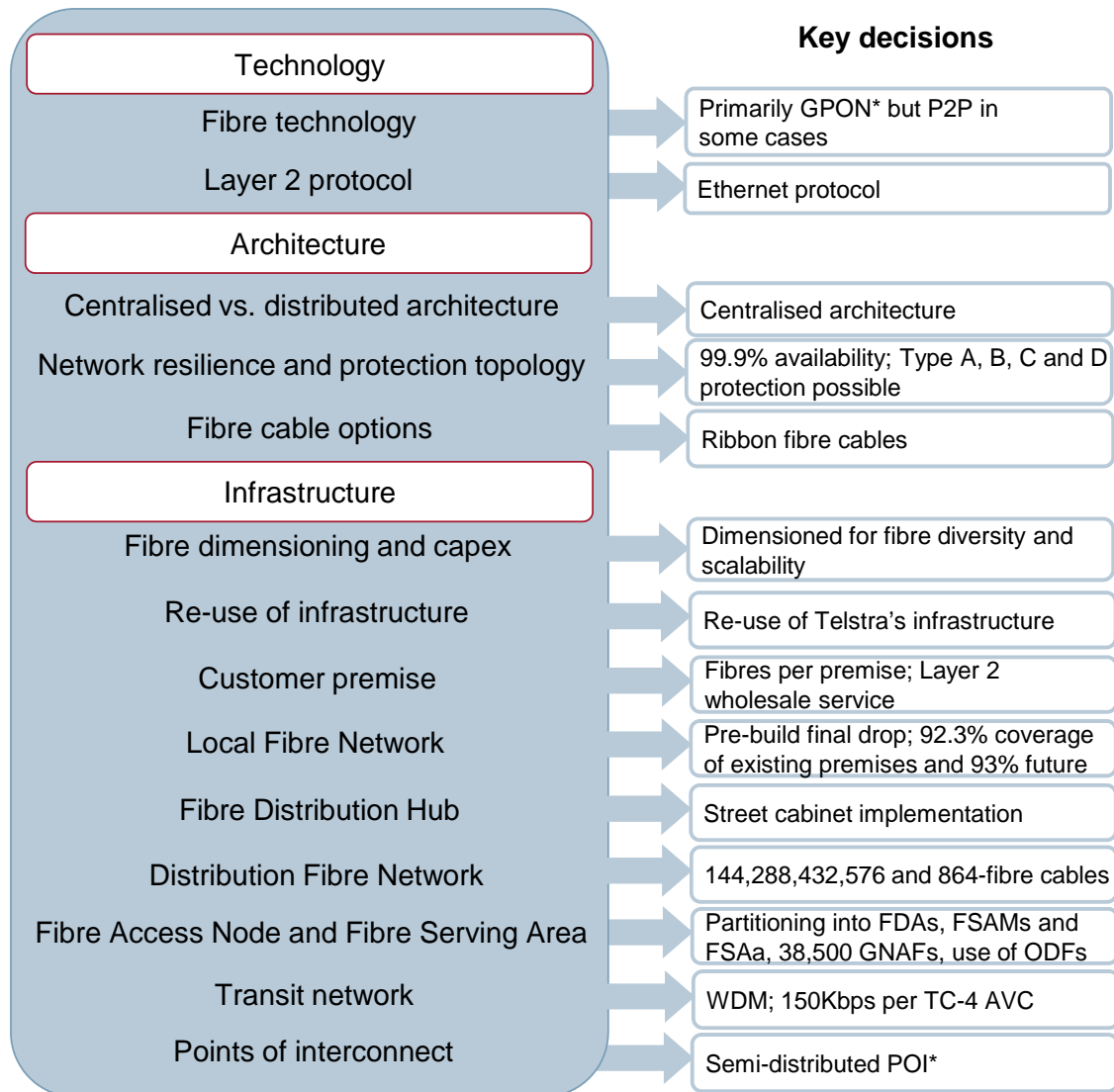
It is also important to note that our analysis has sought to analyse each of these design choices from an efficiency and prudence perspective. However, it is the combination of these individual design choices and decisions that together determine whether the NBN Co fibre network, as a whole, is efficient and prudent from a design perspective. Therefore, while we have made individual assessments on the efficiency and prudence of individual design choices and decisions (and have outlined our views on each of those elements in this section), our overall conclusion on the question of whether, and the extent to which, NBN Co's design for its fibre network reflects an efficient and prudent network design, is based on Analysys Mason taking a view on NBN Co's fibre network design as a whole.

Figure 6.1 below summarises the critical decisions faced by NBN Co in respect of the design of its FTTP network from a technology, architecture and infrastructure perspective.

³⁹ The *Statement of Expectations* states that the Australian Government “notes and supports the NBN Co product, pricing and service offerings developed to date following consultation with industry and including...providing a Layer 2 bitstream service which enables multi-operator delivery of next generation video services to industry standard”. However, the *Statement of Expectations* does not specify the number of UNI ports on the NTD that are to be selected by NBN Co to achieve multi-operator delivery of video services and other services, thereby making this a decision choice for NBN Co.

⁴⁰ The *Statement of Expectations* states that the Australian Government “has determined that a semi-distributed PoI structure which extends the NBN Co network to meet with, but not overbuild competitive backhaul routes is the preferred outcome”. And further, “The Government expects that NBN Co will act to ensure that POIs are located in accordance with the ‘competition criteria’ formulated by the ACCC. It expects NBN Co to provision its physical infrastructure, including POIs and fibre exchanges, to accommodate reasonable expectations for retail competitors’ equipment, in anticipation of multiple retail competitors. While NBN Co is expected to consult closely with the ACCC in relation to the POIs, the specific location of the POIs will be a matter for NBN Co”.

Figure 6.1: FTTP network – Physical network design and implementation options [Source: Analysys Mason, 2012]



*Specified by the Australian Government and implemented by NBN Co

Finally, we note that some of the key decision choices that impact upon the efficiency and prudence of NBN Co's fibre network have been specified or influenced by the Australian Government in its *Statement of Expectations*. Therefore, in accordance with our instructions, this report does not examine the merits of the specifications given by the Australian Government to NBN Co, but instead examines the key choices or decisions that have been made by NBN Co in the design of its network within the overall parameters that have been established by the Australian Government at a policy level through its *Statement of Expectations*.

6.2 Fibre technology assessment

6.2.1 Fibre technology

As discussed in Section 3, the two predominant FTTP technologies used to deliver ultra-fast broadband are:

- TDM PON – comprising EPON and GPON
- Ethernet P2P networks.

As per the requirements of the *Statement of Expectations*,⁴¹ NBN Co is implementing GPON as the primary access technology for its fibre footprint. NBN Co is planning to use GPON for the delivery of services to residential customers, small and medium business customers and for lower-bandwidth services that are provided to enterprise and government customers.

In addition to GPON architecture, NBN Co will deploy P2P technology to serve the enterprise and government segment, which has large bandwidth and service symmetry (same upstream and downstream bandwidth) requirements. NBN Co is also planning to provide ‘enhanced service levels’ for large enterprise and government customers to reflect their requirements in terms of business continuity.

Below we provide further information of our assessment of NBN Co’s implementation of GPON and P2P design.

6.2.2 Layer 2 protocol

Critical decision and related issues

As per the requirements of the *Statement of Expectations*, the Australian Government has declared its choice of wholesale service provision at Layer 2. In particular, the *Statement of Expectations* provides that NBN Co “will offer open and equivalent access to wholesale services, at the lowest levels in the network stack necessary to promote efficient and effective retail level competition, via Layer 2 bitstream services”.

The provision of wholesale access at Layer 2 usually refers to providing access seekers with access to the electronic layer of the network (i.e. the data link layer of the OSI model).⁴²

⁴¹ In its *Statement of Expectations*, the Australian Government has accepted that the planned GPON architecture will be the most practical solution in brownfields areas based on the agreement with Telstra and provides that NBN Co should proceed with network planning and construction of the roll-out on the basis of GPON architecture.

⁴² If additional background on Layer 2 service delivery is needed, a full discussion of the impact of providing wholesale services at different layers in the OSI model can be found in the following report: Analysys Mason, *GPON Market Review - Competitive Models in GPON: Initial Phase*, Report for Ofcom, Ref: 15340-512, 26 October 2009. See, http://stakeholders.ofcom.org.uk/binaries/research/technology-research/Analysys_Mason_GPON_Market_1.pdf.

Notwithstanding that NBN Co has been required to supply Layer 2 wholesale services, NBN Co is required to take a critical decision regarding the Layer 2 protocol that will underpin the supply of wholesale services.

Ethernet is now the ubiquitous Layer 2 protocol, not only for local area networks but also for metropolitan and national area networks. Ethernet has been prescribed and recommended by a number of standards bodies (e.g. the Broadband Forum and the Metro Ethernet Forum) and regulators around the world as the preferred Layer 2 broadband access technology.

NBN Co's position

NBN Co plans to adopt Ethernet as the Layer 2 protocol to deliver its wholesale services for both the fibre network and the fixed wireless network.

Analysys Mason's assessment

Analysys Mason considers that NBN Co's choice of Ethernet as a Layer 2 protocol is both efficient and prudent, as the choice of Ethernet aligns with global standards and is a proven technology, and will facilitate competitive vendor pricing and minimises technology risk/risk of stranded assets.

This view is also shared by the Australian telecoms industry. The results from the consultation process in response to NBN Co's initial consultation paper on the design of its proposed wholesale fibre bitstream products suggest that there is general consensus on adopting Ethernet as the protocol of choice for Layer 2 wholesale service.

6.3 Fibre network architecture assessment

Here we present our assessment of the choices regarding the architecture of NBN Co's network, including:

- comparison between centralised and distributed architecture in terms of network scalability, flexibility and cost
- network resilience and protection options
- fibre cable options.

6.3.1 Comparison between centralised and distributed architecture in terms of network scalability, flexibility and cost

Critical decision and related issues

NBN Co needs to assess whether implementing a centralised or a distributed architecture⁴³ represents the optimal choice in view of its objectives (refer to Section 3.3.2 for definitions of centralised and distributed architectures). The choice of architecture is a function of many

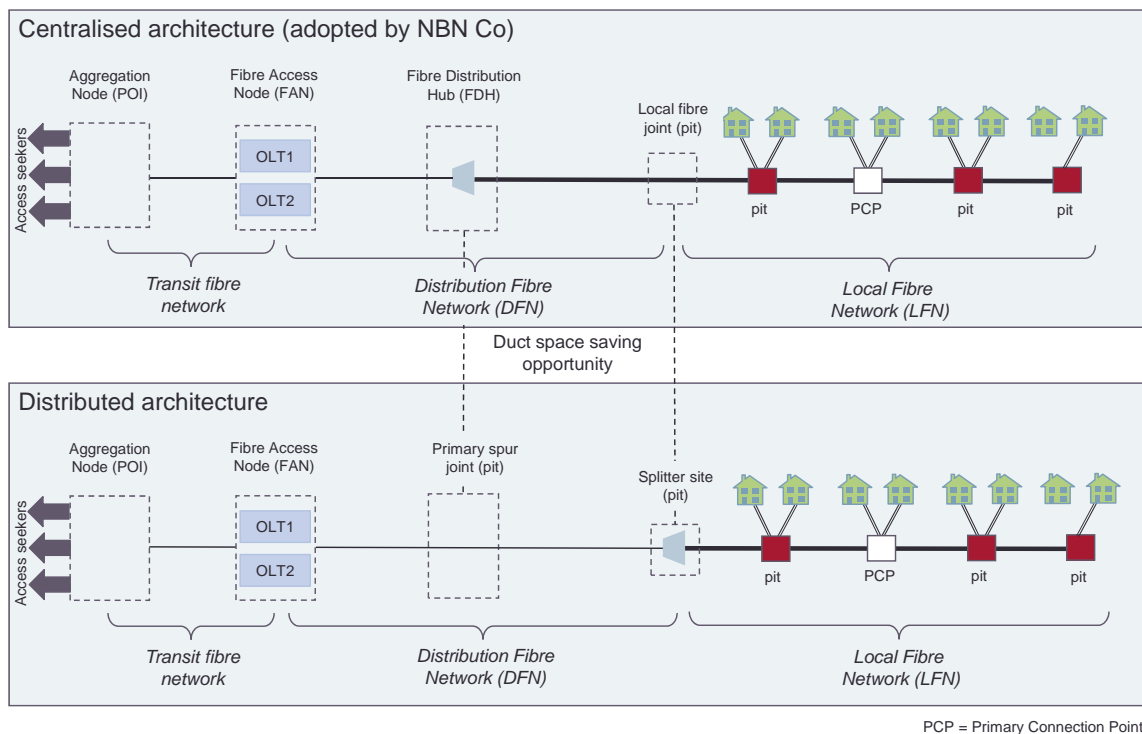
⁴³ Please note that the cascaded architecture is an example of distributed architecture and is therefore not considered explicitly in this comparison.

parameters such as capex, opex and network evolution. Below we discuss the impact of NBN Co's choice on each of these parameters.

► *Impact on capex*

First, by definition, in a centralised architecture, many splitters are aggregated to a single site, leading to fewer splitter sites overall. Therefore, in a centralised architecture, splitter sites will be located further away from end-user premises than in a distributed architecture. This is because, in a centralised architecture, the location of the splitter sites has to be optimised for a larger number of households than in the distributed architecture, where a splitter site location can be optimised for as few as 32 end-user premises. Therefore, a distributed architecture maximises the length of the distribution network, and is therefore often referred to as a 'duct and fibre lean architecture', providing an opportunity to save significant capex in civil works (as it maximises the re-use of existing ducts). Since civil works can represent up to 80% of the total deployment cost of an FTTP network, the impact of reducing the amount of space required in ducts to deploy fibre is significant. This is illustrated in Figure 6.2.

Figure 6.2: Comparison of distribution (feeder) network between a centralised and a distributed architecture
[Source: Analysys Mason]



As explained in Section 3.3.2, more splitter sites are required in a distributed network than in a centralised architecture, and therefore it may be argued that more pits may be required. If the pits do not exist and need to be built from scratch, the associated extra capex could partially offset the capex savings associated with the higher percentage of duct re-use. However, given the significant reduction in space required to host a single splitter (as opposed to 5 or 6), existing pits can often be re-used to accommodate a single splitter. Therefore, a distributed architecture can be more cost-effective than a centralised architecture.

It should be noted that, despite the potential capex savings associated with a distributed architecture, many GPON operators throughout the world have opted for a centralised architecture. For example, Verizon has adopted a centralised architecture for its FiOS network, which represents one of the largest GPON deployments in the world. Also, Chorus in New Zealand has opted for a centralised architecture for the delivery of its ultra-fast broadband network.

► *Impact on opex*

In a distributed network architecture, there will be significantly more splitter sites to operate and maintain than in a centralised architecture. Therefore, intuitively, a centralised architecture will be cheaper to operate and maintain, as when a fault occurs fewer sites have to be considered, leading to an easier deployment of the operational team.

► *Impact on network evolution and scalability*

When GPON active equipment reaches the end of its life or no longer provides sufficient capacity to meet end-user demand, a technology upgrade will be required. As discussed in Section 3.8, two options are available for a GPON upgrade: NG PON and WDM PON. Despite the fact that GPON and NG PON can co-exist on the same network by using wavelength separation (see Figure 3.17 in Section 3.8), a number of operators are considering *not* using the same PON when considering the migration from GPON to NG PON (10G PON), to avoid the problem of having to retrofit a wavelength blocker filter on existing NTDs. For these operators, a new splitter will be required at every splitter site to provide a dedicated NG PON system. The use of a centralised architecture means that fewer sites would have to be visited to install the new splitters for the NG system, which would optimise the efficiency of the operational team and accelerate the roll-out of NG PON. A similar argument is applicable to an upgrade to WDM PON, where each splitter site should be upgraded with a WDM multiplexer, as mentioned in Section 3.8.

Also, it is worth noting that a centralised architecture provides high flexibility to 'balance the load' between different GPONs. For example, if in a particular area, high take-up of high-speed tiers were to occur (e.g. if service providers required a high proportion of 1000/400Mbps TC_4 services in a particular area), it would be relatively easy to balance the load imposed by these customers across different GPONs, by connecting them to different splitters in the FDH, thus reducing the number of customers on each GPON covering that area.

NBN Co's position

NBN Co has adopted a centralised network architecture for its FTTP network, where splitters are aggregated in fibre distribution hubs. NBN Co's decision was primarily driven by ease of operation and maintenance, mainly due to the reduced number of splitter sites compared to a distributed network architecture.

The choice of a centralised architecture will also ensure that NBN Co can more easily upgrade bandwidth on the network. For future network upgrades, NBN Co intends to deploy NG PON

using a separate PON in order to avoid having to retro-fit wavelength blocking filters to existing GPON NTDs.

Analysys Mason's assessment

Analysys Mason considers that a centralised architecture for GPON is both efficient and prudent, as it represents the best choice of architecture from a long-term cost management, network scalability and flexibility perspective.

In particular, a centralised architecture:

- has been adopted by large operators, including Verizon in the United States and Chorus in New Zealand and is therefore a proven architecture
- reduces opex due to the presence of fewer splitter sites in the network, which facilitates operation and maintenance
- offers greater flexibility in implementing aggregated flexibility points (i.e. FDH) in the network to connect both GPON or P2P customers (or to migrate a customer from GPON service to P2P service)
- offers more flexibility to upgrade the network to higher-bandwidth technology (e.g. migration from GPON to NG PON or from GPON to WDM PON), as fewer splitter sites have to be visited
- provides more flexibility to balance the load between different GPONs, especially in areas where there is a high percentage of high tier bandwidth end users.

6.3.2 Fibre network resilience and end-to-end service availability

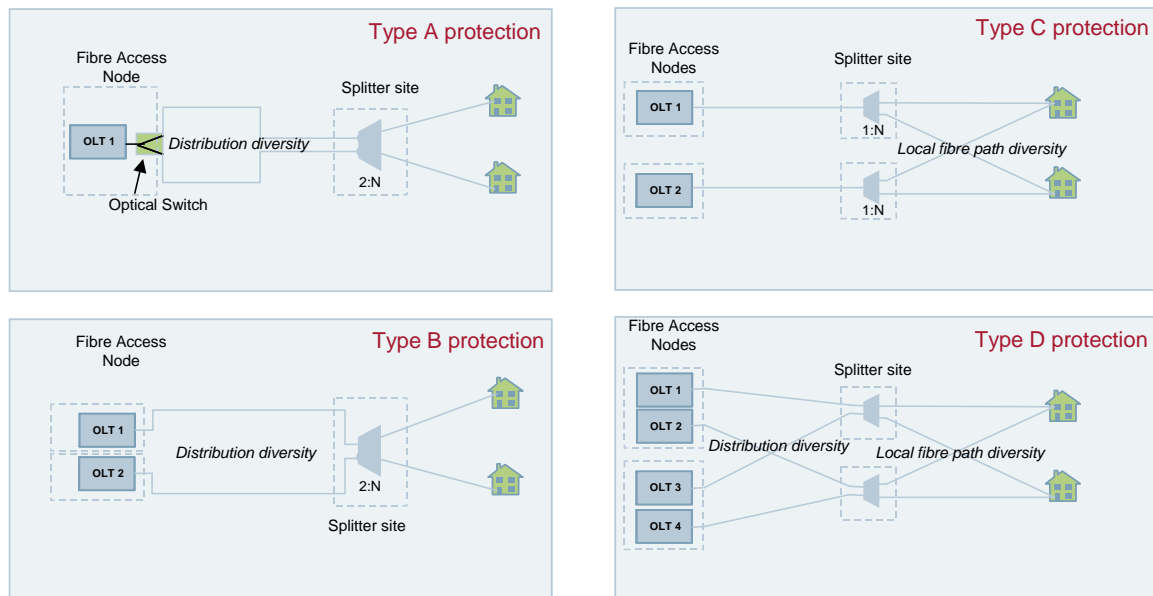
Critical decision and related issues

The end-to-end availability of a service is defined as the amount of time the service will be operational for the user. In this context, the end-to-end availability of a service has to take into account all passive and active equipment present in the network from the NTD, located at the end-user premises, to the PoI. The availability of the passive infrastructure makes a significant contribution when defining the end-to-end service availability. For example, if the fibre network is designed as rings, then a single fibre cut will **not** be service affecting, therefore increasing the overall end-to-end service availability.

Also, when defining its end-to-end service target availability, it is very important to consider the geographical area and the maximum distance of fibre between the end-user premises and the PoI, especially for the more remote premises (which will represent the worst case in terms of end-to-end service availability). This is because, the longer the fibre run, the more likely a fibre cut or other service affecting fault may occur. In this context, it should be noted that Australia's geography results in longer fibre runs than in most other countries, mainly due to the large distances to be covered. This factor will significantly influence the availability target that will be defined by NBN Co for its offered services.

Often, the bottleneck in the fibre network in terms of availability is the distribution and local network, because a single fibre is usually deployed between the FAN and the end-user premises. In order to overcome this issue, the ITU-T G984.1 GPON standard defines four types of resilience: Type A, Type B, Type C and Type D, as illustrated in Figure 6.3.

Figure 6.3: Illustration of ITU-T Rec G984.1 GPON protection options [Source: Analysys Mason]



Type A protection only protects against a fibre break in the distribution network and does not protect against an OLT failure. It also requires an optical switch to switch the signal to the protection route, should the main route fail.

Type B protection allows protection against both a fibre break in the distribution network and an NTD failure. Note that in order to further enhance protection against catastrophic events, both OLTs could be located in different FANs and feed the same splitter. This protection mechanism is ‘cold standby’ as both OLTs cannot operate at the same time. To be effective, Type B protection requires both fibres used in the distribution network to be routed through different routes in different ducts.

Type C protection provides a protection mechanism on an end-to-end basis and protects against fibre cuts at any point in the network. To be effective, Type C protection requires both local network fibres (from the splitter site to the end-user premises) to be routed through path disjoint routes.

Type D protection combines Type B and Type C protection, enabling the infrastructure provider to mix the types of customer and protection that can be provided on a single PON system (e.g. residential customers can be protected using Type B protection, while business customers can be protected using Type C protection).

The protection options adopted in a GPON will be a balance between the customers' requirements and the costs of implementing resilience in the network. It is expected that business customers will require a higher degree of protection for business continuity reasons, while residential customers will not typically require protection. It should be noted that current copper-based networks supporting DSL broadband residential customers are typically unprotected.

In any case, when considering protection options in a GPON, an important requirement is to provide path diversity between any two nodes in the GPON (e.g. path diversity between the FAN and the splitter sites to implement Type B protection and path diversity in the local network to implement Type C protection).

NBN Co's position

NBN Co has designed its fibre network to be able to offer service with end-to-end service availability target of at least 99.9%, as discussed in NBN Co's network availability discussion paper.⁴⁴

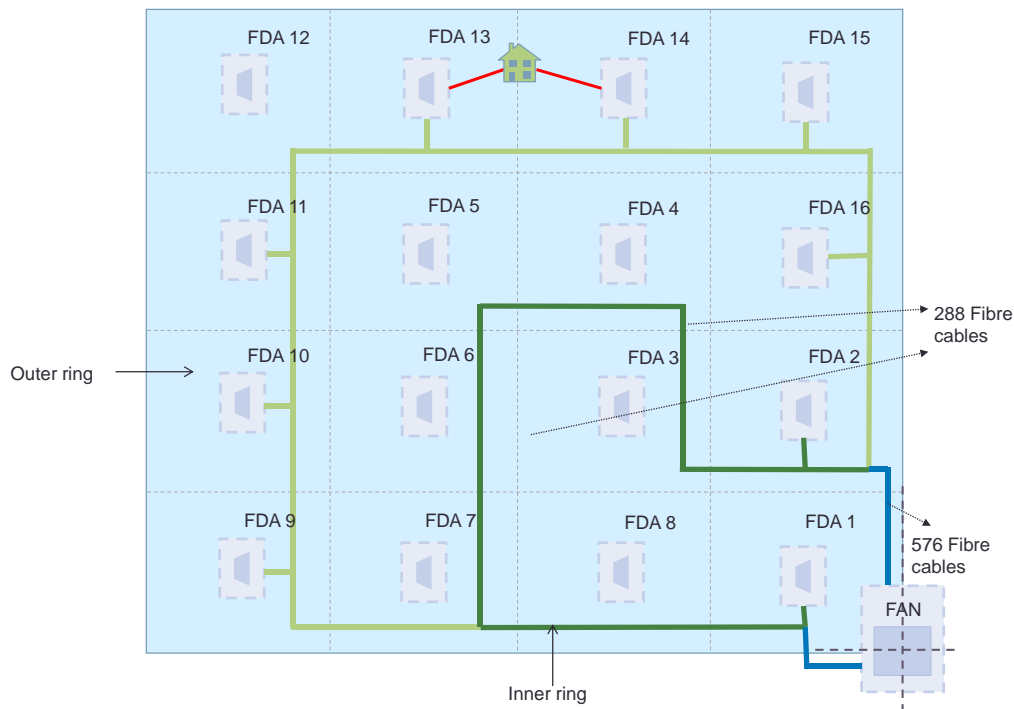
To meet and exceed this availability target for particular services, NBN Co has designed its network to provide path diversity in the transit network⁴⁵ and also in the distribution network. In particular, in the distribution network, an FDH can be fed via two different routes. This means that NBN Co will have the flexibility to implement Type B protection in its network if required by the type of customers in the served area. Note that, in relation to the previous section, a centralised architecture provides greater flexibility in the implementation of protection in the DFN as it is easier to design a ring topology around fewer sites hosting the splitters.

The local fibre network will provide spare fibres at each primary connection point (PCP). Therefore, Type C redundancy can also be provided to businesses on a case-by-case basis, by attaching a premises to two distinct PCPs to provide path diversity (as two fibres from the same PCP would follow the same route in the same cable, and so would not protect against a cable cut). This is illustrated in Figure 6.4 below.

⁴⁴ <http://www.nbnco.com.au/our-network/industry-consultation/network-availability-discussion-paper.html>.

⁴⁵ See assessment of infrastructure network in Section 6.4.

Figure 6.4: Type C protection implemented in NBN Co's network [Source: NBN Co]



Analysys Mason's assessment

Analysys Mason considers that NBN Co's proposed end-to-end service availability target of 99.9% is prudent. Based on our international experience, FTTP operators tend to adopt a service availability target of 99.95% for services provided over their fibre networks, although we acknowledge that the manner in which this percentage is calculated varies between FTTP operators to some extent⁴⁶. In any event, due to the geography of Australia and specifically due to the significantly longer fibre runs that exist in Australia relative to most overseas jurisdictions, we consider that a minimum end-to-end service availability of 99.9% for all services is prudent.

We believe that the fibre network designed by NBN Co can provide an end-to-end service availability of 99.9% or higher as it follows best industry practice in terms of resilience. In particular:

- the DFN is based on rings which provide path diversity from the FAN to every FDH
- using the proposed architecture, NBN Co could implement all standardised GPON protection options (Type A, B, C and D) if required
- NBN Co plans to have at least two independent entry/exit locations in each FAN, which will ensure that each segment of the rings is diversely routed
- a centralised architecture provides greater flexibility in the implementation of protection in the DFN as it is easier to design a ring topology around fewer sites

⁴⁶ Different operators include different elements in this calculation.

hosting the splitters.

The architecture devised by NBN Co will also enable NBN Co to enhance its portfolio of services, including services with higher availability, if there is a demand from service providers for new protection services (although we note that protection services are unlikely to be required for the residential segment).

6.3.3 Fibre cable options

Critical decision and related issues

In general, a fibre cable includes several strands of fibre. A fibre cable has a number of important characteristics such as:

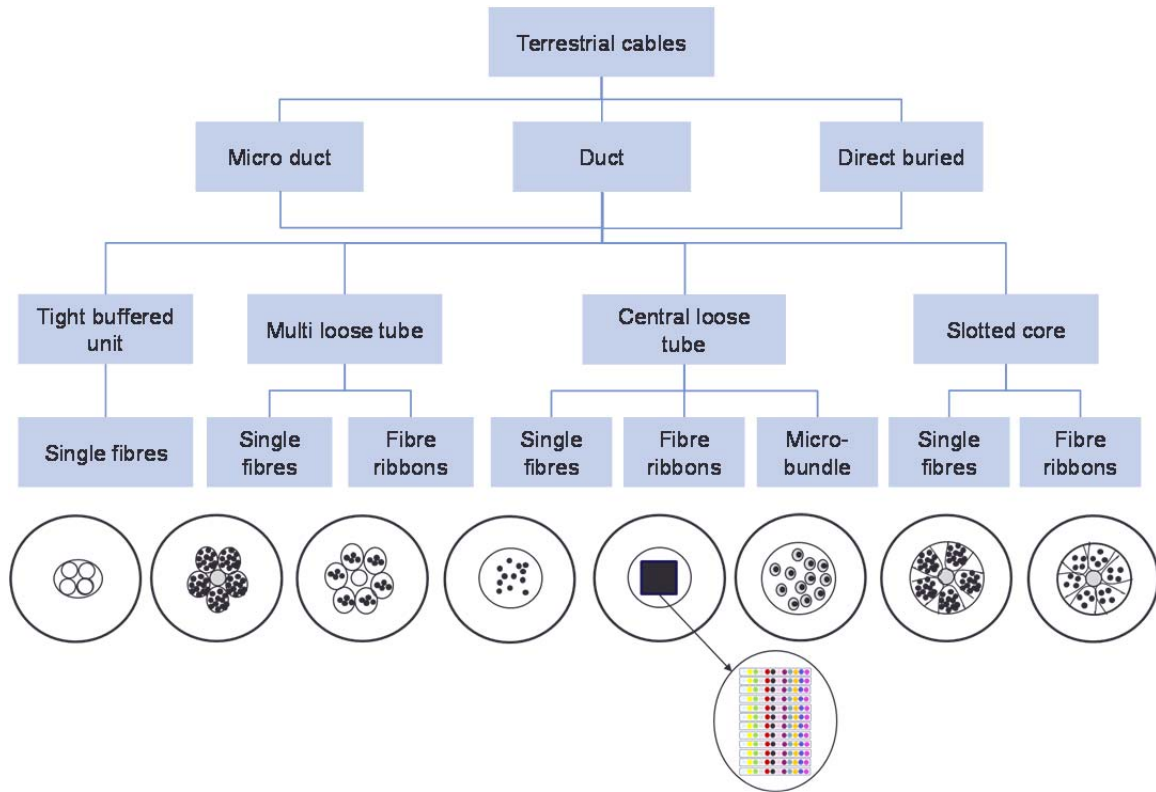
- number of fibres in the cables
- overall diameter of the cable
- cable design and protection specifications

Today, fibre cables can include between one and in excess of 800 fibre strands. Standard size cables include 1, 4, 12, 24, 48, 96, 144, 288, 576 and 864 fibres. The size (number of fibre strands) of the cable is standardised to create economies of scale for cable manufacturers, reducing their unit costs.

The overall diameter of the cable is usually a function of the number of fibre strands, but is not necessarily proportional to the number of fibres present in the cable. This is because the vast majority of the area in the fibre cable is occupied by protection material (see Figure 6.5) to prevent fibre strands from being damaged. When used in areas where underground infrastructure already exists, the diameter of the cable is one of its most important parameters as it will ultimately dictate the amount of civil works to be performed by the operator installing these cables. Existing underground ducts have a finite capacity in terms of volume and will typically contain some existing cables. If there is inadequate space in the duct to install the new cable, then the operator has to increase its duct capacity in that section of the network, which will involve trenching. As mentioned in Section 6.4.1, the cost of civil work represents the most significant part of the total cost of an FTTP network. Therefore, any optimisation of the cost associated with civil works by, for instance, reducing the size of the fibre cable and increasing the percentage of the existing infrastructure that can be re-used, will have a major impact on the overall capex of the network. In this context, it is important to try to use the smallest possible cable diameter, while at the same time meeting the required fibre cable count and cable protection requirements.

The structure of the cable itself is very important as it ultimately determines if a cable is suitable for use in the outside plant or just in the inside plant. Obviously, for use in the outside plant, the cable structure needs to be more robust than if used for the inside plant. However, the extra protection required for the outside plant generally means that the diameter of the cable is increased, due to the protective material and structure. The different types of fibre cable suitable for underground deployment is summarised in Figure 6.5 below.

Figure 6.5: Fibre cable type [Source: FTTH Council, 2010]



While it is outside the scope of this report to describe each of the above fibre cables, there is a wide variety of fibre structures that can be used to implement the outside plant. A key consideration in the design of fibre cables is to have the adequate protection to avoid fibres being damaged in the outside environment, while at the same time trying to minimise the cable diameter to reduce the amount of civil works⁴⁷ and therefore reduce the overall capex for the solution.

Note that in Figure 6.5 a relatively new type of fibre cable, based on fibre bundles or ‘ribbons’, is increasingly popular for its operational properties. This is because, in such cables, fibres are grouped into bundles of 12 fibre strands, which can be all spliced at once.

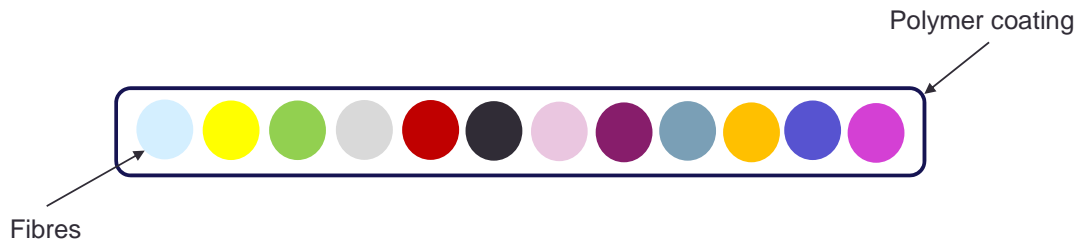
NBN Co's position

In terms of fibre cable for its outside plant, NBN Co has selected ribbon fibre technologies for all parts of its network. A 12 fibre ribbon strand is illustrated in

Figure 6.6 below.

⁴⁷ In areas where underground infrastructure already exists.

Figure 6.6: Ribbon of 12 fibres [Source: NBN Co, 2011]



As shown in

Figure 6.6, each fibre within a ribbon is colour-coded. This makes it significantly easier for operational staff to identify what fibre should be connected where, and therefore avoid human errors of connecting the wrong fibre to the wrong port.

NBN Co has selected Corning as the supplier for its ribbon fibre, which can provide between 12 to 864 fibres cables. The physical size of each ribbon-based cable used by NBN Co in the DFN is illustrated in Figure 6.7.

Figure 6.7: Ribbon-based DFN cable characteristics [Source: NBN Co, 2011]

Cable type	External diameter (mm)	External cross sectional area (mm ²)
144 fibre cable	17	511
288 fibre cable	24	1019
432 fibre cable	26	1196
576 fibre cable	28	1386
864 fibre cable	29	1487

Figure 6.7 shows that the cross-sectional area of the fibre cable does not increase linearly with the number of fibre strands in the cable. Interestingly, when doubling the number of fibre strands from 288 to 576, the physical diameter of the cable only increases by 16%. This is a very important property of the cable selected by NBN Co as more traditional cables would be larger in size.

Importantly, from an operational perspective, the use of ribbon fibre simplifies the splicing process as a 12-fibre ribbon can be fusion-spliced at once, saving significant time compared to splicing individual fibres in more traditional multi-strand fibre cables.

Also, it is important to note that ribbon fibre has some physical properties that are very attractive for aerial deployment, which may be used by NBN Co in certain areas, where duct infrastructure is not available. For example, a 144 fibre ribbon based cable used for aerial deployment weighs 94kg/km, whereas its stranded cable equivalent weighs 265kg/km. This means that in areas where aerial infrastructure is deployed, it is likely that more existing poles will be able to support the additional fibre cable from a loading perspective, leading to potentially higher utilisation levels for existing pole infrastructure and a potential improvement in capex as less poles would have to be replaced than if using a more traditional stranded fibre cable.

The 12-fibre ribbon also suits the modularity of Factory Installed Termination Systems (FITS) being used by NBN Co. FITS is a pre-connectorised system which pre-terminates fibres in the local fibre network onto multiple connectors in groups of 12, and multiports are then connected into these as required. An illustration of a multiport device is illustrated in Figure 6.8.



Figure 6.8: Illustrative example of a multiport device [Source: NBN Co, 2011]

Analysys Mason's assessment

Analysys Mason considers that NBN Co's choice of ribbon technology for fibre cables is efficient and prudent for the following reasons:

- ribbon technology is modular and can provide adequate fibre counts for all parts of the network, standardising cable size and associated deployment processes
- ribbon technology minimises opex as it allows the operational team to deal with bundled fibres at a time rather than single individual fibres (e.g. fusion splicing can be performed on 12 fibres at a time)
- each fibre in a ribbon is colour-coded, which mitigates against human connection errors, and therefore optimises quality of service and opex
- fibre ribbon suits the pre-connectorised system being used by NBN Co as part of its fibre network roll-out
- fibre ribbon cable is better suited for aerial deployment where required because it weighs 60% less than a traditional stranded fibre cable, maximising the number of existing poles that can be potentially used for FTTP deployment
- fibre ribbon cable is extensively deployed by leading FTTP operators internationally, including Verizon, NTT and Korea Telecom.

6.4 Fibre network infrastructure assessment

Here we present our assessment of choices regarding the infrastructure used in NBN Co's network. We have reviewed the following network elements:

- fibre dimensioning and capex
- re-use of existing infrastructure
- customer premises
- local fibre network
- FDH
- DFN
- FAN and FSA
- transit network

- semi-distributed PoIs.

We discuss each item in turn below.

6.4.1 Fibre dimensioning and capex

Critical decision and related issues

One of the key decisions will be for NBN Co to dimension its fibre network in such a way that it allows for expansion (e.g. split of premises into two, construction of greenfield and in-fill new premises). At the same time, the network should not be 'gold plated' by systematic fibre overprovisioning to mitigate the risks associated with network scalability, as this may result in higher prices for end users.

To better understand this issue, it is first important to consider the cost contribution of fibre in a typical FTTP solution. Figure 6.9 provides a typical breakdown of the capex of different components of an FTTP solution. This has been developed from our experience of working with different operators worldwide.

Figure 6.9: Illustrative breakdown of capex for FTTP networks [Source: Analysys Mason, 2011]

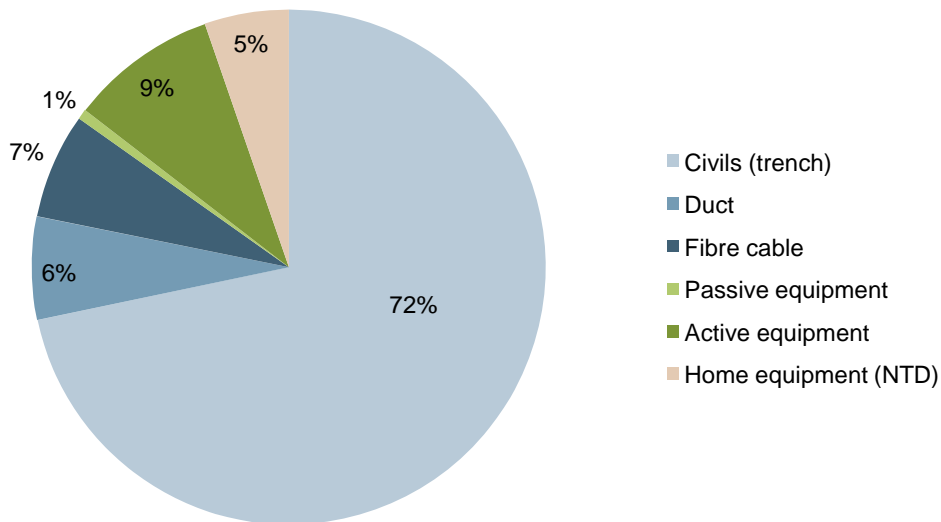


Figure 6.9 does not represent NBN Co's capex but an illustrative benchmark based on our experience with real deployment throughout the world. This breakdown will vary depending on the amount of infrastructure that the operator can re-use (e.g. duct utilisation) and on the architecture used to implement the network.

Figure 6.9 shows that the vast majority of the cost of the network is in the civil works (i.e. trenches) to install the ducts and fibres underground. Importantly, only 7% of the overall cost of the network is associated with fibre cables themselves. Also, from our experience, the cost of the fibre cable does not increase linearly with the number of fibre strands, but tends to increase in a logarithmic manner with the number of fibre strands. Therefore, any increase in the fibre count in a cable will only result in a marginal increase in cost.

Therefore, when considering the cumulative effects of a) the cost contribution of the fibre cable (which is only about 7% of the total cost based on our experience) and b) the marginal cost increase with the number of fibres, it can be seen that, even if the network is over-dimensioned in terms of the number of fibres, it does not have a significant direct impact in terms of capex. Therefore, over-dimensioning the network would not greatly affect the overall build cost.

However, the real issue of 'over-dimensioning the network' is the potential increase in the diameter of the fibre cables. Since larger cables need more space in the ducts, then increasing the size of the cables may increase the amount of civil works to be carried out. However, this is mitigated by the fact that the cable size is not proportional to the number of fibres in it, as demonstrated in Figure 6.7.

Importantly, if the network was to be under-dimensioned in terms of number of fibres in the first place, additional fibre cables would need to be installed after the network build period, which could have a significant impact in terms of capex for the following two reasons:

- additional civil work may need to be performed because the size of two fibre cables is significantly greater than the size of a single cable containing twice the amount of fibre⁴⁸
- the operational staff will have to come back after build time to install the second fibre cable, duplicating installation costs.

As an illustrative example, the size of two 96 fibre cables will be significantly greater than the size of a single 192 fibre cable. Therefore, there may not be enough space in the sub-duct to install the second cable to provide the required additional fibres that were under-provisioned during roll-out. In this case, NBN Co may have to perform some civil works to increase the capacity of the existing infrastructure to install the second fibre cable, which would significantly increase capex (e.g. civil work has a greater impact than fibre cable size).

Secondly, the new fibre cable would need to be installed post roll-out, which would duplicate installation costs. This cost would be significantly greater than the incremental cost of selecting a slightly larger cable in the first place. Also, we note that, depending on how the additional cable is installed, there may be an operational risk of damaging cable already installed in that duct.

Therefore, it is always more prudent to slightly over-dimension the network in terms of the number of fibres as the incremental cost is insignificant compared to the situation where the network is under-dimensioned and a second cable needs to be installed post roll-out.

NBN Co's position

NBN Co has dimensioned the local and distribution network in a way that can accommodate fibre diversity and scalability in the network, as described in more detail in the following sections of this report (i.e. local fibre network and DFN analysis).

⁴⁸ See Figure 6.7 for cable size.

Analysys Mason's assessment

Analysys Mason considers that the fibre has been prudently dimensioned by NBN Co in different parts of the network, as explained in further detail in the local fibre network and DFN sections below.

As a general point, Analysys Mason considers that, even if the network had been over-dimensioned, it would not have a material impact on the overall build cost due to the low contribution of fibre cables to the overall cost of the network.

We do not believe that any increase in the cable size would have a material impact on the overall build cost. The use of ribbon fibre technology by NBN Co means that the cable diameter only marginally increases (i.e. 16% as explained in Section 6.3) in the event of a doubling of the number of fibre strands in the cable.

6.4.2 Re-use of existing infrastructure

Critical decision and related issues

As discussed in Section 2.2, in its *Statement of Expectations*, the Government mentioned: “NBN Co is expected to re-use existing infrastructure in providing these services, where efficient and economic to do so.”

Analysys Mason believes that the re-use of existing infrastructure:

- significantly accelerates the roll-out of the network
- significantly reduces civil works and therefore reduces disruption to local communities
- mitigates risks associated with variations in construction cost.

The most obvious supplier to NBN Co is Telstra, which owns the largest purpose-built infrastructure for telecoms in Australia. Since a high proportion of capex for FTTP deployment is attributed to civil works, the re-use of existing infrastructure will significantly reduce this cost. For example, based on our overseas experience, we estimate that the cost of deploying fibre cables in re-used ducts would be around 80% less than in cases where civil works are also required, resulting in significant capex savings.⁴⁹

NBN Co's position

On 23 June 2011, NBN Co announced that it had signed Definitive Agreements with Telstra (subject to certain conditions, including shareholder and regulatory approvals), to facilitate the efficient roll-out of the NBN. Telstra's shareholders approved the agreement in October 2011 and

⁴⁹ Please note that these costs are based on Analysys Mason's experience of a similar country, not for Australia specifically.

since 7 March 2012, all conditions precedent to the Telstra Definitive Agreements have been satisfied and the Telstra Definitive Agreements has now become wholly unconditional.

For the purposes of our operational review, the agreements with Telstra involve two key components (amongst other things):

- Infrastructure Services Agreement – it grants NBN Co access to Telstra's facilities and infrastructure (over a minimum period of 35 years), ensuring that the fibre-optic component of the NBN (which serves 93% of premises) can be rolled out efficiently and in a manner that avoids the unnecessary duplication of infrastructure.
- Subscriber Agreement – it provides for the progressive disconnection of Telstra's copper and HFC broadband customers (but not HFC pay-TV customers) and the provision of a payment by NBN Co to Telstra in respect of each disconnection, with the NBN being Telstra's preferred fixed-line network.

In addition, NBN Co and Telstra have negotiated interim arrangements for immediate access to Telstra's infrastructure.

Specifically, under the Infrastructure Services Agreement, Telstra will provide the following infrastructure to enable NBN Co to build its network efficiently:

- access to lead-in conduits through which the NBN fibre will be connected to each premises (which will then be transferred by Telstra to NBN Co)
- access to underground ducts and pits through which the NBN fibre will run
- lease of dark fibre links, and
- rack space in Telstra's exchanges.

Importantly, under this agreement, NBN Co has committed to pay for, and Telstra has committed to make available within specified timeframes, certain minimum quantities of infrastructure that meet the agreed fitness standards. The payment and availability commitments are based on incentive mechanisms known as 'provide-or-pay' (or PoP) and 'take-or-pay' (or ToP). The PoP is an incentive mechanism to encourage Telstra to maximise the amount of infrastructure it makes available to NBN Co up to the agreed minimum quantities. The ToP is a mechanism to encourage NBN Co to maximise the use of the infrastructure that Telstra makes available up to the agreed minimum quantities.⁵⁰

This effectively means that Telstra will have an incentive to provide a minimum volume of available and fit infrastructure to NBN Co to deploy its network. This is of significant importance as it means that NBN Co will have an incentive to use Telstra's ducts instead of alternatives, such as aerial, which will have a different and more uncertain cost profile compared to underground deployment.

⁵⁰ Telstra's Participation in the Rollout of the National Broadband Network, Explanatory Memorandum, Annual Meeting 18 October 2011, Telstra.

Analysys Mason's assessment

Analysys Mason considers that NBN Co's decision to re-use Telstra's infrastructure is prudent from an operational perspective. There are strong operational reasons to use underground infrastructure wherever it exists and is fit for purpose.

In particular, the re-use of existing Telstra's infrastructure will provide more certainty (and therefore reduce risks) in a number of areas, including significantly reducing the need for NBN Co to construct its own duct infrastructure (which would increase NBN Co's construction costs and delay the roll-out of fibre network). It will also overcome some of the downsides that may be associated with aerial deployments, such as lower levels of reliability and higher associated opex.

In principle, we also welcome the PoP provisions contemplated under the NBN Co–Telstra deal, which will further increase the certainty of the available infrastructure. The ToP provisions contemplated under the NBN Co–Telstra deal will give NBN Co an incentive to use Telstra's ducts instead of alternatives, such as aerial deployment.

6.4.3 Customer premises*Critical decision and related issues*

We believe that there are three major issues to consider when specifying the technical strategy for the end-user premises:

- number of fibres to provide to each premise
- demarcation point for the wholesale service
- number of UNI ports on the NTD

Each of these issues is discussed below.

► *Number of fibres to provide to each premises*

NBN Co has to make a decision about the optimal number of fibres that are to be deployed to each premises. The optimum number of fibres to be provided to every premises involves a balance of the following factors:

- the layer at which wholesale service should be provided
- operational issues that may arise during service migration
- requirements for spare fibres to provision non-addressable locations and residential second lines.

As NBN Co is supplying a Layer 2 wholesale service, a single fibre⁵¹ could potentially be sufficient to provide access to a number of service providers.

⁵¹ It should be noted that in countries such as France and Switzerland, up to four fibres are delivered to each premises, but this is because the wholesale service is at Layer 1 – i.e. each SP connects its dedicated fibre to the premises in the local fibre network.

However, from an operational point of view, a second fibre would minimise service downtime if a GPON customer wanted to upgrade its service to a P2P or NG PON service, as the new service could be provisioned independently of the customer's existing service and so would minimise service outage. Therefore, the provision of two fibres would optimise the customer's experience during service migration. The advantages of providing more than one fibre in a Layer 2 wholesale FTTP network are:

- the ability to offer services over the additional fibre in addition to the first (useful when the number of dwelling units in a single plot/block increases)
- support for migration to other service providers
- support for migration to P2P connections
- support for migration to NGN GPON connections.

Furthermore, it is also important to recognise that non-addressable entities will need to be networked. Examples of such entities are CCTV cameras, traffic lights, power transformers and various sensors. If no provision has been made for these entities, major infrastructure work will be required to re-fit additional connections in the network for these entities. It is therefore more cost-effective to design and dimension the network from day one to accommodate these non-addressable entities during the network build phase. Also, spare fibres should be accommodated to account for the fact that premises may split into two single dwelling units or that two independent lines might be required for a single dwelling.

► *Demarcation point for the wholesale service*

The demarcation point depends upon the layer of the network at which wholesale access is provided.

For wholesale access at Layer 2, the demarcation point is usually the UNI ports on the NTD.

In general, the higher the layer at which wholesale access is provided in the network, the further away the demarcation point is from the OLT site.

► *Number of user network interface (UNI) ports on the NTD*

In order to allow for the simultaneous delivery of multiple applications by multiple SPs, multiple UNI ports have to be provided on the NTD (assuming the network provides wholesale services at Layer 2).

Typically, UNIs relate to the service the service provider has to deliver and categories of UNI can be defined to provide voice services, data services and, in some cases, TV services. Since the UNI defines the physical port where the service provider can connect to provide services, the number of UNIs per service on the NTD will define how many service providers can simultaneously provide that service to the end user.

Therefore, a key aspect is to define the number of UNIs per service category to ensure that a sufficient number of service providers can compete for the same services. Defining too many UNIs per service is not realistic, as in practice only a given number of service providers will be prepared

to compete for the same service. Defining too many UNIs will also increase the cost of the NTD, and so increase the overall build cost of the network.

An important aspect when defining the UNI is that for a particular service, each UNI should be rated equally for the same traffic classes. Although service providers may purchase different amounts of bandwidth from the Layer 2 wholesale provider, the treatment of each traffic stream associated with each UNI should be similar from a wholesale point of view.

NBN Co's position

► *Number of fibres in the local fibre network*

In the local fibre network, NBN Co plans to allocate fibre in its design, covering:

- the provision of a single fibre for the initial service connection to a premises
- a second fibre to a premises to meet future capacity requirements (e.g. subdivision of the relevant property).

In addition, NBN Co plans to allocate an extra fibre for use at the multiport location (see Figure 6.18 for more detail) for non-addressable connections or extra connections that may be required per SDU.

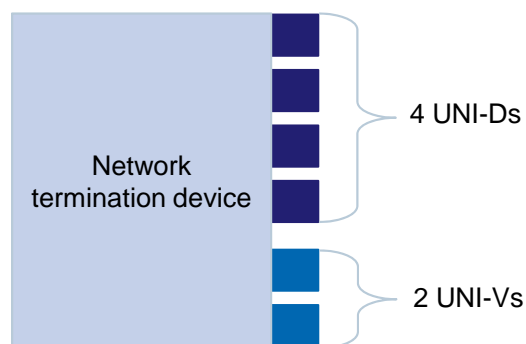
Also, it should be noted that NBN Co has adopted specific planning rules for commercial buildings; NBN Co plans to allocate 12 fibres per floor, or two fibres per premises, whatever the greatest value.

► *Demarcation point for the wholesale service*

Since NBN Co will provide a Layer 2 wholesale service, the demarcation point at the user premises is defined to be the user network interface (UNI) port.

► *Number of UNI ports on the NTD*

NBN Co will deploy a standard NTD at each of the premises with multiple UNIs. NBN Co is proposing to offer two types of UNI: data UNI (UNI-D) and voice UNI (UNI-V), as illustrated in Figure 6.10.



*Figure 6.10: Proposed UNI configuration for premises served by fibre
[Source: NBN Co]*

NBN Co is planning to provide two UNI-Vs, with an integrated analogue telephone adapter (ATA)

to provide voice services, which will allow up to two service providers to provide legacy analogue telephony services. UNI-Vs will only be available in areas served by fibre and will be provided at no additional cost to the service provider with the purchase of a UNI-D and AVC. NBN Co also proposes to provide four UNI-Ds dedicated to data services, all rated equally for the same traffic classes, to allow up to four different service providers to provide data services (including broadband, IP telephony and video content) simultaneously to their end users. It should be noted that NBN Co will allow a service provider to use one or more UNI-Ds as required.

Analysys Mason's assessment

Analysys Mason considers that NBN Co's decision to provision a single fibre in the local fibre network for the initial service connection to the premises, along with a second fibre to meet future capacity requirements in respect of the relevant premises (e.g. to take account of subdivision of the relevant property), is both efficient and prudent, as we would recommend a strict minimum of two fibres per premises in the local fibre network for operational, growth and potential protection reasons. While the number of fibres that are needed in the local fibre network to cover non-addressable premises is challenging to evaluate at this point, we consider that NBN Co's overall provisioning of fibre in the local fibre network is prudent.

Analysys Mason considers that NBN Co's decision in respect of the design of NTDs in areas served by fibre infrastructure is prudent, as it will allow simultaneous delivery of multiple applications and services by multiple service providers through the available UNI ports. This approach is consistent with industry best practice.

We also believe that NBN Co is taking a prudent approach to the architecture and features provided on the NTD in areas served by fibre infrastructure. In particular, the provision of an ATA port will give the service provider the ability to provide a cost-effective voice service for end users that do not require other services, such as broadband or IPTV.⁵² Finally, we note that NBN Co's product construct will offer service providers the ability to offer high-quality voice services to its end users, with service providers being able to acquire TC-1 (150kbps) over AVCs (mapped to either the UNI-D or UNI-V) and TC-1 over CVCs.

6.4.4 Local fibre network

Critical decision and related issues

Here we analyse the local fibre network in terms of the following characteristics:

- coverage
- infrastructure options (overhead versus underground)
- local fibre network dimensioning and architecture
- final drop provisioning.

⁵² This is due to the fact that the service provider will not be required to invest in, and install, separate CPE to support analogue telephony devices.

► *Coverage*

As with any access network deployment, target coverage is an important consideration. In its *Statement of Expectations*, the Australian Government believes that: “*the objective for NBN Co is to connect 93% of Australian homes, schools and businesses with fibre to the premise technology providing broadband speeds of up to 100Mbps, with a minimum fibre coverage obligation of 90% of Australian premises*”.

In order to achieve this objective, it is important to consider population densities, which are usually defined by geotypes.

In Australia, the PSTN is currently segmented into areas called distribution areas (DAs). DAs are geographical areas based on the planning of the telecoms copper network, and an exchange area serves several DAs. Typically, DAs have been designed around the limitations of the copper network and are served by a single street cabinet.

DAs have variable geographical coverage and serve different numbers of premises, depending on the geotype considered. In addition, four geographic bands have been historically used in respect of ULLS in Australia, which have been defined by reference to teledensity and location. Figure 6.11 summarises the four ULLS bands used in Australia.

Figure 6.11: Definition of ULLS bands in Australia [Source: NBN Co and ACCC]

Band	Teledensity	Telstra ULLS bands (as defined in 2000)	ACCC description
1	Central business districts (CBDs)	CBD areas of Sydney, Melbourne, Brisbane, Adelaide and Perth	CBD
2	Metro	Urban areas of capital cities, metropolitan regions and large provincial centres (including other CBD areas not already included in Band 1)	Metro Provincial cities
3	Regional	Semi-urban areas including outer metropolitan and smaller provincial towns	Semi-urban Provincial
4	Remote	Rural and remote areas	Rural

Based on the bands defined in Figure 6.11, the geotypes and their associated DA characteristics are illustrated in Figure 6.12 below for the case of Australia.

Figure 6.12: Characteristics of distribution areas by ULLS bands and geotype [Source: NBN Co and ACCC]

ULLS Band	Geotype	Total number of DAs	Average DA diagonal distance	Total % population living in geotype	Cumulative % population
1	Urban	700	399	1.4%	1.4%
2	Urban	47 398	948	63.9%	65.3%
2	Major rural	482	1499	0.8%	66.1%
2	Minor rural	57	1794	0.1%	66.2%
3	Urban	7856	2067	10.1%	76.3%
3	Major rural	4637	2177	6.5%	82.8%
3	Minor rural	2314	2547	3.8%	86.6%
3	Remote	674	3019	0.9%	87.5%
4	Urban	358	2200	0.5%	88%
4	Major rural	1254	3300	1.5%	89.5%
4	Minor rural	2730	2544	5.5%	95%
4	Remote	670	540	5%	100%

As illustrated in Figure 6.12, areas in Band 1, 2 and 3 areas cover 87.5% of the population. Therefore, in order for NBN Co to cover at least 90%⁵³ of the population with the FTTP infrastructure, some of the population living in urban, major rural and some in minor rural area (that is, Band 4 areas) will need to be covered.

► *Infrastructure options (overhead versus underground)*

Most operators that deploy FTTP infrastructure have to make a decision between aerial and underground infrastructure.

For NBN Co, this decision has been greatly simplified by the agreement with Telstra, which means that NBN Co will be able to access Telstra's duct and fibre infrastructure wherever it is available. Therefore, given that Telstra has a national underground network of infrastructure, it can be expected that the FTTP deployment will be mainly underground, re-using Telstra's ducts and fibre.

However, it should be noted that, in some areas, underground duct infrastructure from Telstra:

- may not exist (e.g. areas where cables are directly buried)
- may be damaged (e.g. collapsed ducts)
- may be too congested to accommodate any additional fibre cables from NBN Co
- may not be otherwise fit for purpose.

In these circumstances, NBN Co may have to use aerial infrastructure. In general, aerial infrastructure is more cost-effective than underground infrastructure from a capex perspective.

⁵³ Aiming for a target of 93% of the population.

However, it is widely accepted that underground infrastructure is more reliable, because it is more prone to faults due to external conditions (e.g. bad weather) than underground infrastructure and therefore requires significantly more operational interventions (e.g. repair). Consequently, aerial infrastructure will provide a lower Quality of Service and will require more opex than underground infrastructure.

► *Local fibre network dimensioning and architecture*

Since FTTP technology has a longer reach than copper-based broadband and its performance does not degrade with distance, FDAs for FTTP can be larger than the legacy DAs.

Since NBN Co will be re-using Telstra's duct infrastructure, it is very important to take into account the existing Telstra infrastructure when designing the network to maximise its re-use, and therefore minimise costs. This is because all existing duct routes will naturally converge to one or several Telstra exchanges, where NBN Co is planning to locate its FANs.

Another important consideration when dimensioning the physical infrastructure of the network is to ensure that there will be enough fibre in the local network to serve all existing residential and business customers and to provide additional fibres for:

- future growth of premises
- implementation of protection services (when required).

Examples of future growth of premises include the split of a house into two different households or the installation of an additional business broadband connection for a home worker. Also, the provision of additional fibres to businesses is also required if protected services are to be implemented. An example of a protection service for a GPON user in the local network is the Type C protection scheme defined by the ITU-T/FSAN standardisation body (illustrated in Figure 6.3 earlier). It should be noted that for this protection scheme to be effective, the main protection fibre in the local fibre network should follow a different path/duct route to ensure that a single cut does not result in the loss of both fibres.

► *Final drop provisioning*

In this report, we define the final drop as the fibre segment between the PCP and the end-user premises. For the provision of the last drop, infrastructure providers have two options:

- install the last drop on demand as service providers purchase new connections; or
- pre-build the network from day one all the way to the end-user premises (i.e. as part of the initial truck roll).

It should be noted that the approach adopted for provisioning the last drop does not only affect the capex, but also significantly changes the processes involved in service provisioning to a customer, which has to be robust and well specified to meet any applicable SLAs.

In an environment where service take-up is expected to be slow initially, it is considered more prudent to install the last drop on demand rather than to invest in upfront capex. This is the approach that most FTTP infrastructure providers adopt.

However, in an environment where one expects a high service take-up from day one, it may be more cost- and time-effective to pre-build the network up to the end-user premises, including the pre-installation of the last drop to all premises covered by the network footprint. This is because it is more cost-effective to provision the final drop as the network is being deployed than to send back technicians each time a new service provider requires a new connection.

Given that the current penetration of broadband in Australia is 63%⁵⁴, the agreement between NBN Co and Telstra, and the agreement between NBN Co and Optus⁵⁵ regarding the migration of Optus customers to NBN Co network), we consider that it is appropriate for NBN Co to expect high take-up. This is because, as the copper is de-commissioned on the Telstra network, end users who wish to retain a fixed-line service will need to migrate to the fibre network and because Optus end-users will migrate in time to the fibre network.

As well as deciding to pre-build the final drop or to install it on demand, NBN Co will be faced with a key architectural decision to connect the last drop to the local network at the PCPs.

Two options exist at the PCP:

- implement a multiport device⁵⁶ which makes use of connectors to connect the final drop to the local network
- implement fusion splicing, where the fibre from the local network and the fibre for the final drop are fused together, resulting in a continuous fibre from the FDH to the premises.

When implementing a multiport device at the PCP, an additional connector is introduced in the network. Each connector introduces an additional point of failure within the network, as operational activities can lead to accidental line disconnection at the PCP. Consequently, this can have adverse implications on the number of faults per line, the user quality of experience and the opex for the operator.⁵⁷ On the other hand, connectors provide a flexibility point where a fibre can be connected and disconnected with relative ease. Therefore, a connector introduces flexibility in the network but at the potential expense of a degraded user quality of experience and a higher opex.

If we assume that the final drop is going to be 'pre-built' as part of the general network roll-out, all premises will in effect be pre-connected, which will lower the requirement for connection flexibility at the PCP for these premises as they will stay connected to the same fibre for a number

⁵⁴ Australia profile, TeleGeography, September 2011.

⁵⁵ Determination, Application for authorisation, lodge by NBN Co in respect of the provision of HFC subscribers entered into with SingTel Optus Pty LTD and other Optus entities, ACCC, 19 July 2012.

⁵⁶ See Figure 6.8 for an illustration of a multiport device.

⁵⁷ Due to the increase in frequency of fault repair.

of years. Therefore, in this scenario, the fusion splicing option at the PCP may be preferable because it will improve the user quality of experience and lower opex.⁵⁸

However, if we assume that the final drop is deployed 'on demand', the requirement for flexibility overweighs the degradation in user quality of experience because it will be more important to minimise the provisioning time. Connectors in such scenario would be better suited as operational staff in charge of provisioning the service will just have to connect the final drop to the multiport device, without requiring any fusion splicing equipment or fusion splicing skills, which will result in a shorter and cheaper provisioning of the service.

Therefore, the optimum choice of whether to implement a multiport or a fusion splice at the PCP will depend upon whether or not the final drop is prebuilt or provisioned on demand and will be a trade-off between connection flexibility and user quality of experience/opex.

It is important to note that both models have been implemented internationally. For example, while Openreach in the United Kingdom uses the fusion splicing technique at the PCP, Verizon in the USA and Chorus in New Zealand have implemented a connectorised approach.

NBN Co's position

► *Coverage*

In order to determine the exact coverage of the fibre network, NBN Co has adopted a high-level methodology, which is summarised in Figure 6.13 below.

⁵⁸ Spare fibre that is not connected to any premises will need to be terminated at the PCP using fit for purpose devices.

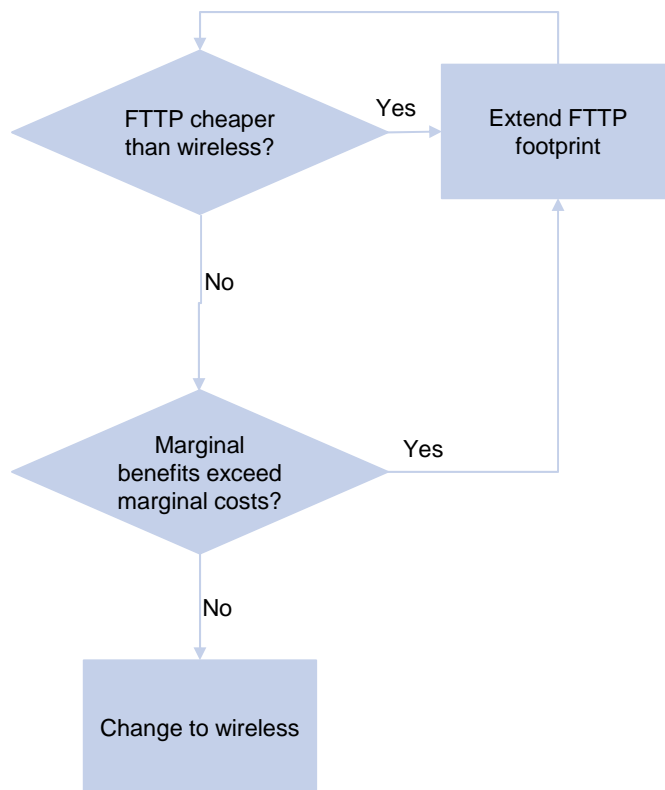


Figure 6.13: NBN Co's methodology for defining FTTP coverage [Source: NBN Co, 2011]

In this methodology, NBN Co assesses the marginal cost of providing FTTP infrastructure versus the cost of wireless. It is important to note that the study undertaken by NBN Co was conducted for existing premises and that new developments were treated separately.

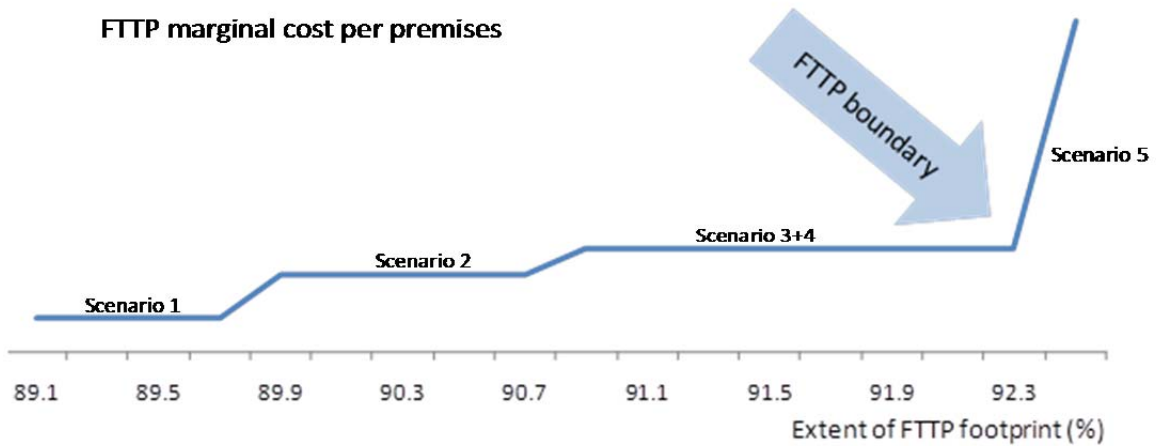
In this assessment, NBN Co used the following priorities for assigning premises:

1. All communities with 1000 premises or more were mapped, and then those that were in 'remote' locations (i.e. where kilometres per premises of transit backhaul,⁵⁹ and hence cost, were high) were excluded. Coverage: 89.7%.
2. Transit backhaul necessary to serve 8 satellite earth stations was added, and communities of over 1000 premises near these additional routes were added. Coverage: 90.8%.
3. All other communities of over 1000 premises were added, along with the necessary transit backhaul. Coverage: 91.4%.
4. All communities with greater than 500 premises that are close to transit backhaul routes (under scenario 3) were added. Coverage: 92.3%.

A fifth scenario was also mapped, where all communities in Australia with over 500 premises were added. As discussed below, this scenario was rejected on grounds of incremental cost. The results are illustrated in Figure 6.14 below.

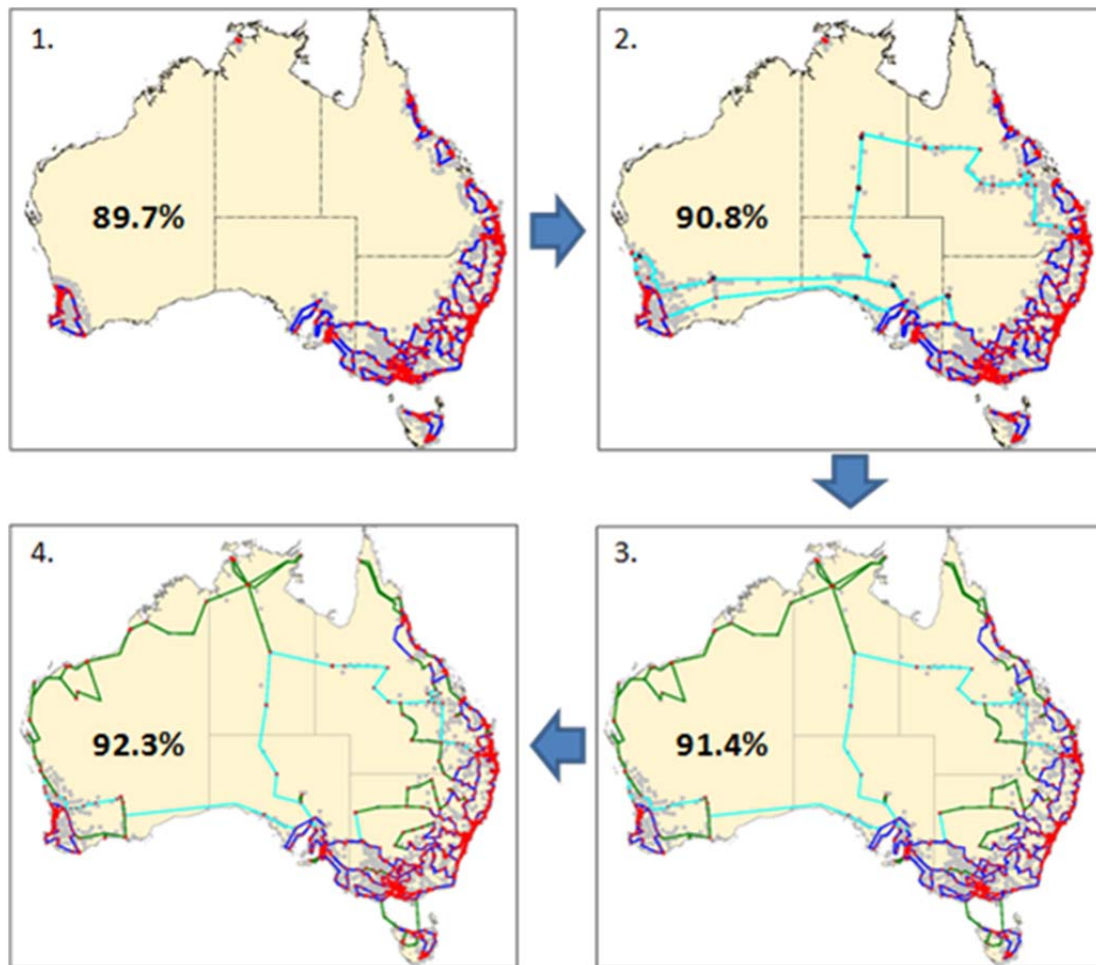
⁵⁹ The transit backhaul is the additional fibre required to link the different communities considered in each scenario. The transit fibre backhaul excludes distribution and local fibre network.

Figure 6.14: Incremental marginal cost for FTTP infrastructure footprint [Source: NBN Co, 2011]



The step changes in the FTTP marginal costs shown above are as a result of the additional transit fibre costs required to reach additional communities. A geographical representation of the fibre required to cover the different scenarios is provided in Figure 6.15 below.

Figure 6.15: Fibre network for different FTTP coverage scenarios [Source: NBN Co, 2011]



Under scenarios 2 and 3+4 the incremental cost of extending the FTTP footprint is less than three times the average cost per premises for the first 90%. Given the substantially improved service and increased utility to end users that fibre offers (compared with wireless and satellite), and the relative costs associated with the other technologies, NBN Co believes it is desirable to extend the FTTP footprint to 92.3%.

However, NBN Co believes that increasing the FTTP coverage from 92.3% to 92.5% (and beyond) will result in disproportionate costs for incremental premises, because the marginal cost for these incremental premises is nearly ten times the cost per premises for the first 90%.

It should be noted that this 'cut-off' point is only provisional, as the precise FTTP footprint will only be known when NBN Co completes detailed suburb-by-suburb designs for the network, which will happen progressively during the construction period of the project (i.e. as NBN Co rolls out in each geographical area).

Therefore, NBN Co is planning to cover approximately 92.3% of the population for existing premises. However, with the natural growth in population and the increasing number of new homes (greenfield), NBN Co is confident that an additional 0.7% of the population will be covered

within the nine and a half years of the deployment. Therefore, overall, NBN Co is planning to cover 93% of the population, taking into account both existing and new premises that will be built.

► *Infrastructure options (overhead versus underground)*

As mentioned in Section 6.4.2, since NBN Co will have access to Telstra underground infrastructure, it will re-use Telstra infrastructure wherever possible. As Telstra has a national infrastructure network, NBN Co's intention is to deliver the vast majority of the FTTP network using Telstra's underground infrastructure.

Wherever Telstra infrastructure is unavailable, NBN Co will either:

- negotiate with, or otherwise acquire access to, other infrastructure owner (e.g. utility companies) to gain access to their existing infrastructure where this makes economic sense, or
- undertake civil works to build the necessary infrastructure.

In order to take the optimum decision, NBN Co has developed a planning tool that determines the cost optimum solution between trenching (to deploy underground infrastructure) and renting utility poles (to deploy aerial infrastructure). Based on the planning tool, NBN Co has determined that, for short spans that do not have duct, it is more cost effective to trench than to pay for utility poles or other aerial infrastructure.

Also, especially considering the fact that NBN Co has committed to pay for minimum quantities of infrastructure that meet the agreed fitness standards, referred to as 'take-or-pay' (or ToP). The ToP mechanism encourages NBN Co to maximise the use of the infrastructure that Telstra makes available, and therefore directly incentivise NBN Co to use underground infrastructure whenever possible.

This strategy is in line with the Australian Government's expectation that NBN Co should "*re-use existing infrastructure in providing these services, where efficient and economic to do so*".

► *Local fibre network dimensioning and architecture*

While NBN Co is using Telstra's infrastructure and is optimising its network design for the existing infrastructure, NBN Co is also re-partitioning the country into FDAs, fibre serving area modules (FSAMs) and FSAs compared to the current DA and ESA used by Telstra.

In general, Telstra uses two types of deployment to serve existing households in a street:

- single-sided deployment, or
- double-sided deployment.

Therefore, NBN Co will have to follow the infrastructure that is in place to minimise additional civil works. Figure 6.16 below illustrates a single-sided deployment, where each PCP (or multipoint device) connects up to four premises.

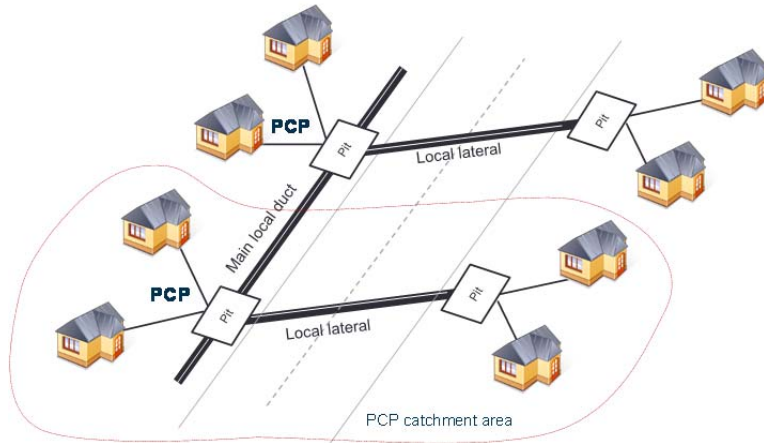


Figure 6.16: Single-sided deployment [Source: NBN Co, 2011]

Figure 6.17 illustrates a double-sided deployment.

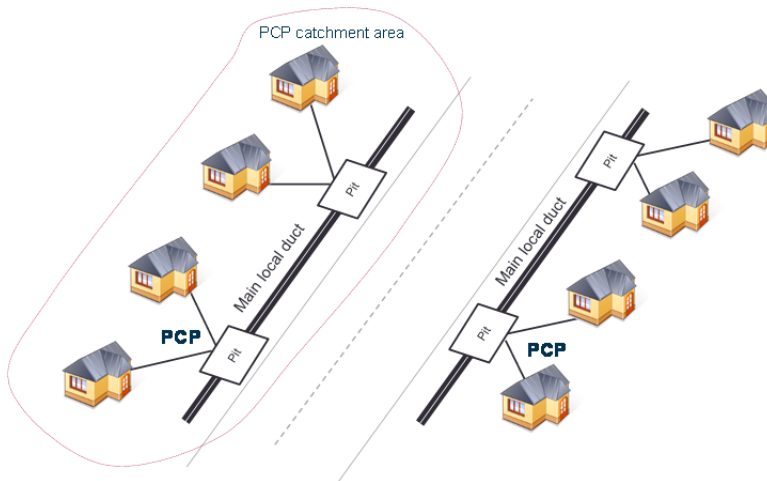
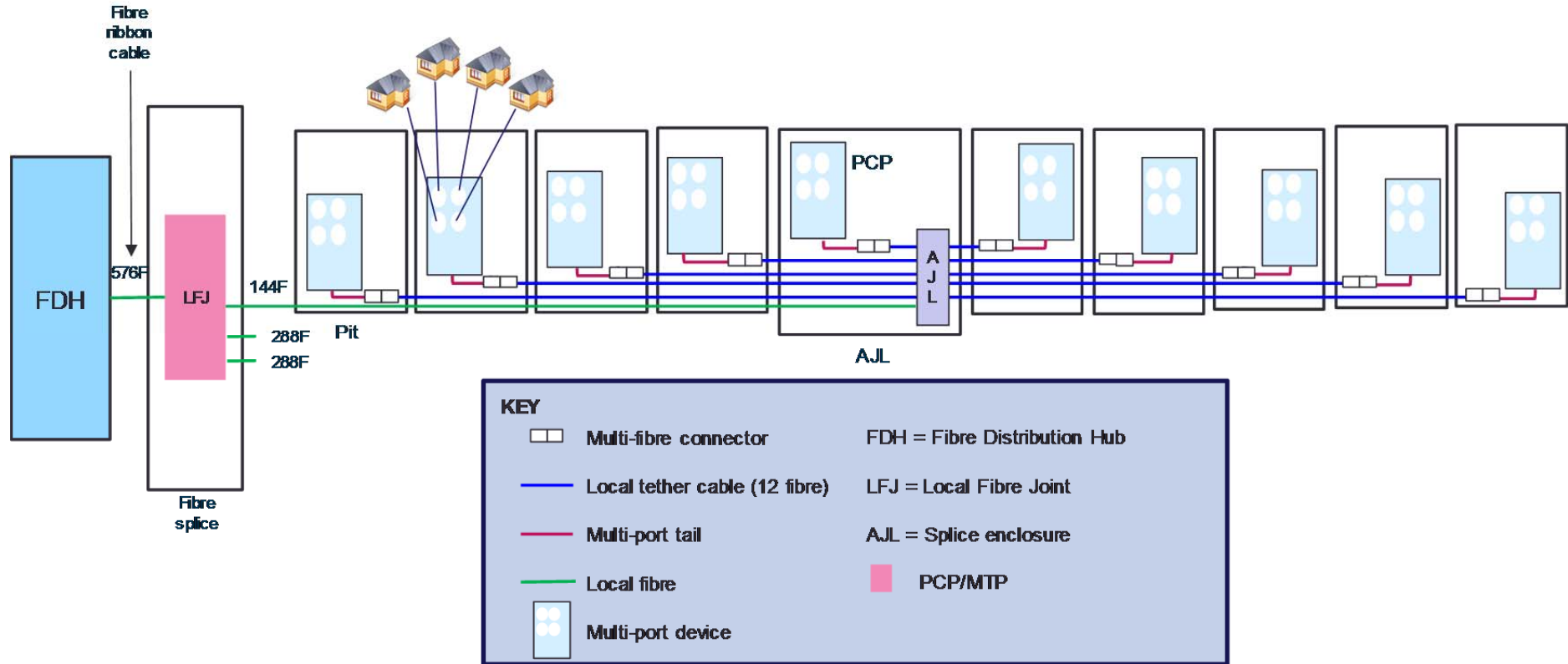


Figure 6.17: Double-sided deployment [Source: NBN Co 2011]

NBN Co has standardised the design of the local fibre network to be the same, irrespective of the deployment type. This is illustrated in Figure 6.18 below.

Figure 6.18: Generic local fibre architecture design [Source: NBN Co, 2011]



As shown in Figure 6.18, an FDA will have a maximum of 576 connections, limited by the fibre cable from the FDH. The 576 fibre ribbon cable will be connected to the FDH, and will be spliced into smaller (72, 144, or 288 fibre) cables at the local fibre joint. In the above diagram, we assume that the local cable is 144 fibres. Then, the 144F cable will extend from the LFJ to the splice enclosure, where it will be spliced into smaller tether cables, each containing 12F. The tether cable will then be connected to the multiport (or PCP) through a multi-fibre connector. Then, each port of the multi-port device (or PCP) will be used to connect a house. The multi-port device can have between 4 and 12 ports, to suit the particular geotype.

Note that this architecture allows up to three fibres to be connected to every home, provided that each PCP or multiport serve up to four premises. Therefore, the 144 local fibres, which contain 12 tether cables, each of 12 fibres will serve up to 48 premises.

In Figure 5.27 it can be seen that another two 288 fibre cables are spliced in the splice enclosure, and will each serve up to 80 houses. Therefore, the design illustrated in Figure 5.27 will allow up to 200 premises to be connected, which is in line with a standard DA size. Note that, given the number of spare fibres, up to 600 connections could be made in such an architecture, showing that the architecture and design is future-proof.

In order to gain insight into the physical and operational challenges associated with the deployment of the FTTP network in different geotypes, NBN Co has deployed an FTTP network to five 'first-release' sites on mainland Australia, as part of live trials of its network design and construction methods. The first-release sites have been carefully chosen to be in different geotypes and therefore represent the diversity of situations NBN Co will encounter across Australia. The five first-release sites and their characteristics are summarised in Figure 6.19.

Figure 6.19: Characteristics of NBN Co's first-release sites [Source: NBN Co]

New release site	Band	Geotype	Characteristics
Melbourne	2	Urban	High-density, terraced type architecture
Townsville	2	Urban	Suburban, timber fully detached dwellings
Minnamurra and Kiama Downs	3	Urban	Suburban, brick fully detached dwellings, coastal community
Armidale	3	Major rural	Full township
Willunga	3	Minor rural	Full township

The experience that NBN Co gains through deployment of the first-release sites should ensure that many operational issues encountered in the wider deployment of the network can be anticipated and mitigated.

► *Final drop provisioning*

NBN Co has confirmed that, given the operation of the Subscriber Agreement between NBN Co and Telstra⁶⁰ and the Agreement with Optus⁶¹, they are currently assuming a build drop in their deployment plans. NBN Co's information from the industry is that a take-up rate of approximately 30% or above will make the build drop a more cost-effective option overall.

With the agreement in place with Telstra, NBN Co is expecting a take-up rate of 70% when the copper is fully de-commissioned. This forecast is conservative as it does not take into account the migration of Optus end users, which will provide an additional addressable market of 500,000 end-users, in areas served by the Optus HFC network. In September 2011, the fixed broadband penetration rate stood at 63.3%⁶² and it is planned that existing broadband customers will be migrated onto NBN Co's network. Thus, it is reasonable to assume, with existing and new customers, a take-up rate of 70%.

Finally, it should be noted that NBN Co will implement the PCP in the form of a multiport device to ensure there is enough flexibility for connecting premises which may not exist at the time of deployment (i.e. new households or non-addressable premises).

Analysys Mason's assessment

► *Coverage*

As NBN Co has a mandate to provide services to 100% of the Australian population through a combination of FTTP, fixed wireless and next generation satellite technology, it is important that a prudence and efficiency analysis has regard to this fact. Analysys Mason considers that the methodology used by NBN Co to determine the boundary between the FTTP network and the fixed wireless network is both prudent and efficient, as it will ensure that a maximum number of end users are covered by the FTTP network, while at the same time not resulting in NBN Co incurring disproportionate costs in the relevant circumstances.

In particular, based on NBN Co's estimate of FTTP coverage of 92.3% for existing premises and 93% of existing and future premises (taking account of population growth), NBN Co will meet the Australian Government's minimum fibre coverage obligation of 90% and its objective of connecting 93% of premises with fibre. In other words, NBN Co's decision to set the reach of the fibre network at 92.3% for existing premises (and at 93% when taking account of both existing and future premises) serves as an efficient breakpoint for determining the boundary of the fixed and wireless network footprints.

⁶⁰ which provides for the migration of end users from Telstra's copper and HFC networks to the NBN and the decommissioning of Telstra's networks

⁶¹ Determination, Application for authorisation, lodged by NBN Co in respect of the provision of HFC subscribers entered into with SingTel Optus Pty LTD and other Optus entities, ACCC, 19 July 2012.

⁶² TeleGeography, 2011.

► *Infrastructure options (overhead versus underground)*

As mentioned previously, Analysys Mason believes that the deal with Telstra will give NBN Co an incentive to use Telstra's ducts instead of alternatives, such as aerial. Therefore, NBN Co will only deploy overhead infrastructure, in exceptional circumstances, where there is no other choice. We believe that this will have a positive impact on the reliability of the network and will deliver a better quality of service to end users compared to an equivalent aerial infrastructure. We also believe that the use of underground infrastructure will minimise long-term opex relative to an aerial deployment option.

Overall, we believe that NBN Co's infrastructure policy regarding overhead versus underground infrastructure is prudent and in line with the infrastructure that is available.

► *Local fibre network dimensioning and architecture*

Analysys Mason considers that the design of the local fibre network is prudent on the basis that it uses a standard architecture for FTTP with a centralised architecture.

As mentioned previously, Analysys Mason believes that NBN Co's decision to provision a single fibre in the local fibre network for the initial service connection to the premises, along with a second fibre to meet future capacity requirements in respect of the relevant premises (e.g. to take account of subdivision of the relevant property), is both efficient and prudent, as we would recommend a strict minimum of two fibres per premises in the local fibre network for operational, growth and potential protection reasons. While the number of fibres that are needed in the local fibre network to cover non-addressable premises is challenging to evaluate at this point, we consider that NBN Co's overall provisioning of fibre in the local fibre network is prudent.

Finally, we note that NBN Co has developed a high-level design for central business districts, which will need to be refined for deploying the network in these areas. However, we are not unduly concerned about this, given that services for large businesses (Enterprise Ethernet services) are not planned to be introduced until 2014, according to the roadmap.

► *Final drop provisioning*

Analysys Mason considers that NBN Co's decision to pre-build the final drop is efficient and prudent, having regard to the current levels of broadband penetration in Australia (63%) and the deal between NBN Co and Telstra, which provides for the migration of end users from the PSTN and HFC network to the NBN. It is reasonable for NBN Co to assume a take-up profile of 70%⁶³ for its services in light of these factors, and we therefore believe that pre-building the final drop in these circumstances is the most cost-efficient approach.

⁶³ The expected penetration of 70% does not take into account the agreement between NBN Co and Optus which should increase the penetration further.

NBN Co will implement the PCP using multipoint device for the mass fibre roll-out. Whilst we believe that implementing fusion splicing at the PCP would provide a better quality of service (because of fewer faults in the network), the decision from NBN Co is prudent as flexibility has to be provided in the network to accommodate the connection of premises that do not exist at the time of the network rollout (i.e. new households or non-addressable premises).

6.4.5 FDH

Critical decision and related issues

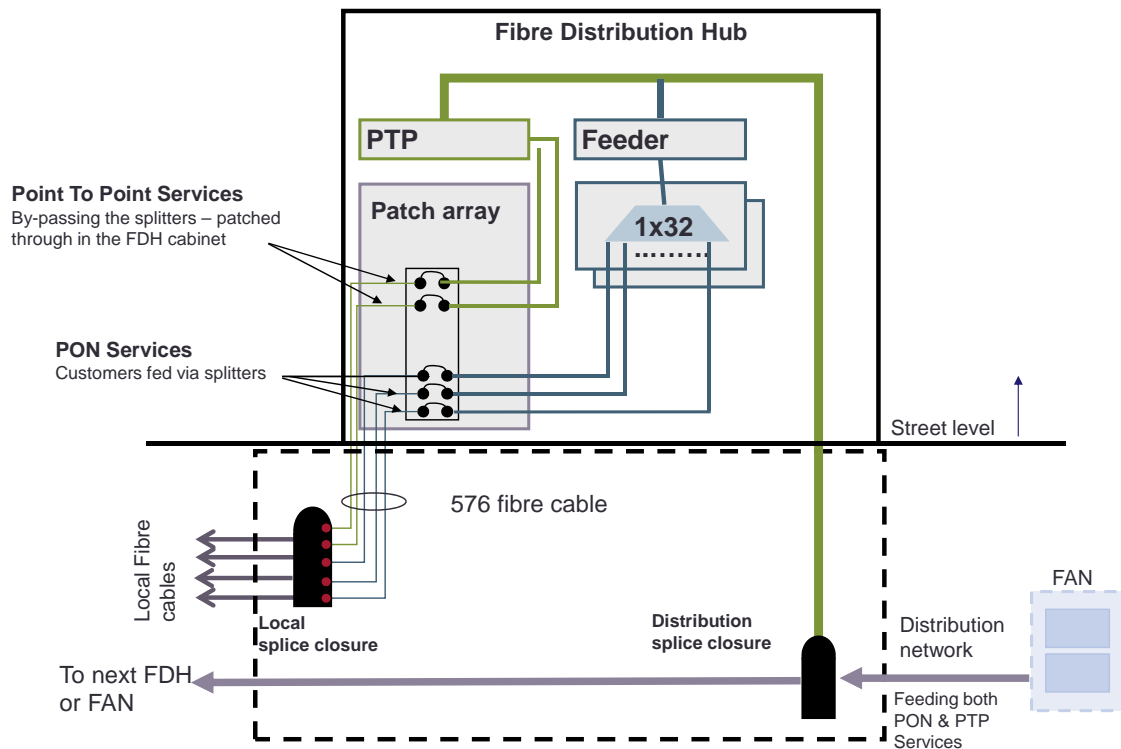
NBN Co will need to choose the type of FDH it would like to implement. The FDH's main function is to host the splitter modules and to provide connectivity between the distribution network and the local fibre network for both GPON and P2P customers. Two types of FDHs could be used (as illustrated in Figure 3.5 in Section 3.3.2 earlier):

- **Underground splitter enclosure** – A standard design for an underground splitter enclosure involves an underground unit with a swinging arm in a suitable hand-hole which is sealed from the environment. Figure 3.5 (in Section 3) illustrates this type of underground splitter enclosure. In general, underground units that use fusion splices offer the best reliability performance, and the fact that the enclosure is underground discourages unplanned intervention and further improves reliability, but at the expense of network flexibility and ease of re-configuration.
- **Street cabinet** – In marked contrast, splitters can be hosted in a street cabinet, which have a similar appearance to the street cabinets currently used in the distribution network for the PSTN. Street cabinets are easily accessible, and usually use connectors to provide connectivity between distribution fibres and local fibre networks. Street cabinets are therefore more flexible to reconfigure than underground splitter enclosures, but are more prone to human intervention and therefore more vulnerable to faults, which can have an impact on customers' experience. It should be noted that the majority of countries that have adopted a centralised architecture implement the FDH in the form of a street cabinet (e.g. Verizon's FiOS network and the Chorus UFB network).

NBN Co's position

NBN Co will implement the FDH using street cabinets. Figure 6.20 below illustrates NBN Co's street cabinet architecture, including the configuration of the FDH and the associated two splice joints in the pit – one for the local fibre cable and one for the distribution fibre cable.

Figure 6.20: NBN Co's FDH [Source: NBN Co]



The street cabinets that will be used by NBN Co are manufactured with pre-terminated fibre cable stubs, and will enable connectorised splitter modules to be easily installed as required, or pre-installed in the factory. Individual customers will be connected with a single patch lead as required. Importantly, the use of a central FDH allows both PON and P2P connections to be provided. GPON will serve residential and SME end users, while P2P will serve large enterprise and government customers in CBD and other areas.

Finally, if the FDH cabinet experiences a fault, this will not affect the previous or the next FDH cabinet because the distribution splice closure is isolated from the cabinet. This particular feature makes the distribution network design more robust.

Analysys Mason's assessment

Analysys Mason considers that NBN Co's decision to implement FDHs using street cabinets is prudent. The same choice has been made by the majority of operators using GPON centralised architectures worldwide. Also, since roadside cabinets in Australia are covered under the Low Impact Facilities Determination (LIFD) made pursuant to the Telecommunications Act, we do not anticipate any major problems in terms of the planning permissions required to install such cabinets.

6.4.6 DFN

Critical decision and related issues

We have investigated the following features of the DFN:

- the distribution network architecture
- the resilience of the distribution network.

► *Distribution network architecture*

The distribution network will provide connectivity between the FAN and many FDHs. The distribution network should provide a flexible configuration to provide protection between the FAN and the FDHs for customers that require this service (see Type A and Type B GPON protection topologies illustrated in Figure 3.11). It should be noted that providing protection between the FAN and the FDHs represents a significant improvement over the existing PSTN, which does not usually provide such protection. A standard topology to provide protection against fibre is to use a ring topology, which provides two different paths between the FAN and any of the FDHs present on the ring.

Also, an important consideration in the design of the FTTP network is the dimensioning of the distribution cables. The distribution cable usually serves three distinct purposes:

- provide feeder cables to connect the FAN and the splitters in the FDH (for GPON customers)
- provide feeder cables to connect P2P customers
- provide spare fibre to accommodate growth (e.g. new development or new MDU).

When dimensioning the distribution cable, it is therefore important to consider the fibres required for all of the above purposes.

► *Resilience of the distribution network*

Since the FDHs are implemented in the shape of cabinets, and so are at street level, it is possible that they might be damaged by cars or malicious individuals. For this reason, the distribution network should be designed in such a way that any internal FDH disconnection does not result in the disconnection of the adjacent FDH, connected to the same distribution fibre cable.

NBN Co's position

► *Distribution network architecture*

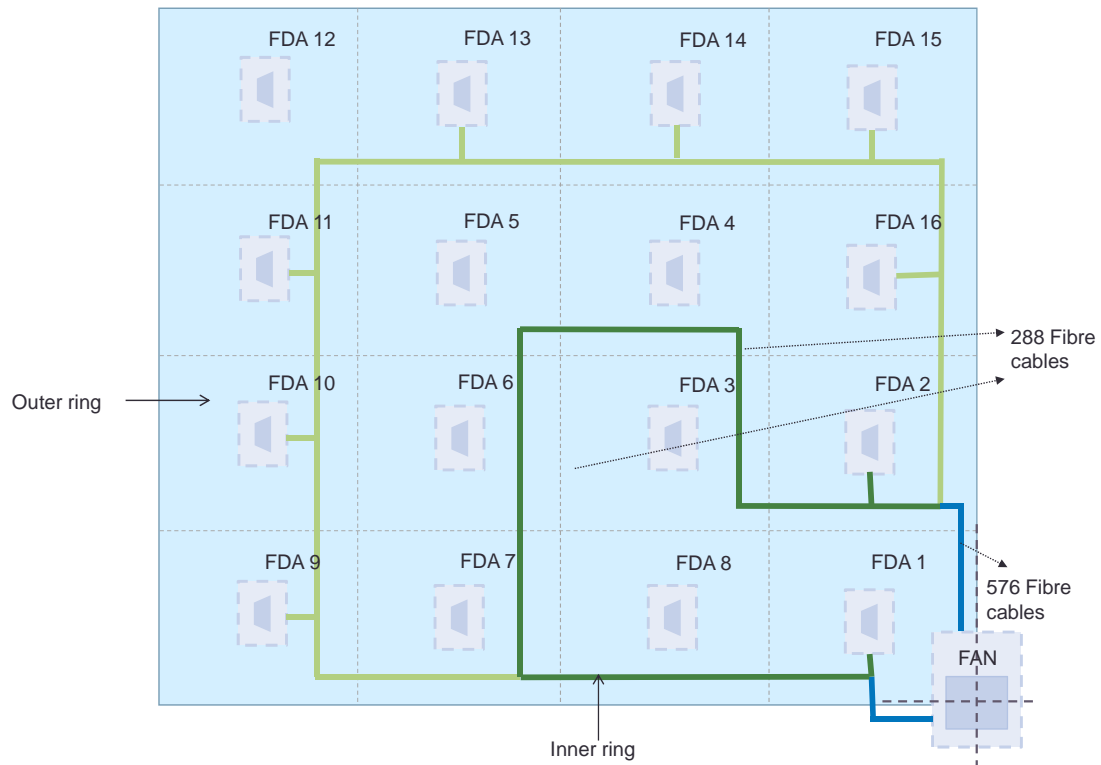
NBN Co is planning to implement a regular topology in its distribution network, consisting of up to 16 FDAs per FSAM. In an FSAM, NBN Co is planning to deploy two independent rings (i.e. an inner ring and an outer ring), each connecting 8 FDHs.⁶⁴ A typical FSAM is illustrated in

⁶⁴ Each FDH serves a single FDA.

Figure 6.21. In order to optimise the length of feeder fibre, the first four FDHs would be connected from the FAN in a clockwise direction and the next four FDHs in an anti-clockwise direction.

Importantly, since there are two different routes between the FAN and any FDH, each FDH can be protected using Type A or Type B protection, as described in Figure 6.3 earlier.

Figure 6.21: FSAM in urban geotypes [Source: NBN Co]



The allocation of fibres to FDHs and the provision of a diverse pathway for each connected FDH requires a higher fibre count cable, and the use of ribbon-based fibre cable is required in order to maximise the use of existing assets. The fibre counts selected for use in NBN Co's DFN are:

- 144-fibre cable
- 288-fibre cable
- 432-fibre cable
- 576-fibre cable
- 864-fibre cable.

These cables are of a loose tube construction, with each tube containing up to 12 individual 12-fibre ribbons.

Figure 6.22 shows the number of fibres for different sizes of FSAM.

Figure 6.22: Cable size configuration per FSAM [Source: Analysys Mason, 2011]

Number of FDA per FSAM	Distribution cable size (fibres)
1–8	288 (single loop)
9–12	432 (single loop)
13–16	576 (two loops of 288 fibres)

If we assume 200 end users per FDA and a split ratio of 32, then an average of 7 GPON splitters will be required per FDH, and therefore 7 feeder fibres. Also, if we assume that 5% of users will require a P2P service, an additional $5\% \times 200 = 10$ fibres will be required for a P2P connection. Overall, therefore, 17 fibres per FDA may be required if services are unprotected or 34 fibres if services are protected.

Therefore, in the worst case (all services are protected in a 1+1 scheme), an FSAM of 8 FDAs will require a maximum of 272 fibres and NBN Co will provision 288 fibres.

► *Resilience of the distribution network*

The architecture illustrated in Figure 6.21 is highly resilient, as it ensures that at least two different fibre routes exist to reach any FDH. Therefore, in the event of a fibre cut on the clockwise route, an FDH will always have connectivity to the FAN through the anti-clockwise route.

NBN Co has performed extensive modelling of the availability of the fibre network. The results show that the network availability target set by NBN Co can be achieved with an unprotected link between the FAN and the FDA, if the distance is less than 4500 metres. For practical purposes, NBN Co limits the distance between the FAN and the furthest unprotected FDH to 4000 metres to account for unforeseen alterations to the network in the construction phase and to provide flexibility for future maintenance.

Analysys Mason's assessment

Analysys Mason considers that NBN Co's architecture and dimensioning of the distribution network is efficient and prudent and provides a resilient infrastructure for the urban model described in Figure 6.21. We believe that, even in a worst-case scenario, NBN Co will provide sufficient fibres.

The use of standard-size cables is good practice and will simplify the deployment process.

However, it should be noted that the FSAM model illustrated in Figure 6.21 will need to be adapted on a case-by-case basis, depending on available infrastructure and the local geotype characteristics of areas where the fibre is deployed.

6.4.7 FAN and FSA

Critical decision and related issues

There are three main decisions that NBN Co has to make regarding FANs:

- FAN location
- the size of each FSA
- use of an OFDF.

► *FAN location*

In general, local exchanges from incumbent operators are geographically located to serve a particular area in the optimal way, from an infrastructure perspective. Furthermore, duct infrastructure for a particular area is generally configured to terminate in local exchanges.

► *Size of FSA*

The size of the FSA served by a single FAN needs to be considered carefully. The larger the FSA, the fewer FAN sites are required. This optimises capex and opex. Also, due to the longer reach of FTTP technologies, a FAN can cover a larger area than legacy local exchanges, which were designed for copper access technology. On the other hand, the larger the FSA, the more subscribers are affected in the event of a catastrophic failure, unless an appropriate protection strategy has been implemented. Therefore, the size of the FAN is a balance between costs and protection strategy, including the number of customers who would be affected by a catastrophic failure at the FAN.

It is also important to note that the geographical size of the FSA should be limited to ensure that the reach offered by GPON and P2P equipment covers the entire area. GPON has a reach of approximately 20km⁶⁵ for a 32-way splitter and OLTs using class B+ optics (see Section 3 for more details). P2P has a reach of 10km using standard 100/1000 base BX interfaces.

► *Use of an OFDF*

As explained in Section 3.3.2, the OFDF provides flexibility to allow incoming feeder fibres to be connected (patched) to the OLT cards (for both GPON or P2P systems). The spatial flexibility in an OFDF is provided using a patch panel, where input and output ports can be connected using a patch cord. Input and output connectors constitute a potential point of failure and encourage repeated human intervention, which will in itself create faults as a side effect. However, these risks are mitigated by the fact that the OFDF connectors will exist in a local exchange, where physical access and human intervention is strictly controlled.

The alternative to an OFDF is to use an optical consolidation rack (OCR). This provides less flexibility, as it uses fusion-spliced connections to minimise the risk of faulty and wrong

⁶⁵ In some circumstances, the reach of a GPON system can be extended to 30km (by using class C+ optics, for example).

connections. This option is used by BT in the UK, for example, but the OFDF option remains the preferred option for the vast majority of operators.

NBN Co's position

► *FAN location*

NBN Co is planning to implement FANs in the existing Telstra local exchanges, subject to the terms and conditions of its agreement with Telstra. This will provide an ideal location for NBN Co to host its active equipment, as the existing Telstra duct infrastructure is designed to consolidate all the fibre back in the exchange.

Analysys Mason's assessment

Analysys Mason considers that NBN Co's decision to re-use existing Telstra local exchanges for the FAN is both a prudent and an efficient approach, especially in the context of the NBN Co–Telstra agreement. Since the Telstra infrastructure network is built around them (i.e. all ducts in the distribution network come back to the local exchanges), the additional civil works that NBN Co has to undertake will be minimised.

Further, while NBN Co is using Telstra's infrastructure and is optimising its network design for the existing infrastructure, NBN Co is also re-partitioning the country into FDAs, FSAMs and FSAs compared to the current DA and ESA used by Telstra, meaning that the overall network design is one that has been optimised for FTTP.

► *Size of the FSA*

NBN Co is proposing to deploy FSAs of up to 12 FSAMs, representing up to 192 FDAs, each served by an FDH. Based on 200 premises per DA, a single FSA could serve up to approximately 38 500 geocoded national address files (GNAF) (premises) in urban areas. According to NBN Co, this maximum will only be reached for one of the FSAs, and all other FSAs will contain fewer than 36 000 GNAFs. An FSA with 6 FSAMs (serving up to 19 000) is illustrated in Figure 6.23 below.

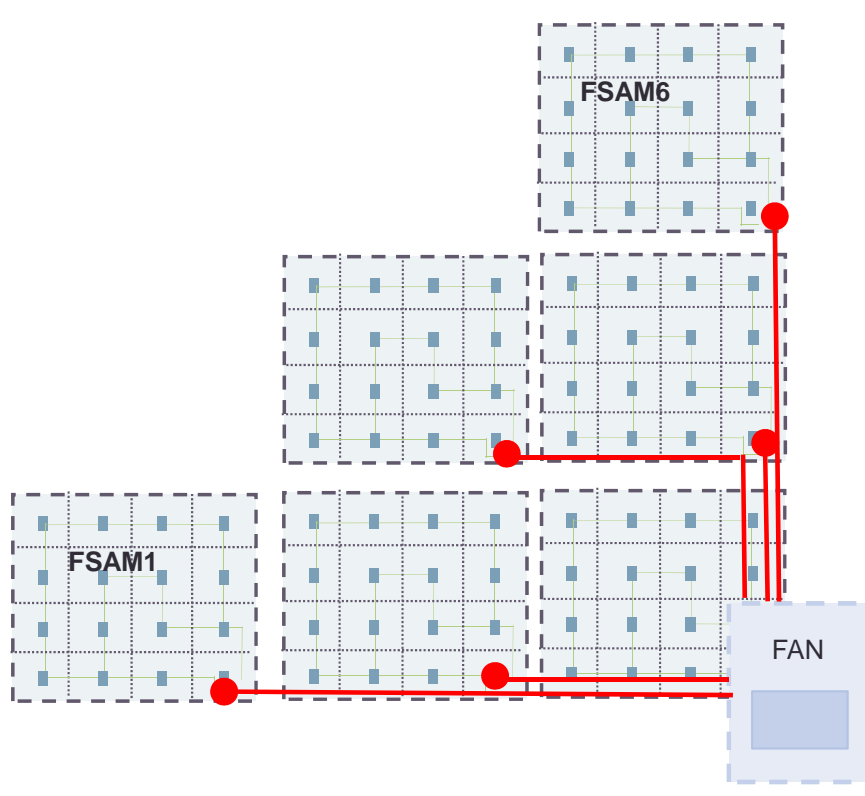


Figure 6.23: Example of an FSA with six FSAMs
[Source: NBN Co]

In addition, NBN Co is planning to limit the length of the distribution fibre to 15km, to ensure that the GPON link budget is easily accommodated.

In the exceptional case where a large business customer is more than 10km away from the FAN, services could not be deployed using P2P technology as it has a 10km reach limit. For these areas, NBN Co plans to serve business customers by dedicating full GPON ports to each customer, which will provide 2.5Gbps downstream and 1.25Gbps upstream and will overcome the technology reach issue.

► *Analysys Mason's assessment*

Analysys Mason considers that NBN Co's decision to define the size of FSAs at a maximum of 38 500 GNAFs is prudent, having regard to NBN Co's deal with Telstra and NBN Co's decision to use Telstra's exchanges as FAN sites, as well as the geographical reach of GPON and P2P technology. Currently, in Australia, the ten largest ESAs for the PSTN each serve between 30 000 and 40 000 GNAFs. NBN Co is proposing a maximum FSA of 38 500 GNAFs, which is similar to the size of existing ESAs. We therefore believe that NBN Co's approach to the size of the FSA is efficient and prudent, as it is in line with Telstra's existing infrastructure that serves PSTN exchanges.

We believe that NBN Co's design of the other aspects of its distribution network are also prudent,⁶⁶ as it allows for different levels of protection to be implemented in the FTTP network.

⁶⁶ In addition to the maximum number of GNAFs served per FSA.

6.4.8 Use of an optical fibre distribution frame

NBN Co is planning to use standard OFDFs to provide flexibility to connect different customers to different services (e.g. GPON and P2P).

Analysys Mason's assessment

Analysys Mason considers that NBN Co's decision to implement an OFDF to connect FANs to the distribution network is prudent, as it will provide flexibility in the network relative to other options, such as an OCR.

6.4.9 Transit network

Critical decision and related issues

► *Architecture and technology*

In order to meet the service delivery requirements of the Government's New Developments policy, NBN Co has designed, tested and qualified a Temporary Transit network and associated Temporary Fibre Access Node (FAN) solution to meet Greenfields requirements prior to the deployment of NBN Co's Transit network. In the context of this report, we have not analysed the design of the Temporary Transit Network nor the design of the Transit FAN, but have assessed the long term, permanent solutions (Transit Network and FAN) proposed by NBN Co.

The transit network can simply be described as the network that provides connectivity between the FANs and the PoIs. There are three key criteria to take into account when designing the transit network:

- it must be based on a resilient architecture because each transit network link could potentially carry the traffic for tens of thousands of users and therefore cannot have a single point of failure
- the transit network topology must be optimised to provide reliable connectivity between FANs and PoIs
- the transit network must be scalable to accommodate capacity growth as more and more users in a given CSA take on the service.

To address resiliency, fibre transit networks are traditionally designed in rings to ensure that there is always two paths or distinct routes between any source/destination node pairs.

The scalability component is usually addressed by deploying the WDM technology, which currently allows in excess of 1Tbit/s⁶⁷ capacity to be deployed over a single fibre pair. WDM technology enables the transmission of several signals along the same fibre, separated in the frequency domain. Each signal is assigned a different wavelength (sometimes called a different

⁶⁷ 1 000 000Mbps.

colour of light). A detailed explanation of WDM technology can be found in the *Fibre capacity limitations in access networks* paper, which is available from Ofcom's website.⁶⁸

► *Bandwidth dimensioning*

For NBN Co to meet any applicable service level agreements (SLAs) with service providers, it will be important that the network is dimensioned with enough capacity to meet the minimum bandwidth requirement. Since TC_4 traffic is, by definition, a contended service (PIR), it is important that the transit network is dimensioned with enough capacity for that bandwidth to be available at the PoI.

NBN Co's position

► *Architecture and technology*

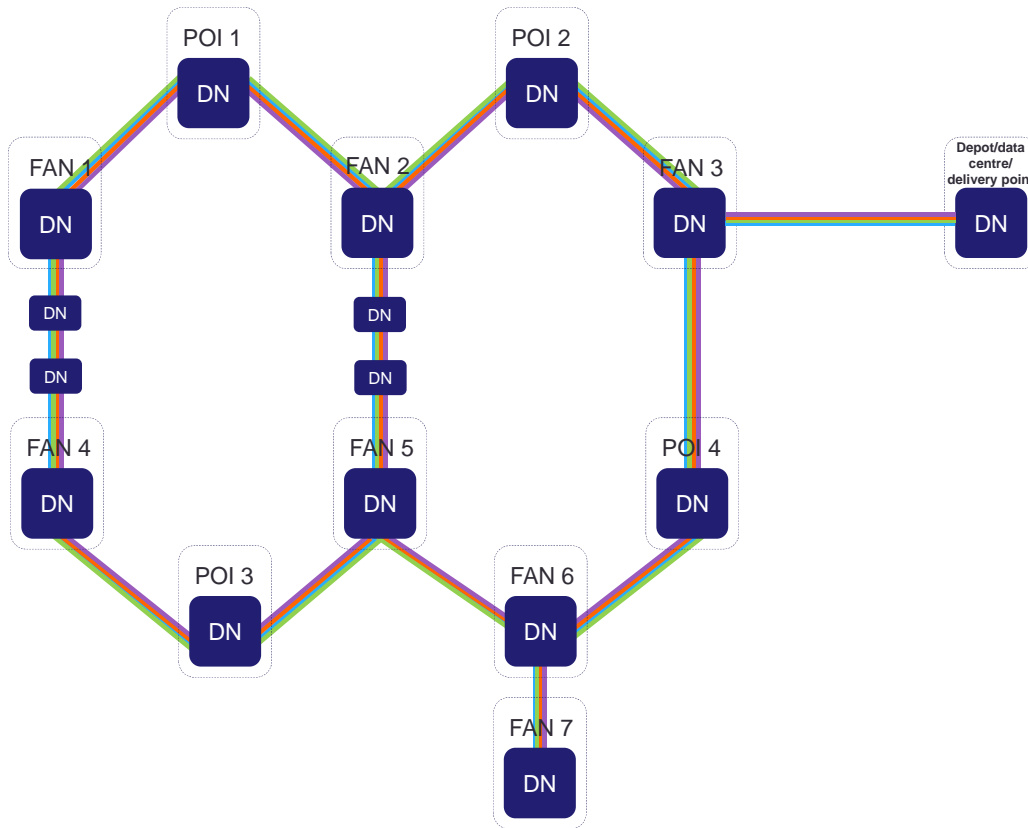
The main architecture choice made by NBN Co is the use of dense wave division multiplexing (DWDM) implemented in a ring topology for the transit network. The WDM platform chosen by NBN Co can transmit up to 96 wavelengths in a single fibre pair.

The transit network contains several DWDM nodes (DNs), which are located at the PoIs and FANs, as illustrated in Figure 6.24. In addition, DWDM repeater nodes are implemented at regular intervals along the links to ensure that the signal is regenerated when the distance between the FAN and the PoI is too great.

Figure 6.24 below illustrates the basic architecture adopted by NBN Co for its transit network. While NBN Co has defined several configurations for DWDM to optimise its network, NBN Co will use primarily an overlapping physical ring topology in which adjacent DWDM rings share physical infrastructure and routes to optimise resources. This choice is based on the provision of a single pair of dark fibre for a given route by Telstra.

⁶⁸ <http://stakeholders.ofcom.org.uk/binaries/research/technology-research/fibre.pdf>.

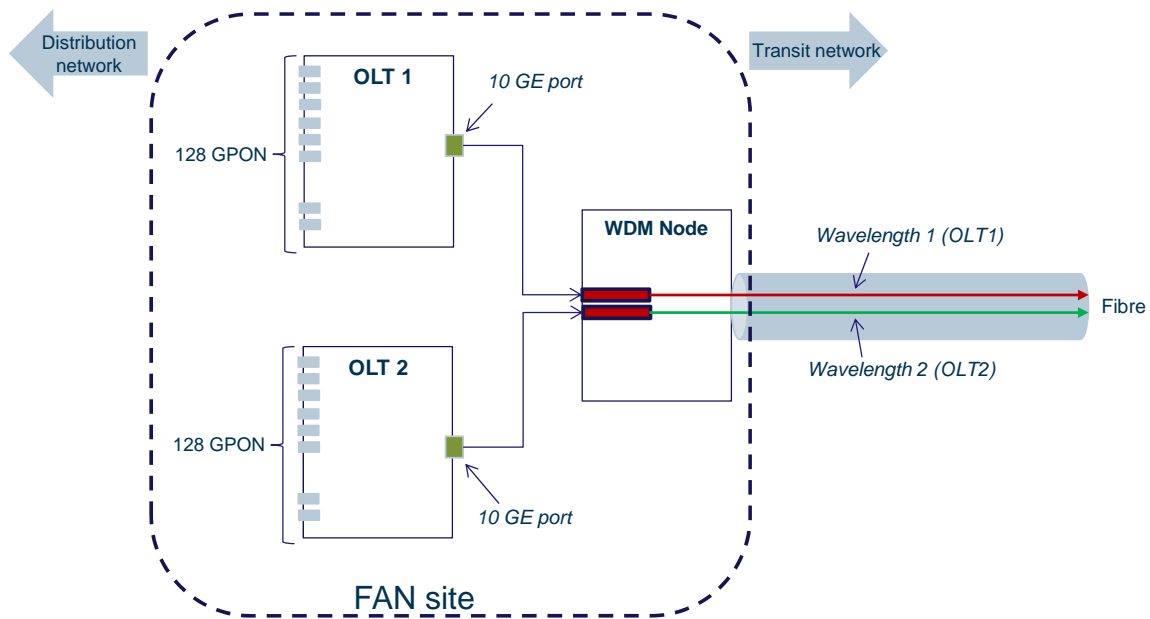
Figure 6.24: Basic DWDM physical connectivity scenarios [Source: NBN Co, 2011]



At the FAN, the 10 Gigabit Ethernet ports, which aggregate the traffic of all GPON in a single OLT,⁶⁹ are mapped directly out of the OLT onto wavelengths in the DN. This is illustrated in Figure 6.25 below.

⁶⁹ An OLT comprise 128 GPON networks (16 card * 8 GPON port per card).

Figure 6.25: Mapping of OLT Gigabit ports into wavelengths⁷⁰ [Source: Analysys Mason, 2012]



Importantly, no traffic grooming occurs in the transit network. This effectively means that the signal present in the OLT gigabit port is directly transmitted to the PoI, with no further grooming in the network.

Analysys Mason's assessment

Analysys Mason considers that NBN Co's decision to use WDM technology is prudent as it is a mature technology, which has been adopted by most operators in their core network throughout the world to minimise the number of fibres to be deployed. In the context of NBN Co, we foresee that a single dark fibre pair leased from Telstra will be sufficient to carry traffic in different sections of the transit network, thereby minimising opex.

Analysys Mason also considers that NBN Co's adoption of a ring topology is prudent, as it adequately addresses the requirements for a resilient transit network and provides an optimal solution in this regard for linking the PoIs and the FANs. We also agree that NBN Co's decision to implement an overlapping physical ring topology is prudent, as we believe that this makes the most efficient use of the infrastructure that is available without compromising the resilience of the network.

Analysys Mason considers that a single fibre pair leased from Telstra will be able to accommodate all traffic requirements over the medium and long term, minimising NBN Co's opex.

Therefore, we believe that the design and architecture for the transit network is both prudent and efficient.

⁷⁰ Each OLT shows 16 cards, each capable of accommodating 8 GPON ports.

► *Bandwidth dimensioning*

NBN Co has assumed a minimum capacity of 150kbps per TC-4 AVC, based on 30Gbytes average monthly download, which is the expected average fixed download volume for NBN services for 2012, using Australian Bureau of Statistics fixed broadband internet download data and forecasted growth rates. NBN Co's decision to dimension each TC-4 AVC at 150kbps was based on empirical evidence collected by NBN Co. Based on the data published by the Western Australia Internet Exchange (WAIX),⁷¹ NBN Co has been able to analyse the usage on peering links across the aggregate of a large number of users (rather than using discrete end-user assumptions as Analysys Mason has done). NBN Co expects that traffic flows from an OLT will approximate aggregate flows across service providers' peering points, as both represent consolidated traffic. This aggregate data demonstrates that the average utilisation across peering links is around 65% to 70%, which accounts for the non-busy hours (generally from 2am to 8am). With a 70% utilisation of a 1Mbps link (which supports a maximum of 324GB per month), this equates to 220GB per Mbps per month. Thus, a 30Gbyte average user will require approximately 140kbps of aggregate backhaul capacity and NBN Co has provisioned 150kbps. NBN Co has validated these assumptions with the Institute for Broadband Enabled Societies (IBES), from the University of Melbourne.

NBN Co's capacity planning guidelines will require a minimum TC-4 shared network capacity allocation of 300Mbps per OLT device (see Gigabit port in Figure 6.25). This is expected to be sufficient for the introduction of wholesale downstream PIR service speeds up to 100Mbps.

Certain locations within the NBN Co fibre footprint, such as certain MDUs and greenfield estates, that are outside NBN Co's own transit network may present exceptions to this guideline, particularly where the number of end users serviced by a particular shared network capacity allocation is approximately 100 or less. In these instances, the amount of shared network capacity that NBN Co initially provisions may be less than 300Mbps.

Note that NBN Co has not yet provided any dimensioning rules for traffic other than TC_4 traffic. For TC_2 and TC_3, we expect NBN Co to dimension its transit network in such a way that it supports the full CIR for these AVCs.

Analysys Mason's assessment

Analysys Mason has used a different methodology from NBN Co to assess whether the minimum bandwidth for each TC_4 AVC used by NBN Co is prudent. Our approach is based on the average bandwidth that an end user will require during the busy hour to download 30 Gbytes of data. Based on our own calculations, which assume that end users will use their broadband service for 20 days a month for two hours each day, and taking a 10:1 contention ratio to account for the fact that not all users will access services at the same time, we believe that TC_4 AVC's should be provisioned with 166kbps bandwidth.

⁷¹ See https://monitor.waia.asn.au/cacti/graph_view.php.

In light of our own calculations, we consider that NBN Co's decision to provision 150kbps per TC_4 AVC is prudent, especially as a starting point for the dimensioning of NBN Co's network in the start-up phase of its business operations and in light of the forecast average fixed download volume for NBN services up to 2013.

Based on a minimum of 150kbps per TC_4 AVC as currently proposed by NBN Co, we believe that allocating 300Mbps to each OLT will be sufficient for a take-up of up to 50%.⁷² Since NBN Co expects a take-up of 70%, we believe that this provision of bandwidth at the OLT into the transit network will need to increase from 300Mbps to 450Mbps in the medium term. As long as the take-up remains below 50%, the dimensioning of 300Mbps for the transit network is efficient and prudent, and we would expect the amount of bandwidth to be upgraded over time as take-up increases.

6.4.10 Semi-distributed PoIs

The location of PoIs was determined as follows:

- The Australian Government sought advice from the ACCC on the initial PoI locations that would best meet the long-term interests of end users.
- The ACCC advised that the long-term interests of end users would be best served through the application of the ACCC's 'competition criteria',⁷³ which when applied by the ACCC supported the use of a semi-distributed PoI architecture.
- Based on this advice, the Australian Government has set the following requirement in its *Statement of Expectations*:

"The Government has determined that the preferred outcome is a semi-distributed PoI structure which extends the NBN Co network to meet with, but not overbuild competitive backhaul routes is the preferred outcome.

[...]

The Government expects that NBN Co will act to ensure that POIs are located in accordance with the 'competition criteria' formulated by the ACCC. It expects NBN Co to provision its physical infrastructure, including POIs and fibre exchanges, to accommodate reasonable expectations for retail competitors' equipment, in anticipation of multiple retail competitors. While NBN Co is expected to consult closely with the ACCC in relation to the POIs, the specific location of the POIs will be a matter for NBN Co".⁷⁴

⁷² 16 cards per OLT × 8 GPON port per card × 32 end-user per GPON × 150kbps × 50% take-up= 300Mbps.

⁷³ The ACCC's competition criteria broadly comprises the following: (1) It is technically and operationally feasible to allow interconnection; (2) There are at least two competitors with optical fibres within a nominated distance from that location which connect a site to an optical fibre network which is connected to a capital city deliver wholesale transmission services which are suitable for use by service providers who wish to connect to the NBN at that location; and (3) there is other evidence that the particular route is, or is likely to become, effectively competitive.

⁷⁴ *Statement of Expectations*, Minister for Finance and Deregulation and Minister for Broadband, Communications and the Digital Economy, 17 December 2010.

- In December 2010, NBN Co developed a set of network Planning Rules based on the 'competitive criteria',⁷⁵ as well as a list of 120 initial PoIs based on the ACCC's 'competition criteria' and the Planning Rules.⁷⁶
- The revised list of PoIs was developed and published in May 2011. In addition to the Competition Criteria and Planning Rules, the revised list of PoIs took into consideration the duct space, power and cooling issues associated with the PoI locations.

Full details of the PoI locations can be found on the ACCC's website.⁷⁷

As a consequence of the implementation of a semi-distributed PoI architecture, a total of 121 PoIs will be available nationwide for service providers to connect to the NBN Co network and services. The PoIs are classified into three categories, to reflect the geotype they serve:

- Metro PoI (71)
- Outer metro PoI (9)
- Regional PoI (41).

A Metro PoI will be located in metropolitan areas, including central business districts and mainland state capital cities (excluding Darwin, Hobart and Canberra). A Metro PoI will typically comprise a few (typically two) large FSAs. In the rest of this report, we refer to all FSAs served by the same PoI as the connectivity serving area (CSA).

An Outer metro PoI will be located in capital cities, excluding Darwin, Hobart and Canberra, and the furthest end user will be situated beyond the maximum distance required to meet the optical fibre link budget. End users located beyond this maximum distance will be served by a wireless network. Outer metro regions will typically be located in suburban areas.

A Regional PoI will be situated in an area that is neither Metro nor Outer metro, and will comprise many smaller FSAs than a Metro PoI, because it will typically aggregate more rural areas.

Analysys Mason's assessment

Analysys Mason considers that NBN Co's network design prudently implements the semi-distributed PoI architecture requirement set out by the Australian Government in its *Statement of Expectations*. In particular, the location of PoIs has been determined by reference to the availability of competitive backhaul in accordance with the ACCC's 'competition criteria' and also having regard to duct space, power and cooling issues associated with each PoI location.

⁷⁵

<http://www.accc.gov.au/content/item.php?itemId=963440&nodeId=64dbfcea5537a9f435f389288eaa9e80b&fn=PoI%20planning%20rules.pdf>.

⁷⁶

<http://www.accc.gov.au/content/item.php?itemId=974675&nodeId=f3de7278aa3eedebae40a012ed2b275c&fn=List%20of%20revised%20initial%20PoIs%20to%20the%20NBN%20-%20February%202011.xls>.

⁷⁷

See <http://www.accc.gov.au/content/index.php?itemId=952292>.

6.5 Conclusion

Analysys Mason considers that NBN Co's design of its FTTP network reflects an efficient and prudent network design.

In particular:

Technology decisions

- NBN Co's decision to implement GPON for the mass-market segment prudently implements the requirements of the Australian Government under its *Statement of Expectations*.
- NBN Co's decision to use P2P technology for the delivery of services to the enterprise and government segment is a prudent design choice for the supply of higher-bandwidth and symmetrical services to large government and enterprise customers, and represents international best practice.
- NBN Co's choice of Ethernet as a Layer 2 protocol is both efficient and prudent, as the choice of Ethernet aligns with global standards and is a proven technology, and will facilitate competitive vendor pricing and minimises technology risk/risk of stranded assets.

Architecture-related decisions

- NBN Co's adoption of a centralised GPON architecture is both efficient and prudent, as it represents the best choice of architecture from a long-term cost-management perspective and from a network scalability and flexibility perspective.
- NBN Co's network design is prudent from a resiliency perspective for the following reasons:
 - the design of NBN Co's fibre distribution network is based on a ring topology, which provides path diversity from the FAN to every FDH and will prevent any single fibre cut in these networks from being service affecting
 - NBN Co could implement all standardised GPON protection option types, if required, using its proposed architecture
 - NBN Co plans to have at least two independent entry/exit locations in each FAN, which represents best practice and will ensure that each segment of the rings is diversely routed
 - a centralised architecture provides greater flexibility in the implementation of protection in the FDH as it is easier to design a ring topology around fewer sites hosting splitters.
- NBN Co's choice of ribbon technology for fibre cables is both efficient and prudent for the following reasons:
 - ribbon technology is modular and can provide adequate fibre counts for all parts of the network, standardising cable size and associated deployment processes
 - ribbon technology minimises opex as it allows the operational team to deal with bundled fibres simultaneously rather than as single individual fibres

- each fibre in a ribbon is colour-coded, which mitigates against human connection errors, thereby minimising opex
 - fibre ribbon suits the pre-connectorised system being used by NBN Co as part of its fibre network roll-out
 - fibre ribbon cable is also better suited for aerial deployment (where required) because it weighs 60% less than a traditional stranded fibre cable, maximising the number of existing poles that can be potentially used for FTTP deployment
 - fibre ribbon cable is extensively deployed by leading FTTP operators internationally, including Verizon, NTT and Korea Telecom.
- NBN Co's proposed end-to-end service availability target of 99.9% is prudent from a network design perspective, having regard to the geography of Australia and specifically due to the significantly longer fibre runs in Australia compared to most overseas jurisdictions.

Infrastructure-related design decisions generally

- As NBN Co has a mandate to provide services to 100% of the Australian population through a combination of FTTP, fixed wireless and next generation satellite technology, it is important that a prudence and efficiency analysis have regard to this fact. Analysys Mason considers that the methodology used by NBN Co to determine the boundary between the FTTP network and the fixed wireless network is both prudent and efficient, as it will ensure that a maximum number of end users are covered by the FTTP network, while at the same time not resulting in NBN Co incurring disproportionate costs in the relevant circumstances. In particular, based on NBN Co's estimate of FTTP coverage of 92.3% for existing premises and 93% of existing and future premises (taking account of population growth), NBN Co will meet the Australian Government's minimum fibre coverage obligation of 90% and its objective of connecting 93% of premises with fibre. In other words, NBN Co's decision to set the reach of the fibre network at 92.3% for existing premises (and at 93% when taking account of both existing and future premises) serves as an efficient breakpoint for determining the boundary of the fixed and wireless network footprints.
- NBN Co's decision to re-use Telstra's infrastructure is prudent from an operational perspective. There are strong operational reasons to use underground infrastructure wherever it exists and is fit for purpose. The re-use of existing Telstra infrastructure will provide more certainty (and therefore reduce risks) in a number of areas, including significantly reducing the need for NBN Co to construct its own duct infrastructure (which would increase NBN Co's construction costs and delay the roll-out of its fibre network). It will also overcome some of the downsides that may be associated with aerial deployments, such as lower levels of reliability and higher associated opex. We also welcome the PoP provisions contemplated in the NBN Co–Telstra deal, which will further increase the certainty of the available infrastructure.

Infrastructure-related design decisions at the end-user premises and the local fibre network

- NBN Co's design of the local fibre network is prudent, as it uses a standard design for FTTP with a centralised architecture.
- NBN Co's approach to the architecture and features provided on the NTD in areas served by fibre infrastructure is prudent, as it will allow simultaneous delivery of multiple applications and services by multiple service providers and is consistent with industry best practice.
- NBN Co's decision to provision a single fibre in the local fibre network for the initial service connection to the premises, along with a second fibre to meet future capacity requirements in respect of the relevant premises (e.g. to take account of subdivision of the relevant property), is both efficient and prudent, as we would recommend a strict minimum of two fibres per premises in the local fibre network for operational, growth and potential protection reasons. While the number of fibres that are needed in the local fibre network to cover non-addressable premises is challenging to evaluate at this point, we consider that NBN Co's overall provisioning of fibre in the local fibre network is prudent.
- NBN Co's decision to pre-build the final drop is efficient and prudent, having regard to current levels of broadband penetration in Australia and the deal between NBN Co and Telstra, which provides for the migration of end users from the PSTN and HFC network to the NBN, and the agreement between Optus and NBN Co which provides an option for Optus HFC end-users to migrate to the NBN Co. It is reasonable for NBN Co to assume a take-up profile of 70% in light of these factors and a decision to pre-build the final drop is the most cost-effective approach.
- NBN Co's decision to implement FDH using street cabinets is a prudent choice, being the approach that is implemented by the majority of operators using centralised GPON architectures worldwide.

Infrastructure-related design decisions in relation to the DFN

- NBN Co's design of the DFN is prudent, as it allows for different levels of protection to be implemented in the FTTP network, which will ensure high levels of resiliency.
- NBN Co's decision to re-use existing Telstra local exchanges for the FAN is both efficient and prudent, particularly in the context of NBN Co's deal with Telstra. As all ducts in Telstra's distribution network come back to local exchanges, the use of local exchanges as FAN sites will minimise additional civil works that would otherwise be required as part of the roll-out, resulting in cost savings relative to a situation where NBN Co was constructing its own facilities.
- NBN Co's approach to defining the size of FSAs (which sets a maximum size of 38 500 GNAFs) is prudent, having regard to NBN Co's deal with Telstra and NBN Co's decision to use Telstra's exchanges at FAN sites and the geographical reach of GPON and P2P technology.

- NBN Co's decision to use an OFDF at FAN sites to connect to the DFN is prudent, as it will provide a higher level of flexibility than an OCR.

Infrastructure-related design decisions in the fibre transit network

- NBN Co's design and architecture for the transit network is prudent for the following reasons:
 - use of WDM technology is prudent as it is a mature technology, which has been adopted by most operators in their core networks throughout the world to minimise the number of fibres to be deployed
 - a single dark fibre pair leased from Telstra will be sufficient to carry traffic in different sections of the transit network for the medium and long term, thereby minimising opex
 - NBN Co has adopted a ring topology, which adequately addresses the requirements for a resilient transit network and provides an optimal solution for linking the PoIs and the FANs
 - NBN Co's implementation of an overlapping physical ring topology is also prudent as this makes the most efficient use of available infrastructure without compromising the resiliency of the network.
- We believe that the intention of NBN Co to dimension each TC_4 AVC to a minimum of 150kbps per TC_4 AVC is prudent, as our analysis of the busy hour estimates that the bandwidth per TC_4 AVC should be around 166kbps.
- NBN Co's implementation of a semi-distributed PoI architecture is consistent with the requirements of the Australian Government in its *Statement of Expectations* and has been prudently implemented by having regard to the availability of competitive backhaul in accordance with the ACCC's 'competition criteria' and by having regard to duct space, power and cooling.

Future-proofing of NBN Co's fibre network

- NBN Co's network design is likely to have a sufficient upgrade path to meet the reasonably anticipated requirements of access seekers and end users for bandwidth over the next 30 years.
- In terms of bandwidth evolution, the GPON standard has a clear evolution path as the downlink bandwidth can be upgraded from 2.5Gbps to 10Gbps.
- While it is difficult to predict how the technology will evolve in the next 30 years, we have not found any bottlenecks in the choice of the technology or design of the physical network that would mean the network cannot be upgraded in terms of bandwidth or functionality for the fibre network. In 2010, on behalf of Ofcom (the UK regulator), Analysys Mason undertook a large-scale study regarding the capacity limitations in fibre access networks.⁷⁸ In that study, we concluded that we did not believe that capacity will be the main limiting factor in GPON fibre access networks, and we do not foresee a situation where supply is unable to meet the growing demand of users. Instead, the study suggests that the bottlenecks in the access network may be in the operational upgrade of one generation of FTTP technology to the next, but we are confident these issues will be resolved in time.

⁷⁸ See <http://stakeholders.ofcom.org.uk/binaries/research/technology-research/fibre.pdf>.

The proposed GPON architecture is future-proof, especially regarding the dimensioning of the local fibre.

7 Review of the efficiency and prudence of NBN Co's wireless network design

7.1 Introduction

This section sets out Analysys Mason's assessment and conclusions in respect of whether, and the extent to which, NBN Co's design for its wireless network reflects an efficient and prudent network design.

Many decisions have to be made as part of the development of an efficient and prudent fixed wireless network architecture and associated infrastructure.

We consider the key decisions that influence that efficiency and prudence of a network design include:

- technology choices, which mainly relate to the fixed wireless technology being used to supply services (e.g. LTE and WiMAX), as well as related choices of Layer 2 protocol
- architectural choices, which mainly relate to the topology of the network, and spectrum band and channel bandwidth choices
- infrastructure choices, which relate to the physical implementation of different sections and nodes of the network.

In particular, we consider that the following decisions will have the most impact on the efficiency and prudence of the design of fixed wireless networks:

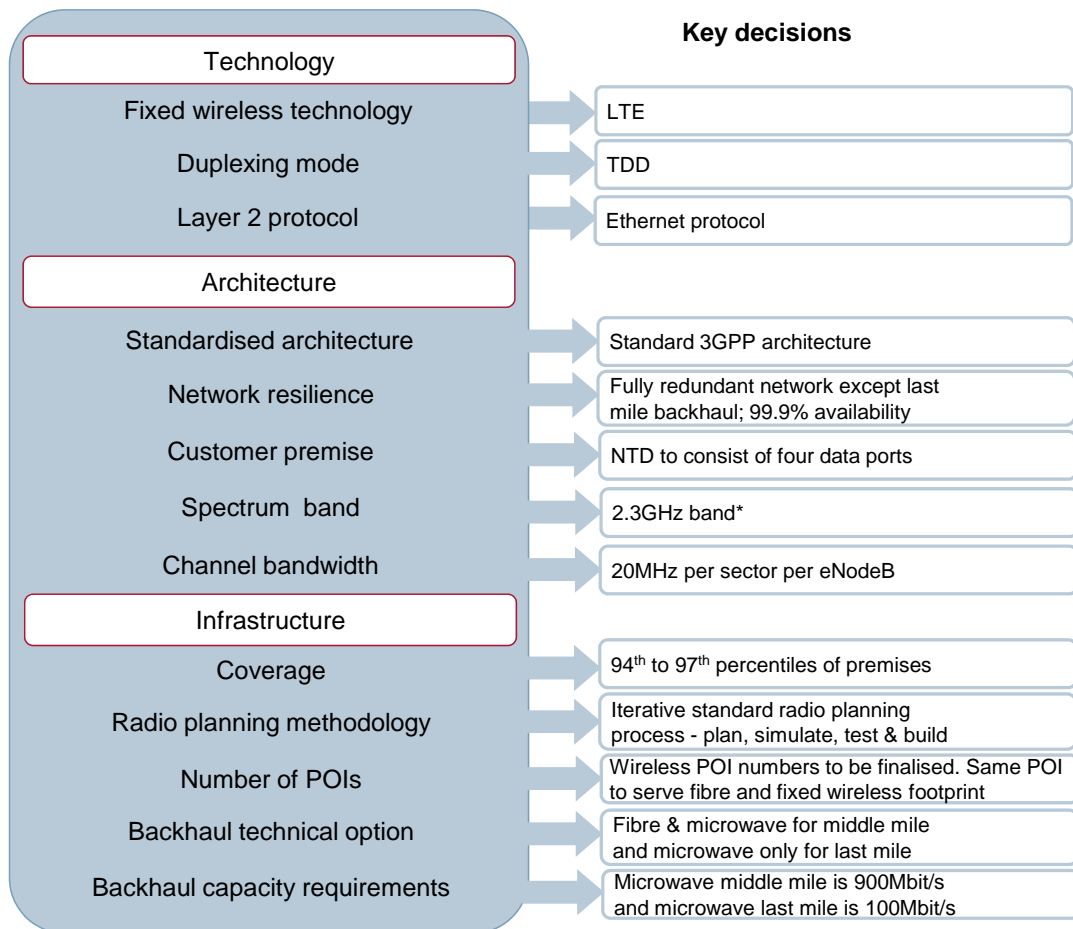
- technology:
 - LTE or WiMAX fixed wireless technology
 - FDD or TDD duplexing mode of the fixed wireless technology
 - Layer 2 protocol
- architecture:
 - standardised 3GPP or IEEE802.16 architecture
 - approach to network resilience (i.e. end-to-end service availability)
 - customer premises, including the demarcation point for the wholesale service and number of UNI-D ports on the NTD
 - the choice of spectrum to implement the wireless network
 - channel bandwidth (10MHz or 15MHz or 20MHz)
- infrastructure:
 - percentiles of premises in the last 10% of Australia to be covered by fixed wireless infrastructure
 - radio planning assumptions and methodology used to plan the fixed wireless network in order to meet service requirements
 - number of PoIs for fixed wireless services
 - technical options for both middle and last mile backhaul (i.e. fibre-only or microwave-only or a combination of both) of fixed wireless network
 - capacity requirements for both middle and last mile backhaul of fixed wireless network.

These are the design choices on which we have focused on our efficiency and prudence analysis below.

As noted in Section 5, it is also important to note that our analysis has sought to analyse each of these design choices from an efficiency and prudence perspective. However, it is the combination of these individual design choices and decisions that together determine whether the NBN Co fixed wireless network, as a whole, is efficient and prudent from a design perspective. Therefore, while we have made individual assessments of the efficiency and prudence of individual design choices and decisions (and have outlined our views on each of those elements in this Section 7), our overall conclusion on the question of whether, and the extent to which, NBN Co's design for its fixed wireless network reflects an efficient and prudent network design, is based on Analysys Mason taking a view on NBN Co's wireless network design as a whole.

Figure 7.1 below summarises the critical decisions faced by NBN Co in respect of the design of its fixed wireless network from a technology, architecture and infrastructure perspective.

Figure 7.1: Fixed wireless network – Physical network design and implementation options [Source: Analysys Mason, 2012]



*Specified by the Australian Government and implemented by NBN Co

Finally, we note that some of the key decision choices that impact upon the efficiency and prudence of the NBN Co fixed wireless network have been specified or influenced by the Australian Government in its *Statement of Expectations*. As per Webb Henderson's instructions, therefore, this report does not examine the merits of the specifications given by the Australian Government to NBN Co but rather examines the key choices or decisions that have been made by NBN Co in the design of its network within the overall parameters that have been established by the Australian Government at a policy level through its *Statement of Expectations*.

7.2 Wireless technology assessment

7.2.1 LTE versus WiMAX

Critical decision and related issues

The choice of wireless technology to deliver the required objectives and services was one of the most fundamental decisions that NBN Co must make.

As discussed in Section 4 earlier, the two future-proofed wireless technologies used to deliver fast wireless broadband are:

- LTE, developed by 3GPP
- WiMAX (worldwide interoperability for microwave access), developed by IEEE and standardised under IEEE 802.16.

Both of these technologies have FDD and TDD variants.

In order to guide our assessment regarding NBN Co's choice of TD-LTE technology, we first provide a summary of our quantitative review of worldwide LTE and WiMAX deployments (the full assessment was provided in Section 4). We then present a similar quantitative comparison of FD-LTE and TD-LTE. Finally, we provide a performance and cost comparison between FD-LTE and TD-LTE.

► *Worldwide deployments of LTE and WiMAX*

There are currently 34 LTE and 428 WiMAX (mostly small-scale niche) networks in operation. The higher number of WiMAX networks is explained by the fact that WiMAX was standardised almost four years earlier than LTE (and so is a much more mature technology). Although there are more WiMAX operational networks, most major mobile network operators are supporting LTE as their next logical step because it is a low-latency network architecture, supports backward compatibility with previous 3GPP technologies and is likely to generate significant economies of scale for equipment and end-user devices. It is expected that more than 200 large LTE networks will be deployed by the end of 2012.

Some WiMAX operators intend to begin roll-out of LTE. For example, Yota in Russia announced LTE plans in May 2010, citing the global shift towards LTE by operators. Similarly, Clearwire in the USA conducted LTE trials from late 2010 to early 2011 and is assessing the potential for LTE to co-exist with its WiMAX network. Finally, more recently, Rogers Communications in Canada announced that it was discontinuing WiMAX in favour of LTE.⁷⁹

Vendors such as Huawei and Qualcomm are also producing chipsets that are workable for both FD-LTE and TD-LTE, which is likely to lead to further growth of the LTE ecosystem. This co-existence of FD- and TD-LTE is also supported by the operators through the GTI (Global TD-LTE Initiative), and examples of FD-LTE and TD-LTE hybrid deployments are already emerging in Germany, Sweden and Denmark.

In summary, there is a global momentum towards LTE among mobile network operators and equipment vendors, and this is likely to provide a more cost-effective solution and competitive end-user services when compared to WiMAX. We expect the LTE ecosystem to experience rapid growth in the short term and even overtake the WiMAX ecosystem in the medium term.

⁷⁹ See <http://www.telegeography.com/products/commsupdate/articles/2011/12/14/rogers-shutting-down-wimax-service-in-march/>.

► *Worldwide deployments of FD-LTE and TD-LTE*

This section summarises our quantitative assessment of the FD-LTE and TD-LTE variants (the full assessment was provided in Section 4).

3GPP technologies have been predominantly FDD based and most 3GPP mobile network operators showed a preference for FD-LTE in the initial years following its release. There are currently 34 LTE operational networks, of which, only two are TD-LTE networks (launched commercially in July and September 2011). However, significant momentum has developed behind TD-LTE recently because of the asymmetrical demand for bandwidth from end users and the availability of a number of unused TDD spectrum bands.

Two of the biggest operators (China Mobile and Reliance Infotel) are currently trialling TD LTE. Reliance Infotel is likely to launch a commercial network, whereas China Mobile is reported to be planning to deploy to nearly 20 000 sites in 2012⁸⁰. Softbank in Japan has also announced plans to deploy 12 000 base stations for its TD-LTE network, to cover 92% of the country's population by next year⁸¹. Clearwire in the USA is conducting TD-LTE trials to assess whether a TD-LTE network can co-exist with its WiMAX network. TD-LTE is also attracting European operators, even though they have traditionally favoured FDD technologies. In summary, both FD-LTE and TD-LTE technologies have gained the backing of major operators and vendors, but TD-LTE now seems to be attracting more attention from operators, because its adoption by two of the biggest operators (China Mobile and Reliance Infotel) is likely to mean lower equipment prices. It should also be noted that both FD-LTE and TD-LTE technologies are considered as future-proof technologies.

► *Performance comparison of FD-LTE and TD-LTE*

Although the two variants differ slightly in terms of physical layer level configurations, TD-LTE offers similar capacity, real life performance and cell coverage to FD-LTE. TD-LTE also offers the flexibility to adjust the ratio between downlink and uplink bandwidth depending on user requirements. For example, if the user requirement is for a high downstream data rate, then more bandwidth can be allocated to the downlink. This gives TD-LTE a major advantage over FD-LTE; on FDD networks not all the allocated uplink spectrum is used, because most applications do not require a high uplink data rate. Video streaming is likely to be the main application for fast broadband, and because this requires high downlink and low uplink data rates, TD-LTE technology is ideally suited for such application.

In summary, TD-LTE technology is more aligned to the asymmetrical data requirements of end users and has the flexibility and adaptability to cope with changes in end-user requirements in future.

► *Cost comparison of FD-LTE and TD-LTE*

TDD spectrum bands are generally cheaper than FDD spectrum bands, and TD-LTE equipment is also likely to be cheaper because of the economies of scale. For the same amount of spectrum (e.g.

⁸⁰ See www.telegeography.com/products/commsupdate/articles/2011/11/23/china-mobile-steps-up-td-lte-development/.

⁸¹ See www.rethink-wireless.com/2011/11/16/softbank-china-mobile-tout-td-lte-progress.htm.

2×10MHz for FDD and 1×20MHz for TDD), both technologies offer similar bandwidth capacity. As a result, the cost per Mbps per MHz of TD-LTE is slightly lower than that of FD-LTE.

NBN Co's position

NBN Co has chosen TD-LTE technology to deliver Layer 2 wholesale services to premises in the 94th to 97th coverage percentiles (see Section 7.4 for more detail on coverage).

Analysys Mason's assessment

Analysys Mason considers that NBN Co's choice of TD-LTE to deliver Layer 2 wholesale services to premises in the 94th to 97th coverage percentiles is an efficient and prudent decision for the following reasons:

- TD-LTE is a standardised technology
- TD-LTE has a clear roadmap, capable of meeting future demand
- TD-LTE has already been deployed and several trials are underway that are giving very encouraging results
- TD-LTE will be deployed by two of the biggest mobile network operators (China Mobile and Reliance Infotel), along with Softbank, which has announced plans to deploy 12 000 base stations for its TD-LTE network, to cover 92% of the population in Japan by next year
- TD-LTE is backed by most equipment vendors and is likely to result in more competitive equipment prices
- TD-LTE devices will be able to support both TDD and FDD frequencies in the future through new chipsets currently being developed by major vendors
- TD-LTE is more aligned to the asymmetrical bandwidth demand from end users, and has the flexibility and adaptability to manage future changes in end-user requirements
- the cost per Mbps per MHz of TD-LTE is slightly lower than that of FD-LTE.

7.2.2 Layer 2 protocol

Critical decision and related issues

NBN Co is required to take a critical decision regarding the Layer 2 protocol. Ethernet is now the ubiquitous Layer 2 protocol, not only for local area networks but also for metropolitan and national area networks. Ethernet has been prescribed and recommended by a number of standards bodies (e.g. the Broadband Forum and the Metro Ethernet Forum) and regulators around the world as the preferred Layer 2 broadband access technology.

NBN Co's position

NBN Co plans to adopt Ethernet as the Layer 2 protocol to deliver its wholesale services for both the fibre network and the fixed wireless network.

Analysys Mason's assessment

Analysys Mason considers that NBN Co's choice of Ethernet as a Layer 2 protocol is both efficient and prudent, as the choice of Ethernet aligns with global standards and is a proven technology, and will facilitate competitive vendor pricing and minimises technology risk/risk of stranded assets.

7.3 Wireless network architecture assessment

Here we present our assessment of the architecture of NBN Co's wireless access network, which will provide wireless coverage to premises that fall within the 94th and 97th percentiles.

7.3.1 Architecture and customer premise assessment*Critical decision and related issues*

NBN Co needs to implement a standardised architecture for its wireless access service that can offer a uniform portfolio of products provided to access seekers. NBN Co's architecture should also have the capability to offer peak speeds of at least 12Mbps downstream if it is to meet the Government expectations.

The use of wireless technology to provide Layer 2 open-access wholesale broadband services to access seekers is still in its infancy; at the time of writing this report no such network had been deployed anywhere in the world. This is mainly because, before the advent of 4G technologies (LTE and WiMAX), wireless technologies could not provide fast broadband services.

However, it has now become a viable option to deploy high-speed broadband using 4G wireless technologies, because of its bandwidth and latency capabilities and the increasing availability of large allocations of spectrum in certain bands, as evidenced by recent and forthcoming 'digital dividend' auctions. As the deployment of fibre in rural and remote areas can be very costly, the business case for deployment of wireless technology in these areas is likely to be a more practical option.

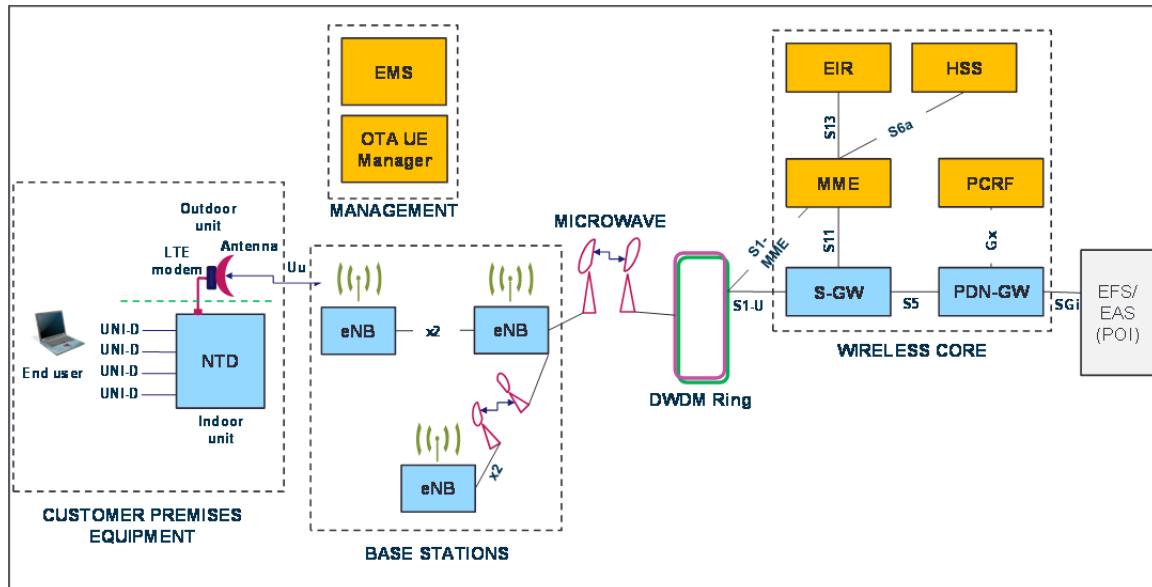
NBN Co's position

NBN Co's wireless access network will be implemented using 3GPP TD-LTE (Release 9), with microwave and fibre backhaul links, connecting the fixed wireless access network to a FAN. A tunnelling protocol, soft GRE, will be used in conjunction with LTE in order to present a Layer 2 view for NBN Co's open-access wholesale products. The full architecture comprises the following network elements (as shown in Figure 7.2 below):

- customer premise equipment
- base stations
- backhaul – microwave link and DWDM ring
- wireless access core

- management.

Figure 7.2: Wireless access network elements [Source: NBN Co, 2011]



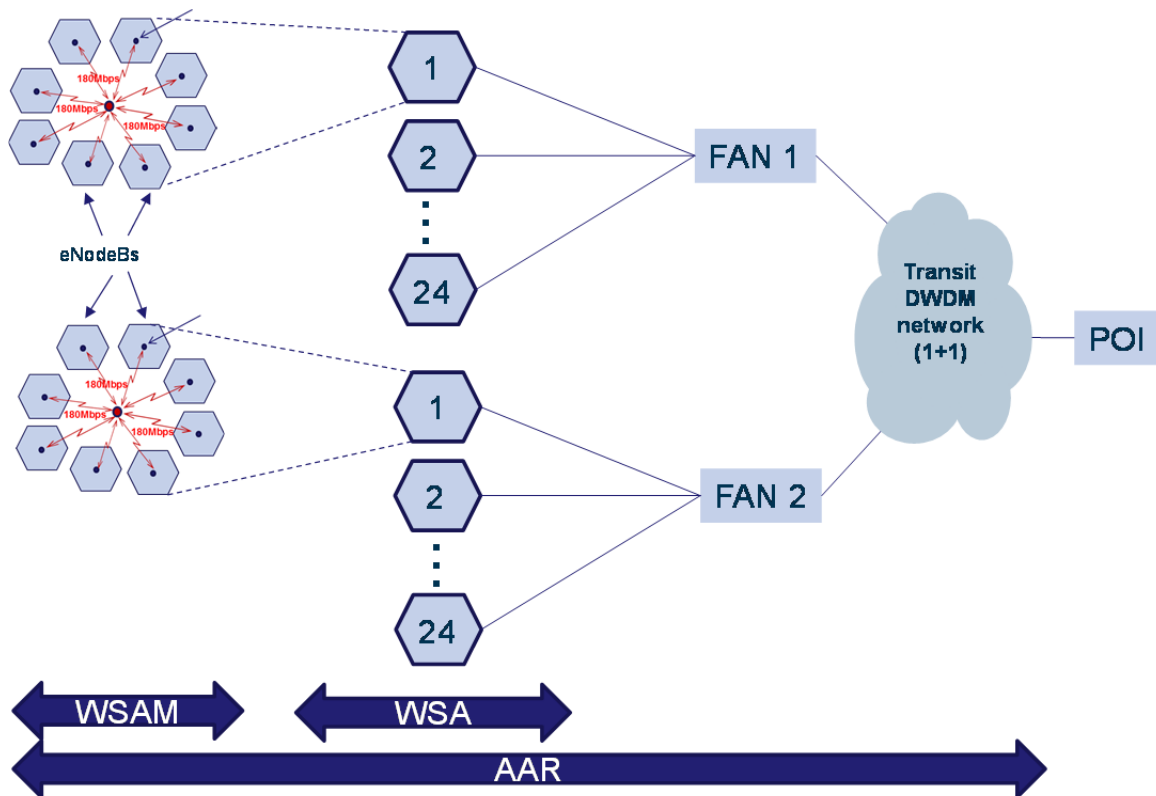
The equipment at the customer's premises will comprise an outdoor unit and an indoor unit. The outdoor unit consists of an integrated LTE modem and directional antenna that will be fixed on the roof of the premises. The indoor unit, the NTD, has four data ports (UNI-D). As opposed to the NTD used in the fibre network, the wireless NTD does not incorporate any voice user interface (UNI-V). This is because, in areas served by fixed wireless services, end-users will be provided with PSTN lines from Telstra, and therefore will not require voice service to be provided through the NBN network, in line with the Australian Government's *Statement of Expectations*.⁸² The NTD indoor unit is connected to the NTD external unit via a power-over-Ethernet cable. A universal subscriber identity module (USIM) will also be integrated within the NTD to identify each premise.

The customer's wireless equipment will communicate with enhanced Node Bs (eNodeB), which represents the base station in an LTE network. Backhaul from the eNodeB base stations will be delivered by a combination of microwave and fibre (the DWDM ring), determined on a case-by-case basis. In some cases, multiple microwave hops will be used for backhaul between base stations and the closest FAN. Generally, a microwave link will backhaul up to eight eNodeB's to a microwave hub, with microwave hops then used to transmit the signal to the nearest FAN site.

In this context, NBN Co defines a Wireless Serving Area Module (WSAM) as a cluster of **up to 8** eNodeB's and up to 24 WSAMs form a Wireless Serving Area (WSA) which will connect to a single FAN. Finally, NBN Co have also defined an Access Aggregation Region (AAR). The wireless area served by a single PoI is an AAR. The maximum number of WSAs in an AAR is determined by the number of FANs that connect back to the PoI. This is illustrated in Figure 7.3 below.

⁸² "the USO Co will fund Telstra to provide copper based phone connection for a ten year period commencing in July 2012 for those consumers wishing to continue that service. Accordingly Battery will not be required for wireless for wireless network termination units", Government Statement of Expectations, 2010.

Figure 7.3: Definition of WSAM, WSA and AAR [Source: NBN Co, 2012]



Gigabit Ethernet links will be used to connect the DWDM ring to the wireless access core.

NBN Co's proposed core network complies with Release 8 of the 3GPP standard and will comprise the following elements:

- **packet data network gateway** (PDN-GW) – provides connectivity from the wireless access network to the Ethernet switching equipment that presents the NNI
- **servicing gateway** (S-GW) – routes and forwards user data packets, to and from eNodeBs
- **mobility management entity** (MME) – responsible for idle mode user equipment (UE) tracking and paging procedure, including retransmissions
- **policy charging rule function** (PCRF) – the node designated in real time to determine policy rules in a multimedia network
- **equipment identity register** (EIR) – a database of prohibited customer devices. If a customer device is blacklisted on the EIR, it is not supposed to work with any service provider
- **home subscriber server** (HSS) – the central database that handles subscription-related information, and performs user authentication and authorisation.

The S-GW will terminate the soft GRE tunnel. The PDN-GW and the S-GW will also provide a standard 802.1ad interface to the Ethernet switching equipment.

Management of the core network will be undertaken by the element management system (EMS) and the over-the-air user equipment management server (OTA UE Manager).

The management and traffic signalling between wireless access nodes and core nodes will be transported over NBN Co's data communications network (DCN).

Analysys Mason's assessment

Analysys Mason considers that NBN Co's approach to network architecture is efficient and prudent, as NBN Co is using standardised 3GPP architecture. The deployment of TD-LTE by major operators, such as China Mobile and Reliance Infotel, will create economies of scale, and so reduce the overall cost of the solution.

Each area that is served by a wireless network will be associated with a FAN, therefore avoiding infrastructure duplication. We therefore believe that this is a prudent architecture design choice.

Layer 2 wholesale services have not previously been implemented on TD-LTE networks, and so this choice represents a technology risk. However, this risk is mitigated by the fact that NBN Co reports that current trials to deliver these products are currently performing according to specification.

7.3.2 Network resilience

Critical decision and related issues

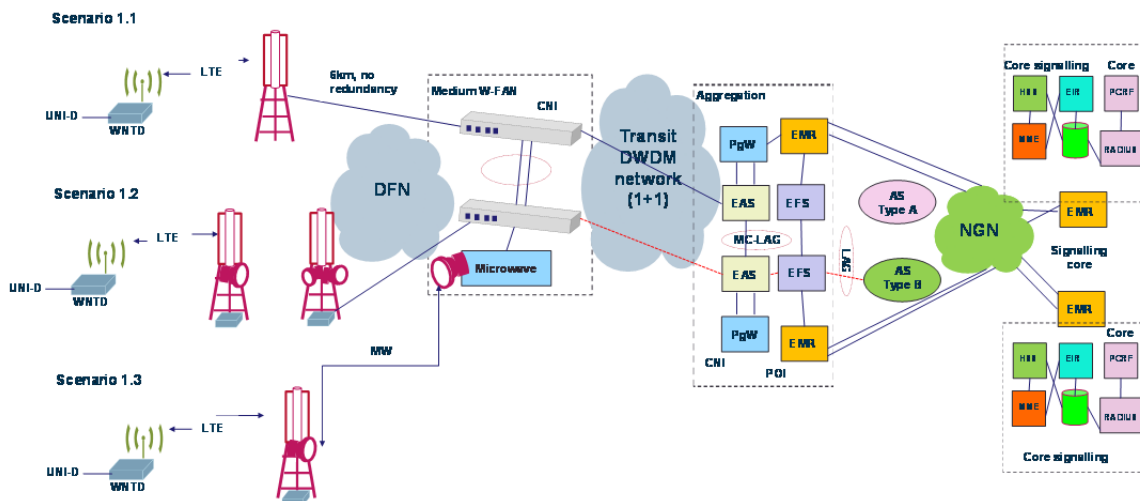
End-to-end service availability is a key factor when designing a network. It is therefore important for NBN Co to define a realistic availability target and to design its network to ensure that it will meet this target.

Different areas are likely to comprise of different technology scenarios to deliver the service (e.g. the backhaul network could be a microwave link, a fibre link, or a combination of both, depending on how close is the base station to the Fibre Serving Area). NBN Co will need to model each of these technology scenarios to ensure that, in the worst case, the availability target is still met.

NBN Co's position

NBN Co designed its wireless to meet an end-to-end availability of at least 99.9%. In order to verify that the wireless architecture will meet the target availability, NBN Co has modelled end-to-end service availability for a number of connectivity scenarios. These scenarios are depicted in Figure 7.4 below.

Figure 7.4: Reference fixed wireless network architecture [Source: NBN Co, 2012]



In their availability analysis, NBN Co shows that, the end-to-end availability with fibre-only backhaul scenarios will provide the highest service availability of all configurations considered, which was expected. Also, the analysis shows that the microwave only scenarios will provide a higher availability than that of aggregated microwave and fibre backhaul. This is because the path distance for the microwave only scenarios is relatively shorter (up to 6km) than the path distance associated with the aggregated microwave and fibre backhaul (up to 26km).

Overall, NBN Co analysis shows that the required end-to-end availability of 99.9% will be met under all analysed connectivity scenarios.

Analysys Mason's assessment

Analysys Mason considers that an end-to-end target availability of 99.9% is prudent for providing residential services with fixed wireless networks.

Although we did not review the availability model in great detail, Analysys Mason considers that the evidence produced by NBN Co indicates that the wireless network architecture will be able to deliver services that meet the end-to-end availability target of 99.9%.

7.3.3 Spectrum band and channel bandwidth

Critical decision and related issues

For any wireless network design, the availability of spectrum is often one of the first questions that arises, and it is essential to make the right choice of spectrum. Standards bodies such as the ITU, 3GPP and the WiMAX Forum have allocated a number of discrete frequency bands to facilitate frequency harmonisation by regulators and production of equipment by vendors, in order to increase volumes and therefore reduce costs. The frequency bands allocated for LTE and WiMAX by the ITU, 3GPP and WiMAX Forum are detailed in Section 4 above.

Two of the likely frequency bands for LTE in Australia are 700MHz and 2.3GHz, which both have their advantages. The 700MHz band offers a larger geographic cell range than 2.3GHz, which generally means that fewer base stations are required to meet coverage requirements. This attribute makes the 700MHz spectrum very valuable, especially in rural areas where the access network is likely to be coverage limited rather than capacity limited. According to 3GPP frequency band allocations (shown in Figure 4.6) only FD-LTE can be used in the 700MHz spectrum band.

One significant advantage of using the 2.3GHz band is that the band is available immediately for deployment of LTE in nearly all areas where NBN Co expects to deploy wireless infrastructure. The 2.3GHz band is also likely to be less costly from a spectrum pricing perspective than the 700MHz band.

Finally, it should be noted that the choice of spectrum also dictates the technology choice, because according to the 3GPP's allocation of LTE bands 700MHz is for FDD and 2.3GHz is for TDD (see Figure 4.6).

NBN Co's position

In its *Statement of Expectations*, the Government noted: *"In support of the fixed wireless solution, the Government expects NBN Co to acquire suitable spectrum on commercial terms but not compete in the auction of 700MHz spectrum."*

To comply with this requirement, NBN Co has chosen the 2.3GHz spectrum band for deployment of its TD-LTE network to provide wholesale services to access seekers. In this context, in February 2011, NBN Co acquired spectrum in the 2.3GHz and 3.4GHz bands from AUSTAR for AUD \$120 million.⁸³ Moreover, in July 2011, NBN Co paid AUD \$1.3 million to acquire additional spectrum in the 2.3GHz band at an auction run by the Australian Communications and Media Authority (ACMA) to complement the spectrum⁸⁴ it had previously acquired for its LTE network.

Initial radio network design, testing and trials have been carried out using the 2.3GHz spectrum band, and it has been confirmed that the 2.3GHz band will be used for the deployment. Currently, the 3.4GHz spectrum band could also serve as a potential LTE deployment band.

NBN Co's current 2.3GHz spectrum band licence is due to expire on 24 July 2015 and NBN Co will need to retain access to this spectrum band to maintain continuity in the supply of fixed wireless services.

To this end, we note that the Minister for Broadband, Communications and the Digital Economy has recently issued a draft determination pursuant to section 82(3) of the Radiocommunications Act 1992

⁸³ www.nbnco.com.au/news-and-events/news/nbn-co-acquires-austar-spectrum-for-rural-and-regional-network.html.

⁸⁴ www.nbnco.com.au/news-and-events/news/spectrum-win-brings-wireless-broadband-to-rural-areas.html.

(Cth),⁸⁵ which identifies (amongst others) “*wireless broadband services provided in the 2.3 GHz spectrum band (frequency range 2302-2400 MHz)*” as a class of service (amongst others) for which re-issuing spectrum licences to the same licensees would be in the public interest.⁸⁶ The draft determination is currently subject to consultation.

The issue of whether any particular spectrum licence is re-issued to the incumbent holder remains a matter for decision by the ACMA. Section 82(1) of the Radiocommunications Act provides that ACMA may, without following the allocations procedures under section 60, re-issue a spectrum licence to the person to whom it was previously issued if the licence was used in the provision of a service included in a class of services specified in a determination under section 82(3), or ACMA was satisfied that special circumstances existed as a result of which it was in the public interest for NBN Co to continue to hold the licence.

Analysys Mason's assessment

Analysys Mason considers that NBN Co's spectrum choice is efficient and prudent for the following reasons:

- 2.3GHz spectrum is a band that 3GPP has standardised for TD-LTE
- China Mobile and Reliance Infotel will use 2.3GHz spectrum for their TD-LTE networks, which will generate significant volumes and so drive down the price of equipment and end-user devices
- 2.3GHz spectrum for TD-LTE is being supported by major network operators and equipment vendors worldwide
- NBN Co cannot compete in the 700MHz band auction in 2012 and in any case this spectrum will only be available for deployment in 2014
- 2.3GHz spectrum has successfully been acquired by NBN Co. The Minister for Broadband, Communications and the Digital Economy has recently issued a draft determination pursuant to section 82(3) of the Radiocommunications Act 1992 (Cth), which would assist NBN Co in its application to ACMA for the re-issuance of that spectrum to NBN Co.

7.4 Wireless network infrastructure assessment

7.4.1 Wireless access network design

In order to assess NBN Co's coverage and access network design we have considered two criteria:

- the methodology used to define wireless geographical area boundaries
- the radio planning methodology.

⁸⁵ Section 82(3) of the Radiocommunications Act 1992 (Cth) provides that the Minister for Broadband, Communications and the Digital Economy may, by written instrument, determine a specified class of services for which reissuing spectrum licenses to the same licensees would be in the public interest.

⁸⁶ Radiocommunications (Class of Services) Determination 2011. See, http://www.dbcde.gov.au/__data/assets/pdf_file/0016/144214/Draft-determination-under-subsection-s82-3-of-the-Radiocommunications-Act-1992.pdf.

Critical decision and related issues

► *Methodology to define wireless geographical area boundaries*

Providing broadband to the last 10% of premises is the most expensive part of the deployment per premises, and the use of only one technology platform for the deployment is not usually the most cost-effective option. For NBN Co, the last 10% of premises will be covered by three main technology platforms: fibre, wireless and satellite. In the same way as the fibre footprint was specified, the footprint of the wireless network needs to be defined using a methodology to ensure that the marginal cost per additional premises remains prudent. In this regard, we note that the *Statement of Expectations* provides that “it is cost effective to deliver peak speeds of at least 12 megabits per services via a fixed wireless solution from the 94th to 97th coverage percentiles” and the Australian Government has requested that NBN Co “provide this network”.

► *Radio planning methodology*

A radio planning exercise must be carried out to estimate the number of base stations needed to provide:

- the required wireless coverage
- the required service characteristics in terms of bandwidth.

Radio planning is an iterative process, and generally consists of the activities listed in Figure 7.5.

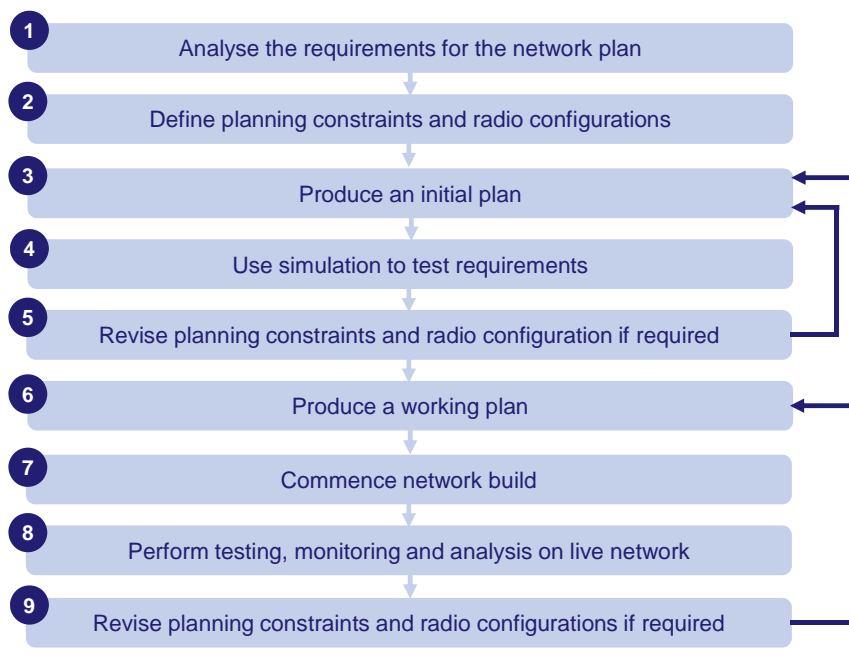


Figure 7.5: Radio planning activities
[Source: Analysys Mason, 2011]

Each of these activities is briefly described below:

1. **Analyse the requirements for the network plan** – a set of design criteria must be set out at the start of planning process, generally including five key factors: coverage, capacity, quality of service, timescale and cost.

2. **Define planning constraints and radio configurations** – for all radio planning exercises, there are constraints that need to be taken into account as they will have a significant impact on the plan. The most influential constraints are generally regulatory (e.g. licensing, spectrum availability and transmission power of base stations), technological (e.g. spectral efficiency and channel size) and budgetary.
3. **Produce an initial plan** – a desktop exercise is carried out by developing a link budget that adheres to the constraints defined in the previous activity. A suitable empirical propagation model needs to be chosen to estimate the cell range of a base station.
4. **Use simulation to test requirements** – a suitable radio planning simulator should be used in order to tune the propagation model. This is essential in order to obtain more accurate coverage predictions, because the propagation of radio signals varies depending on the climatic conditions for instance. Subsequent simulations should be run to check whether the initial plan is meeting the requirements.
5. **Revise planning constraints and radio configuration if required** – if simulation results show that the requirements will not be met by the initial plan, then planning constraints (e.g. the need for more spectrum) and radio configuration (e.g. the use of a different technology) can be revised. If any of the constraints or radio configuration is amended, then another initial plan will need to be produced to reflect those changes. If no changes are made to either the planning constraints or the radio configuration, a working plan can be developed. As shown in Figure 7.5, this is an iterative activity, and the planning constraints and radio configuration may need to be revised a few times before satisfactory results are obtained.
6. **Produce a working plan** – following simulations and the revision of planning constraints and radio configuration, a full working plan can be developed. The working plan will include details of the base stations, such as the number required (both newly built and co-located), locations, transmission powers, operating frequencies and antenna heights.
7. **Commence network build** – the network will be built in several phases, and testing should be performed after each phase to compare the theoretical outputs with practical outputs.
8. **Perform testing, monitoring and analysis on live network** – after deployment of the first phase of the network, a radio coverage survey should be performed over a period of several days, to ensure that a high volume of signal samples is taken. Data analysis should be carried out to verify that the planned network is meeting the requirements.
9. **Revise planning constraints and radio configurations if required** –if results from the previous activity show that the planned network is meeting the requirements, then other phases of the planned network can be deployed. Otherwise, the plan needs to be revised, as shown in Figure 7.5.

NBN Co's position

► *Methodology to define wireless geographical area boundaries*

In its *Statement of Expectations*, the Government mentioned: “*The Government has agreed that it is cost effective to deliver peak speeds of at least 12 megabit/s services via a fixed wireless solution from the 94th to 97th coverage percentile*”.

In order to validate the Government's statement, NBN Co has used the same methodology it used to derive the fibre footprint in order to derive the optimum coverage for the fixed wireless infrastructure. It considered the incremental cost per premises of extending the wireless footprint while ensuring that the cost remained prudent for any additional premises covered.

In its analysis, NBN Co concluded that serving the 94th to the 97th percentiles of the population with fixed wireless infrastructure was optimum in terms of the marginal costs incurred per additional premises.

The coverage range of the wireless network is in line with Government expectations.

► *Radio planning methodology*

A radio planning exercise requires highly specialised resources, and so NBN Co has outsourced this activity to Ericsson.

Before we describe the methodology for planning the network, it is important to define average busy-hour throughput (ABHT). Since the wireless access network is a new network and NBN Co is unable to give empirical evidence to determine expected speeds, it uses ABHT to represent the worst-case (i.e. the minimum speed experienced by a premises). In defining ABHT, NBN Co assumes that all premises in a particular cell are active simultaneously. Also, in its ABHT definition, NBN Co has assumed that, on average, 200 premises would be covered in each cell and that 30% of these premises (i.e. 60 premises on average) will take up the service from a service provider.⁸⁷ In practice, it is unlikely that all 60 premises in a given cell will be active at the same time, and so the speeds experienced by each premise are likely to be significantly higher than the ABHT.

To meet the speed objective set by the Government, the network has been dimensioned with the following ABHT:

- 500kbps for the downlink
- 150kbps for the uplink.

In the following subsections we describe each radio planning activity (classified using the structure shown in Figure 5.34 earlier) that has been carried out to date.

⁸⁷ For the purposes of this calculation, NBN Co has assumed a take up of 30% to be able to balance higher and lower levels of take up in different areas to be able to accommodate the 20% forecast average.

Requirements of network plan

NBN Co has set the following targets for design of the access network:

- in an unloaded cell the end-to-end system shall support a downlink throughput of at least 12Mbps for each premise anywhere in the cell coverage area (95% probability)
- the number of active premises in a cell shall be constrained such that the end-to-end system supports a downlink throughput of at least 500kbps for each premises anywhere in the cell coverage area
- the number of active premises in a cell shall be constrained such that the end-to-end system supports an uplink throughput of at least 150kbps for each premises anywhere in the cell coverage area
- wireless outdoor coverage is to be provided to all premises that fall in the 94th to 97th percentiles of the population of Australia.

Initial radio plan with planning constraints and radio configurations

Based on the previous design targets, two LTE link budgets have been developed to estimate cell ranges for three main clutter classes (suburban, rural and open) for the planned LTE network. Most of the wireless deployment is expected in rural and suburban areas. Both PIR and CIR (during busy hours) link budgets have been developed using the following assumptions:

- base station height is 40m
- user equipment height is 5m
- operating frequency is 2.3GHz
- channel size per sector is 20MHz and three sectors per base station
- downlink-to-uplink configuration is 3GPP Configuration 1 (3:2 ratio)
- propagation model is Ericsson's in-house Hata model
- cell is unloaded.

The proposed frequency plan is to re-use three frequencies across the network; that is, each of the three sectors of a base station will have a unique channel.

The intention is to use as many existing sites as possible for the wireless network to reduce deployment costs but this will be subject to commercial agreements.

Initial radio plan with planning constraints and radio configurations (cont'd)

NBN Co's calculation shows that a range of cell sizes (5.8km to 6.8km) have been estimated. The smaller cell range represents slightly denser areas (with Sydney Metro being the most dense area in the construction zone). The initial radio plan assumes an average cell range of 6.6km.

The calculation shows that a range of cell sizes between 2.4km and 21.23km (depending on clutter classes) can be achieved theoretically. The cell sizes are within the range of NBN Co estimated cell size ranges.

Simulations to test requirements

As described earlier in this section, NBN Co is planning the capacity of the network using the following assumptions:

- average number of premises covered per cell: 200 premises
- average take-up of the service: 30%⁸⁸ of premises
- ABHT (downlink): 500kbps
- ABHT (uplink): 150kbps.

When planning Layer 1 capacity, it is important to account for bandwidth overheads at Layer 2. Through simulations, it has been estimated that the total average Layer 2 capacity per cell would be 36.6Mbps for the downlink and 9.1Mbps for the uplink, assuming premises within the cell were evenly distributed. In practice, active premises do not necessarily have an even distribution within a cell area, and so this will affect the data throughput experienced by end users. If take-up is higher than 30% of premises in some areas, for example, in slightly more dense areas, the ABHT may not be achieved. For these denser areas, two options for providing the required ABHT capacity have been proposed:

- use an extra channel from current spectrum licences to deploy a capacity overlay
- add base stations.

Revision of planning constraints and radio configurations

Six areas (Ballarat, Armidale/Tamworth, NE NSW/SE QLD border, Mildura, Broken Hill and Darwin outlying areas) are being used by NBN Co as experimental areas to collect data points from the deployed base stations. These areas are all different and therefore are characterised by different clutter classes that are representative of Australia due to varying temperatures. Within these areas, 32 site locations are being used for data collection and some RF engineers from NBN Co participated in data collection activities in Mildura, which is located in one of the sampled areas.

NBN Co is using the Mentum Planet radio planning tool to tune propagation models for nine different clutter classes (each corresponding to a different geotype) that are outside the fibre serving areas (FSAs). Data analysis shows that mean square error and standard deviation values are below the globally accepted threshold of 8dB.

Some test results show that the network infrastructure is behaving according to specifications, and demonstrate that cell ranges between 11km and 14km are achievable, depending on the clutter classes tested. However, these cell ranges are for clutter classes that represent primarily line-of-sight areas.

⁸⁸ An average of 60 premises per cell.

Analysys Mason's assessment

► *Definition of wireless geographical area boundaries*

As discussed before, Analysys Mason considers that the methodology used by NBN Co to determine the boundary limits between premises served by the fibre network and those served by the fixed wireless network is both prudent and efficient, as it will ensure that a maximum number of end users are covered by the FTTP network, while at the same time not resulting in NBN Co incurring disproportionate costs in the relevant circumstances. We consider this overall approach provides an efficient basis for determining where the fibre footprint stops and where the fixed wireless footprint starts. Using this process, NBN Co has derived lower and upper bounds for fixed wireless coverage of the 94th and 97th percentiles, which is fully in line with the Australian Government's *Statement of Expectations*.

► *Radio planning methodology*

Initial radio plan with planning constraints and radio configurations:

- We have not been able to fully assess the link budgets developed for NBN Co because some parameters (e.g. the modulation scheme and coding rate assumed at the cell edge for both downlink and uplink) and the underlying calculations of the link budgets were not available for review.
- We have therefore developed our own link budget for comparison purposes. Based on this comparison, we consider that the cell ranges that have been proposed are prudent theoretical estimates as they are slightly more conservative than our own estimated ranges⁸⁹.
- NBN Co's plan to add further base stations and/or channels where the network becomes capacity limited represents best practice and is therefore prudent.
- We also believe that using a three-frequency network plan instead of a single-frequency network is optimal and prudent, as this will give more uniform coverage across a cell and will not create co-channel interference in the cell.

Simulations to test requirements:

- A radio planning tool, together with parameters from the initial plan, has been used to run simulations to verify whether NBN Co's initial plan will meet the requirements. Simulation results show that the average Layer 2 downlink and uplink capacities per cell are 36.6Mbps and 9.1Mbps, based on an even distribution of premises. We believe that these capacities are achievable if a 2×2 multiple-input multiple-output (MIMO) scheme is used for the antennae in a 20MHz channel.

⁸⁹ The link budget developed by Analysys Mason is shown in Annex B

- We note that the overall Layer 2 capacity available per cell will provide the required ABHT of 500kbps and 150kbps per premises, assuming 200 premises covered per cell and a service take-up of up to 30%. However, in practice simulation results will not be 100% achievable and rigorous testing of achievable data throughput needs to be carried out (under different conditions) before the network plan is complete.
- Nevertheless, some early test results do show that the solution is meeting the requirements. NBN Co is planning to implement a fixed wireless network in six first release locations across Australia during 2012, in order to confirm and further 'fine tune' its planning parameters, along with systems and processes.

Revision of planning constraints and radio configurations:

- NBN Co's approach of using a wide variety of geographical areas for testing and data collection is prudent. This approach ensures that more realistic parameters and propagation models will be obtained for radio planning.
- We consider the choice of the Mentum Planet radio planning tool for radio propagation model tuning to be prudent, as this tool is used by a majority of operators worldwide. We believe that the results obtained so far are positive, because the mean square error and standard deviation values are below the globally accepted threshold of 8dB.
- Although some early test results showed that cell ranges between 11km and 14km are achievable in practice, they represent predominantly line-of-sight areas. More tests need to be carried in other clutter classes (where line-of-sight is not predominant). The cell ranges for non-line-of-sight areas are expected to be smaller and thus require more base stations to meet the requirements.

Conclusion:

- Analysys Mason considers that NBN Co has followed a rigorous and best-practice planning methodology to design the wireless access network, and therefore considers this approach to be prudent.
- Testing results show that the estimated cell ranges are prudent. We also believe that the implementation of six 'first release' sites across Australia during 2012 is a prudent step to help further fine-tune the planning parameters (as well as systems and processes) before mass deployment.

7.4.2 Core network design

Critical decision and related issues

Three factors must be taken into account when assessing the design of the wireless core network:

- the core network design
- the number of PoIs for fixed wireless services
- resilience and availability.

► *Core network design*

In order to support interoperability between potential different network elements and different NTDs, NBN Co must ensure that the wireless core network is compliant with 3GPP standards. Ensuring that the network design and architecture are compliant with the 3GPP standards will also allow the use of high-volume (and hence more-competitively priced) equipment.

► *Number of PoIs for fixed wireless services*

NBN Co's wireless network is intended to provide coverage to rural areas. By definition, the majority of rural areas served by fixed wireless infrastructure will be in a connectivity serving area (CSA) served by a regional PoI⁹⁰. Therefore, it can be expected that the total number of PoIs used to connect to areas served by fixed wireless infrastructure will be significantly smaller than the total number of PoIs.

► *Core network resilience and availability*

The core network must meet minimum network availability objectives to ensure an acceptable level of quality of service, connectivity and latency. The loss of core network functionality is likely to affect more users than the loss of an element in the access network, which only affects the users connected to the base station in that area. Traditionally, core telecoms equipment is manufactured to 99.999% availability, which represents a high level of availability. The end-to-end availability of services is significantly impacted by the configuration of the entire network (e.g. it will depend on whether major network nodes are redundant).

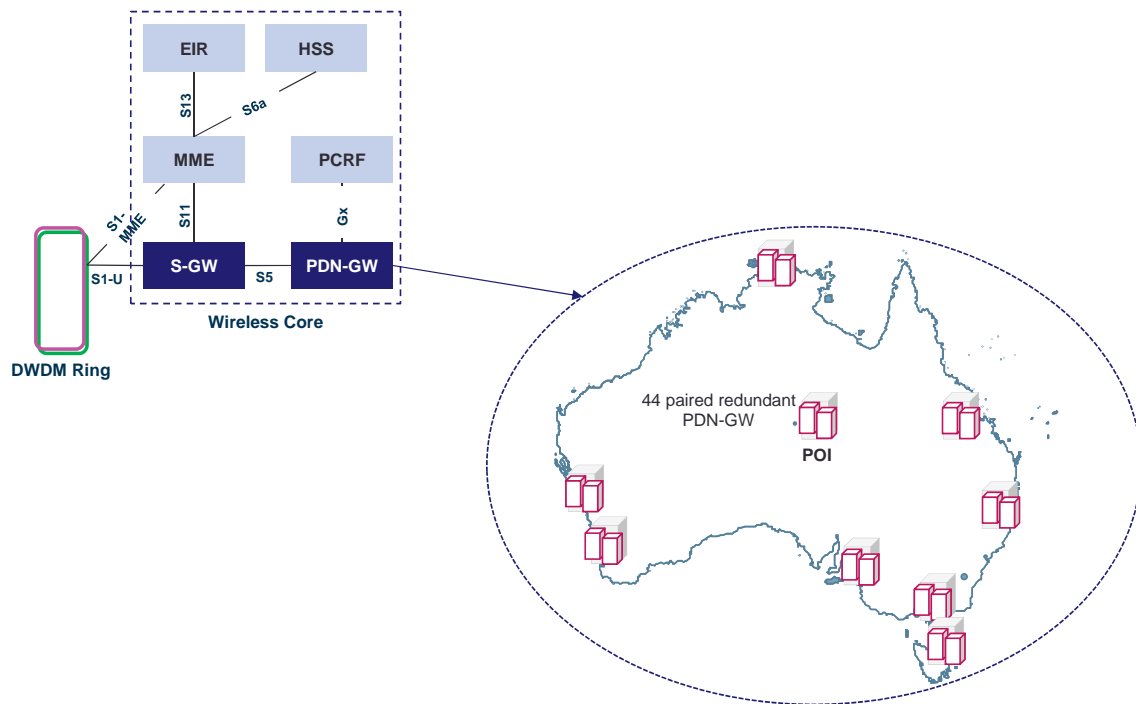
NBN Co's position

► *Core network design*

NBN Co plans to implement a wireless core network in line with the 3GPP standards (Evolved Packet Core 3GPP Release 8/9), containing the elements and architecture shown in Figure 7.6 below. (These elements were described in detail in Section 7.3.)

⁹⁰ Some rural areas will also be served by Outer metro Pols, but no rural area will be served by Metro Pols.

Figure 7.6: Architecture of wireless core network, showing paired PDN-GWs [Source: NBN Co, 2011]



The wireless core network is intended to aggregate all traffic from the wireless access network that comes via the FAN sites. The core is also responsible for ensuring and managing the overall operation of the LTE network. As it represents the interface between the wireless user traffic and the backhaul, reliable operation of the wireless core network and its inter-operability are important to NBN Co.

► *Number of PoIs for fixed wireless services*

NBN Co is currently in the process of finalising the number of PoIs that it will use to serve wireless users within the Wireless Serving Areas. These PoIs will be the same PoIs that are used to provide connectivity to wholesale serves in the fibre footprint.

At the PoI, the NNI provides the handover point for user data traffic from the wireless network to the local access seeker's network. The PDN-GWs are modular and can be scaled over time from a 'mini' configuration (serving 5000 premises) to a 'large' configuration (serving 25 000 premises), as the number of activated premises increases.

► *Core network resilience and availability*

In order to achieve a high end-to-end availability, each of the wireless-serving PoIs that NBN Co is currently planning to use will contain paired PDN-GWs so that the gateways do not present a single point of failure, thereby achieving the requirements for resilience and latency in the network. In addition, each PDN-GW in the pair will have its own internal resilience for the controller, traffic and line cards. In greater detail, the PDN-GW will have two 4×10 GE interfaces to the aggregation domain (via the Ethernet aggregation switch) and two 4×10 GE interfaces to the PoI aggregation switch pair, thus ensuring resilience in network connectivity.

Two wireless core network centres will be implemented in Sydney and Melbourne, and these will contain the necessary management and signalling network elements such as MMEs, HSS, EIR and PCRF. It should be noted that MMEs will operate as a pool of resources. Thus, if the MME fails in one location, the MME in another location will take over seamlessly.

For more details on end-to-end system availability, please refer to Section 7.3.2.

Analysys Mason's assessment

Analysys Mason considers that NBN Co's development of a core wireless network based on 3GPP standards is prudent, as this will ensure that different network elements from several vendors inter-operate. Adopting a standardised approach will also minimise costs because of the large volumes that are generated worldwide,⁹¹ and we therefore believe that this is also an efficient design.

NBN Co is currently in the process of finalising the number of PoIs that it will use to serve wireless users within the Wireless Serving Areas. These same PoIs will also serve as fibre PoIs.

We believe that using the same PoI for both the fibre footprint and the fixed wireless footprint will reduce duplication in the infrastructure and will therefore be more efficient than using separate PoIs for the fibre and fixed wireless footprint. The same argument is valid for the transit network, which will be used for both the fibre footprint and the fixed wireless footprint.

We believe that NBN Co's approach to core network scalability is prudent; the 'modular' PDN-GW will enable NBN Co to invest in line with traffic demand, and avoid over-investment.

We also believe that the use of redundant 1+1 PDN-GWs at every PoI site is prudent. The duplication of wireless network elements (MME, HSS, EIR, PCRF, DNS/DHCP, etc.) in Sydney and Melbourne will also be vital in achieving the target availability set out by NBN Co.

⁹¹ Assuming all operators adopt a standardised approach.

7.4.3 Backhaul network design

Critical decision and related issues

In order to assess the backhaul, we concentrate on two key characteristics of the backhaul network design:

- technical options and design
- capacity requirements.

► *Technical options and design*

NBN Co needs to decide which backhaul technology will be used between wireless access networks and their nearest FAN sites. When making this decision, NBN Co has to consider the evolution in capacity requirements as well as the capex and opex associated with the solution. It should be noted that a technology may be cost effective and provide enough capacity in the short to medium term, but in the long term, it may have to be swapped for a technology that supports higher capacities, depending on the demand growth from each customer and on the overall rise in service take-up.

There are a number of technical options for backhaul connectivity between base stations and their FAN sites. For LTE networks, two main options are typically available:

- fibre-based backhaul
- microwave-based backhaul.

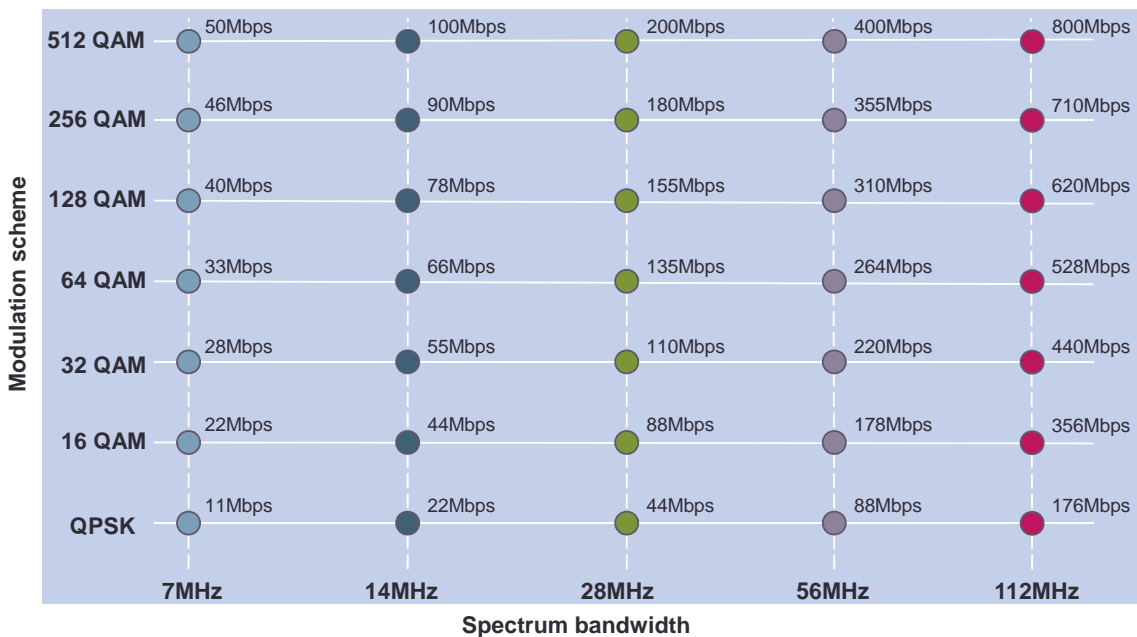
In general, fibre backhaul technology provides higher bandwidth scalability than microwave backhaul, but fibre-based solutions are more expensive than microwave. This is because installation of fibre requires extensive civil works, especially if no infrastructure (ducts or poles) exists between the base station (eNodeB) and the point of aggregation.

Also, the availability of a fibre-based backhaul solution is greater than that associated with a microwave solution. This is because the availability of a microwave solution is weather dependent, whereas underground fibre is not usually affected by external conditions.

Microwave backhauling

A key property of microwave systems is that the bitrate depends on the modulation scheme used – the higher the modulation scheme, the higher the bitrate. However, the use of modulation scheme is dependent on the received signal-to-noise ratio (SNR), and a high modulation scheme requires a high SNR. Therefore, using a higher modulation scheme will typically reduce the distance that can be covered by the microwave link. Figure 7.7 below provides an illustrative example of the expected throughput of current microwave systems, as a function of the modulation scheme and spectrum bandwidth available.

Figure 7.7: Microwave capacity [Source: Analysys Mason, 2011]



From Figure 7.7, it can be seen that for a 180Mbps microwave backhaul, at least 28MHz of spectrum is required at 256 QAM.

When specifying and choosing the microwave equipment solution, it will also be very important to understand the target link availability that NBN Co is willing to consider; that is, the proportion of the time the link is in operation. In practice, lower-order modulation schemes provide better availability over a longer operation time, because they require a lower SNR in order to be correctly detected. This is illustrated in Figure 7.8, which also shows the impact of the weather on availability.

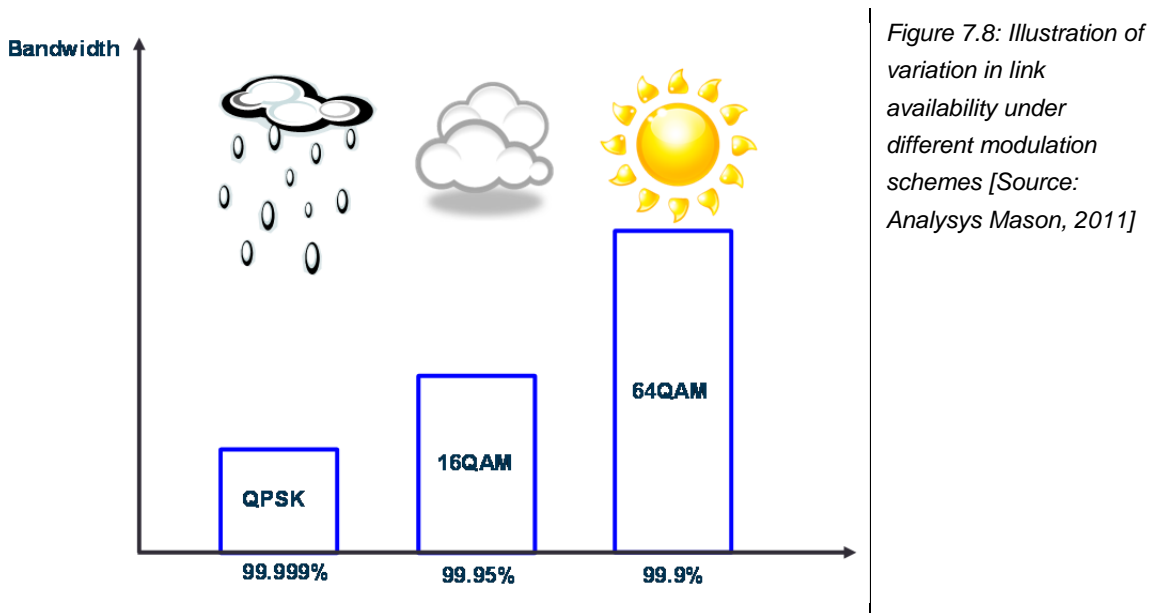


Figure 7.8: Illustration of variation in link availability under different modulation schemes [Source: Analysys Mason, 2011]

As shown in Figure 7.8, QPSK modulation provides the highest availability, even in poor weather conditions. However, as shown in Figure 7.7 earlier, QPSK provides the lowest bandwidth.

Therefore, there is a trade-off that must be made between system availability and bandwidth provided by the system.

Finally, it should be noted that many microwave systems available in the market use cross-polarisation interference cancellation (XPIC), which involves sending two separate signals (one with a polarisation on the X axis and one with a polarisation on the orthogonal Y axis). XPIC enables a reduction in the amount of spectrum required to transmit a targeted capacity.

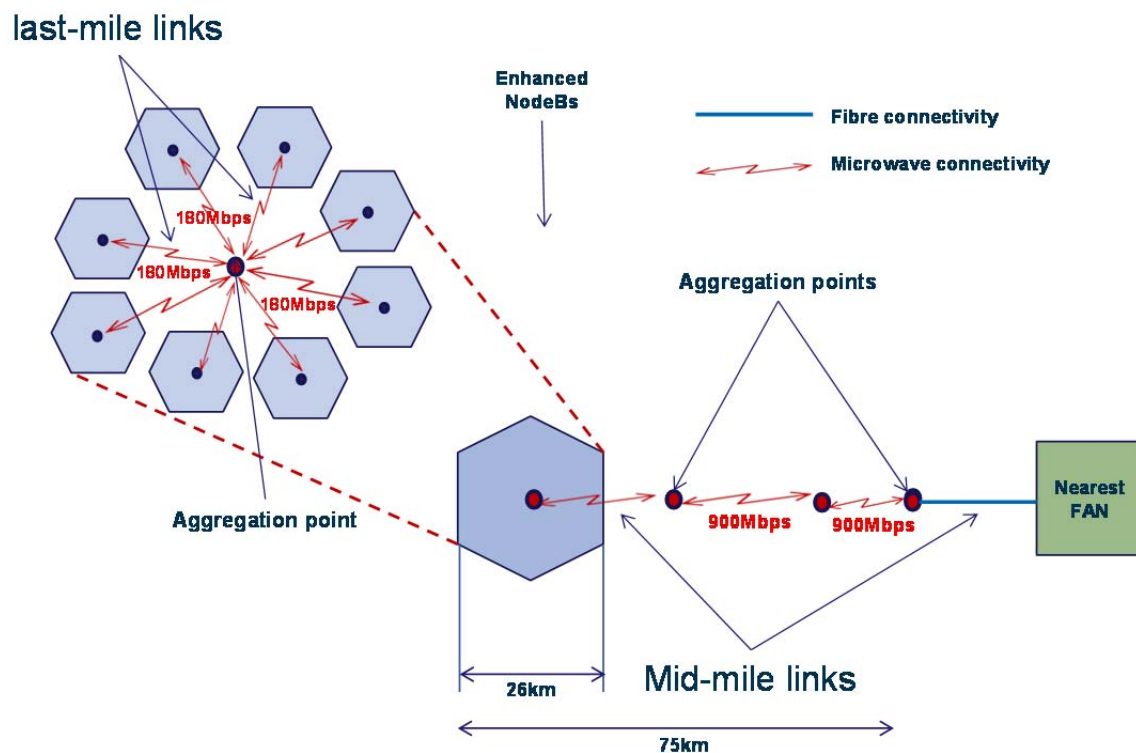
Fibre backhauling

Fibre is the most scalable transmission medium used in telecoms systems. As an example, 10Gbps can be transmitted over long distances (more than 50km) without any regeneration or amplifications.

► *Mid-mile and last-mile backhaul links*

In this report, we differentiate between mid-mile and last-mile backhaul, as shown in Figure 7.9.

Figure 7.9: Definition of mid-mile and last-mile backhaul in a 3GPP LTE network [Source: Analysys Mason and NBN Co, 2011]



Typically, the **last-mile backhaul connectivity** connects an eNodeB to an aggregation point in the aggregation network. This is achieved through a physical star topology, with all eNodeBs connected directly to the aggregation point.

The **mid-mile backhaul connectivity** connects the aggregation points to the core network. The mid-mile network is often referred to as the *aggregation network*.

Fibre backhaul is mostly used for the mid-mile network, where the traffic from several eNodeBs is aggregated, creating high bandwidth requirements. With the growth in demand for mobile and fixed wireless broadband data, fibre backhaul is being extended closer to the base stations (the last mile backhaul), as fibre provides greater capacity scalability.

However, the drawback associated with fibre based backhaul is the high civil works costs associated with such deployments, which makes fibre backhauling less attractive for last mile backhaul.

► *Capacity requirements*

When dimensioning the backhaul capacity for wireless sites, two factors have to be considered:

- the backhaul capacity must allow the minimum bandwidth per end-user (ABHT) to be achieved
- the backhaul capacity must include some provision for growth in the number of active users, as well as an increase in the bandwidth required by individual users.

NBN Co's position

► *Technical options and design*

NBN Co plans to use a maximum of four microwave backhaul hops to connect wireless base stations to their nearest FAN sites, and to use fibre from FAN sites to the core network as shown in Figure 7.9.

Microwave backhaul

The proposed frequencies to be used for microwave (in order of preference) are 11GHz, 7GHz and 18GHz, and the spectrum licences will be obtained on a site-by-site basis. Two microwave transport configurations will be used for the backhaul, as illustrated below:

- **Configuration 1 (last mile backhaul)** – a configuration which is suitable for end-site and repeater site applications; that is, last-mile backhaul, linking an eNodeB to an aggregation transmission site.
- **Configuration 2 (mid mile backhaul)** – a configuration which is suitable for medium-sized hub sites; that is, mid-mile backhaul.

Capacity requirements

► *Capacity requirements for Configuration 1*

For Configuration 1, a **minimum bandwidth** will be required to support the ABHT of 500kbps for the downlink and 150kbps for the uplink. In the worst case, 60 premises are assumed to be active per sector, and so in a three-sectored cell site 180 premises could be active simultaneously.

Considering the Layer 2 downlink speed requirements and the 15% overhead required between Layer 1 and Layer 2, the backhaul to each eNodeB should support a minimum of:

- Minimum Configuration 1 link capacity = $180 \text{ premises} \times 0.5\text{Mbps} \times 115\% = 103.5\text{Mbps}$.

Therefore, a minimum of 103.5Mbps has to be provided to each base station to ensure that, in the worst case, all active premises have a minimum bandwidth of 500kbps for the downlink and 150kbps for the uplink.

When calculating the **maximum backhaul bandwidth requirements**, the peak cell capacity should be considered as a cell that will never exceed its peak capacity, irrespective of the number of active premises in that cell. The ideal peak capacity per sector using a 20MHz channel (TDD sub-frame Configuration 1 and 2x2 MIMO scheme) is 83.5Mbps at the physical layer⁹², which corresponds to approximately 70Mbps of useable bandwidth (assuming 15% overhead). NBN Co expects to achieve a peak capacity per sector of 60Mbps in practice. This has been confirmed by field tests. Therefore, NBN Co has planned the maximum capacity per eNodeB to be:

- Maximum Configuration 1 link capacity = $60\text{Mbps} \times 3 \text{ sectors} = 180\text{Mbps}$.

NBN Co plans to provide 180Mbps for all configuration 1 links (last mile link) to ensure that the maximum capacity offered by LTE cells can be backhauled.

► *Capacity requirements for Configuration 2*

NBN Co has dimensioned its mid-mile microwave links (Configuration 2) in such a way that it will always support the minimum capacity required to meet the ABHT in each backhauled sites. For example, if the mid-mile link backhauls 3 different eNodeB, each with three sectors, the capacity that will be provided by the mid-mile link will be:

$$\begin{aligned} \text{Configuration 2 link capacity (for 3 eNodeB)} &= 3 \times \text{Minimum Configuration 1 link capacity} \\ &= 3 \times 103.5\text{Mbps} \\ &= 310.5\text{Mbps} \end{aligned}$$

NBN Co assumes that a single mid-mile link (configuration 2) may backhaul the capacity for up to eight eNodeBs as illustrated in Figure 7.9. Using the above dimensioning rule, 8 eNodeBs will require a backhaul capacity of 828Mbps ($8 \times 103.5\text{Mbps}$). For such a link, NBN Co plans to provide planned capacity of 900Mbps of capacity, which represents a 10% contingency with regards to the above dimensioning rule.

It should be noted that, in the worst case⁹³, a Configuration 2 link will carry the traffic for approximately 1440 premises (assuming service take-up of 30%) during busy hours. It will

⁹² See www.motorola.com/web/Business/Solutions/Industry%20Solutions/Service%20Providers/Network%20Operators/_Documents/_static%20files/TD-LTE%20White%20Paper%20-%20FINAL.pdf.

⁹³ Backhaul of 8 eNodeB.

therefore be important for this link to be reliable. Currently, no redundancies for the microwave links are planned for Configuration 2 backhaul links. NBN Co target availability for the microwave links (end-to-end) is 99.98%.

However, based on sample deployment within the context of the first six release sites, the maximum number of eNodeBs to be backhauled as part of the same cluster was 5. This number is significantly less than the maximum allowed by the engineering rules. Based on the same sample, the majority of clusters contain only 2 or 3 eNodeBs to be backhauled. This is because the number of eNodeBs in a cluster is greatly influenced by the geographical spread of the eNodeBs and therefore defined on a case-by-case basis.

Fibre backhaul

The fibre backhaul has been chosen to connect a microwave aggregation point to the nearest FAN site, which is part of the mid-mile backhaul design. Transparent⁹⁴ GE transport is used to provide fibre connectivity between the microwave aggregation point and the FAN.

Analysys Mason's assessment

NBN Co has designed its backhaul network using both microwave and fibre technology.

For 'last mile' backhaul, Analysys Mason considers that the use of microwave technology is efficient and prudent for the short to medium term, as it represents the best choice in consideration of bandwidth requirements and costs (compared with fibre). We also believe that the dimensioning of the last-mile microwave link (Configuration 1) will not only support the minimum ABHT bandwidth requirements, but will also provide support for all three sectors of a particular site to operate at or near their peak throughput. The current planned capacities will need to be upgraded to support the likely increase in bandwidth consumption in the medium to long term, especially when LTE Advanced will be introduced.

For Configuration 1 last-mile microwave links, we agree with NBN Co's assumption that it will require a minimum of 28MHz per link for a 256 QAM modulation scheme in the 7, 11 or 18GHz bands. However, in the worst climatic conditions, this high modulation scheme may not meet the target end-to-end link availability (99.98%) and lower modulation schemes may be required to achieve this target availability. However, a lower modulation scheme will subsequently require more bandwidth to achieve the same required backhaul capacity and that the amount of spectrum needs to be determined on a case-by-case basis in respect of every two points that will be linked via microwave.

For the 'mid mile', NBN Co is planning to also use microwave technology to aggregate traffic from a number of eNodeBs on a single link, ranging from two eNodeBs to up to eight eNodeBs on a single link (Configuration 2 link). We note that:

⁹⁴ With no multiplexing.

- in the majority of cases, mid-mile links will generally backhaul between 2 and 4 eNode B as part of the same cluster. Assuming 3 hops, we estimate that this would require between 95MHz and 190 MHz (for a modulation of 256 QAM) of spectrum for the mid-mile link, assuming that Cross Polarisation Interference Cancellation technique is used to differentiate between downlink and uplink. This spectrum requirement may significantly increase depending on the distance to cover.⁹⁶
- in the case where the mid-mile links backhaul the potential maximum of 8 eNodeBs as part of the same cluster, the assumed three mid-mile microwave hops will require a minimum of 375MHz⁹⁵ (for a modulation of 256 QAM) of spectrum. This spectrum requirement may significantly increase depending on the distance to cover⁹⁶. This is in addition to the amount of spectrum required for last-mile backhaul (8 x 28MHz = 224MHz spectrum).

Due to the large amount of spectrum that is likely to be required by NBN Co for a cluster of 3 or more eNodeBs, we consider that when 3 or more eNodeBs need to be aggregated, the use of fibre in the mid-mile backhaul would be a more prudent option for implementing mid-mile backhaul in terms of resiliency and bandwidth scalability but also note that the proposed microwave backhaul option provides the benefit of easier deployment within the proposed build timeframes for the fixed wireless network, which are unlikely to be met with a fibre based deployment in the mid mile.

In addition, we note that:

- there is a high operational expenditure associated with large amount of spectrum
- NBN Co are planning their microwave links to achieve 99.98% end-to-end link (4 microwave hops) availability, which falls within the 99.9% end-to-end service availability mentioned in the previous section. However, since availability is both weather condition and modulation scheme dependent, it will be important for NBN Co to carry out detailed radio planning for each of this link, on a case by case basis, to achieve the availability target
- NBN Co are not planning any redundancy to achieve their 99.98% availability target for mid-mile microwave backhaul links. While this is in line with the 99.9% end-to-end service availability target, a microwave equipment failure would potentially affect between 360 premises (for 2 eNodeB clusters) and 1440 premises (for 8 eNodeB clusters).

Finally, NBN Co's decision to generally use fibre for the last backhaul link before reaching the FAN is a prudent decision for the reasons mentioned above.

7.5 Conclusion

Analysys Mason considers that NBN Co's design of its fixed wireless network reflects an efficient and prudent network design.

⁹⁵ 375MHz = 3x125MHz.

⁹⁶ The longer the distance, the lower the modulation scheme and therefore the lower the bandwidth.

In particular:

Technology decisions

- NBN Co's decision to deploy TD-LTE is efficient and prudent, as its adoption by major operators, such as China Mobile and Reliance Infotel, will create economies of scale, and so reduce the overall cost of the solution.
- Layer 2 wholesale services have not previously been implemented on TD-LTE networks, so this choice represents a technology risk but this risk is mitigated by the fact that NBN Co reports that current trials to deliver these products are currently performing according to specification.

Architecture-related decisions

- As NBN Co is using a standardised 3GPP architecture for its fixed wireless network, we consider that its approach to network architecture is prudent.
- Each area that is served by the fixed wireless network will be associated with a Fibre Serving Area (FSA), therefore avoiding infrastructure duplication. We therefore believe that this is a prudent architecture design choice.
- From our past experience, an end-to-end service target availability of 99.9% is prudent for providing residential services with fixed wireless networks. Evidence produced by NBN Co indicates that the wireless network architecture will be able to deliver services that meet their availability target of 99.9%.

Infrastructure-related design decisions at the end user premises and the wireless access network

- As discussed before, Analysys Mason considers that the methodology used by NBN Co to determine the boundary limits between premises served by the fibre network and those served by the fixed wireless network is both prudent and efficient, as it will ensure that a maximum number of end users are covered by the FTTP network, while at the same time not resulting in NBN Co incurring disproportionate costs in the relevant circumstances. We consider this overall approach provides an efficient basis for determining where the fibre footprint stops and where the fixed wireless footprint starts. Using this process, NBN Co has derived lower and upper bounds for fixed wireless coverage of the 94th and 97th percentiles, which are fully in line with the Australian Government's *Statement of Expectations*.
- NBN Co is using NTDs with four data ports within the wireless footprint. This is a prudent decision, as it will allow simultaneous delivery of multiple applications and services by multiple service providers and is consistent with industry best practice.
- NBN Co has followed a rigorous and best-practice planning methodology to design the wireless access network, with test results showing that the estimated cell ranges are prudent.

We also believe that the implementation of six 'first release' sites across Australia during 2012 is a prudent step to help further fine-tune the planning parameters (as well as systems and processes) before mass deployment.

Infrastructure-related design decisions in the wireless core network

- NBN Co's development of a core wireless network based on 3GPP standards is prudent, as this will ensure that different network elements from several vendors inter-operate. Adopting a standardised approach is also efficient, as it will minimise costs because of the large volumes that are generated worldwide.
- We also note that:
 - NBN Co's decision to use the same PoIs for both the fibre footprint and the fixed wireless footprint will reduce duplication in infrastructure and will therefore be more efficient than using separate PoIs for the fibre and fixed wireless footprint. The same argument is valid for the transit network, which will be used for both the fibre footprint and the fixed wireless footprint.
 - NBN Co's approach to core network scalability is efficient and prudent; the 'modular' PDN-GW will enable NBN Co to invest in line with traffic demand and will also avoid over-investment.
 - the use of redundant 1+1 PDN-GWs at every PoI site is prudent. Also, the duplication of wireless network elements (MME, HSS, EIR, PCRF, DNS/DHCP, etc.) in Sydney and Melbourne will also be vital in achieving the target availability set out by NBN Co.

Infrastructure-related design decisions in the backhaul network

- For 'last mile' backhaul, the use of microwave technology is prudent for the short to medium term, as it represents the best choice in consideration of bandwidth requirements and costs (compared with fibre). We also believe that the dimensioning of the last-mile microwave link (Configuration 1) will not only support the minimum ABHT bandwidth requirement for each premises, but will also provide support for all three sectors of a particular site to operate at or near their peak throughput.
- For 'mid mile' backhaul, NBN Co is planning to also use microwave technology to aggregate traffic from a number of eNodeBs on a single link. This will range from two eNodeBs to up to eight eNodeBs on a single link (although we note that NBN Co intends to keep the number of eNodeBs on a single link to a minimum). When 3 or more eNodeBs need to be aggregated, we consider that the use of fibre in the mid mile would be a more prudent option for implementing mid-mile backhaul in terms of resiliency and bandwidth scalability but also note that the proposed microwave backhaul option provides the benefit of easier deployment within the proposed build timeframes for the fixed wireless network, which are unlikely to be met with a fibre based deployment in the mid mile.

- NBN Co's decision to generally use fibre for the last backhaul link before reaching the FAN is a prudent decision.

Future-proofing of NBN Co's fixed wireless network

- We believe that NBN Co's fixed wireless network design is future-proof for the following reasons:
 - TD-LTE is a standardised technology and 3GPP has clearly defined LTE roadmap to provide higher data rates in the future
 - the technology is supported by major mobile network operators worldwide, including China Mobile, Reliance Infotel and Softbank that will ensure the existence of LTE for a long time in the future
 - TD-LTE is also backed by most equipment vendors creating the high economies of scale for network and customer premise equipment that will benefit both operators and end-users
 - devices will be able to support both TDD and FDD frequencies in the future
 - the wireless core network is based on fibre technology, which provides sufficient scalability in terms of capacity to accommodate increased end-user demands in the future.

8 Review of the efficiency and prudence of NBN Co's satellite network design

8.1 Introduction

This section sets out Analysys Mason's assessment and conclusions in respect of whether, and to what extent, the design of the NBN Co satellite network reflects an efficient and prudent network design.

Many decisions have to be made as part of the development of an efficient and prudent satellite network architecture and associated infrastructure. We consider that the key decisions that influence the efficiency and prudence of a network design include:

- technology choices, which mainly relate to choice of satellite technology, the choice of frequency band for operation, as well as related baseband issues such as the choice of Layer 2 protocol
- architectural choices, which relate mainly to the topology of the network
- infrastructure choices, which relate to the physical implementation of different sections and nodes of the network
- regulatory choices, which relate mainly to the way in which user terminals are licensed.

In particular, we consider that the following decisions will have the most impact on the efficiency and prudence of the design of broadband satellite networks:

- technology
 - conventional fixed services satellite (FSS) technology or high-throughput satellite (HTS) technology
 - satellite frequency band
 - Layer 2 protocol⁹⁷
- architecture
 - target amount of spectrum
 - number of satellites and target throughput per satellite
 - approach to securing orbital positions
 - number, size and distribution of satellite service beams
 - number of gateways and mapping of gateways to satellite service beams
 - interconnection of gateways
- infrastructure
 - CPE
 - gateways
 - spacecraft
 - ground network

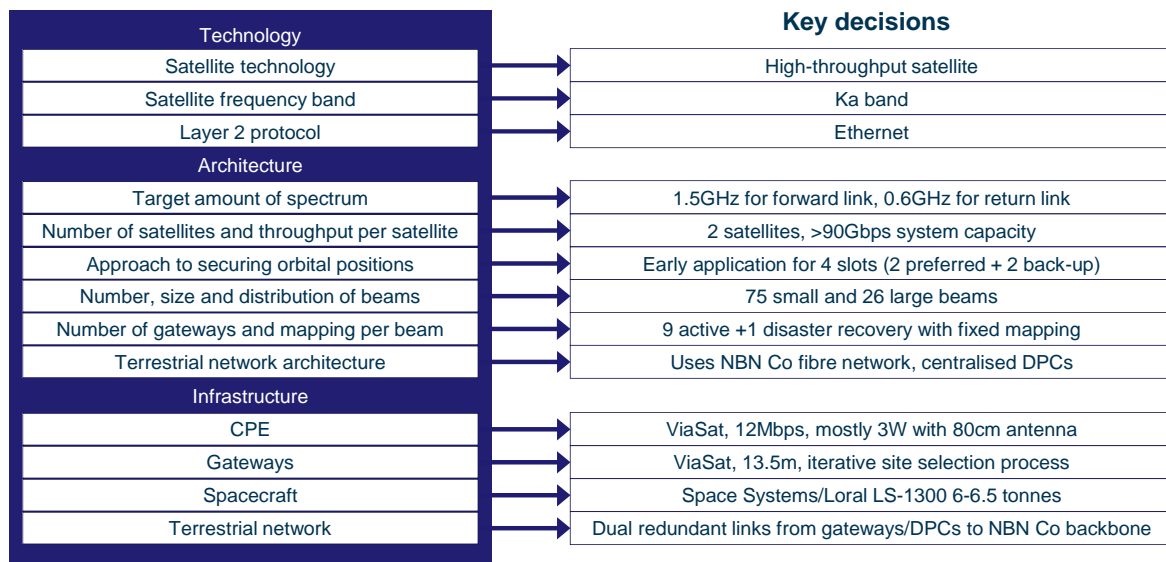
⁹⁷ The Australian Government has specified in its *Statement of Expectations* that NBN Co is to supply "open and equivalent access to wholesale services...via Layer 2 bitstream services". Therefore, this decision relates to the protocol to be used by NBN Co in supplying Layer 2 bitstream services.

These are the design choices on which we have focused our efficiency and prudence analysis below.

It is also important to note that our analysis has sought to consider each of these design choices from an efficiency and prudence perspective. However, it is the combination of these individual design choices and decisions that together determine whether the NBN Co satellite network, as a whole, is efficient and prudent from a design perspective. Therefore, while we have made individual assessments on the efficiency and prudence of individual design choices and decisions (and have outlined our views on each of those elements in this section), our overall conclusion on the question of whether, and the extent to which, NBN Co's design for its satellite network reflects an efficient and prudent network design, is based on Analysys Mason taking a view on NBN Co's satellite network design as a whole.

Figure 8.1 summarises the critical decisions faced by NBN Co in respect of the design of its satellite network from a technology, architecture and infrastructure perspective.

Figure 8.1: Satellite network design and implementation of options [Source: Analysys Mason, 2012]



Finally, we note that some of the key decision choices that impact upon the efficiency and prudence of NBN Co's satellite network have been specified or influenced by the Australian Government in its *Statement of Expectations*. Therefore, in accordance with our instructions, this report does not examine the merits of the specifications given by the Australian Government to NBN Co, but instead examines the key choices or decisions that have been made by NBN Co in the design of its network within the overall parameters that have been established by the Australian Government at a policy level through its *Statement of Expectations*.

8.2 Satellite technology assessment

In this section Analysys Mason considers the technology choices which were available to NBN Co and which mainly relate to choice of satellite technology, the choice of frequency band for operation, as well as related baseband issues such as the choice of Layer 2 protocol. It is structured as follows:

- Section 8.2.1 discusses the choice of a conventional versus a high-throughput satellite
- Section 8.2.2 discusses the choice of frequency band for the satellite
- Section 8.2.3 discusses the choice of Layer 2 protocol for satellite communications.

8.2.1 Satellite technology

Critical decision and related issues

NBN Co needs to decide whether its satellite network should be based on conventional FSS or high-throughput satellites (either approach is, in principle, capable of supporting next-generation broadband speeds). The main issue affecting this decision is the amount of satellite capacity required.

NBN Co's remit involves the provision of a fibre network serving at least 90% and up to 93% of premises in Australia, with the remaining 7-10% of Australian premises to be serviced using next-generation fixed wireless and satellite technologies. In its *Statement of Expectations*, the Government confirms its agreement that it will be cost effective to serve the 94th to 97th coverage percentiles using a fixed wireless solution, which in turn leaves satellite to serve the last 3% of premises.

Likewise, the *Statement of Expectations* confirms that the peak speed of the satellite service should be at least 12Mbps. NBN Co assumes that this will require the provisioning of 300kbps per user on the forward link and 100kbps per user on the return link. This implies that the total throughput required from the satellite network may be up to 64.2Gbps on the forward links and 21.4Gbps on the return links (i.e. around 85Gbps in total).

NBN Co's position

NBN Co has chosen to base its satellite network on high-throughput satellites.

Analysys Mason's assessment

Conventional FSS are rarely devoted entirely to the provision of broadband services. In our opinion, the maximum throughput that could be achieved with a conventional satellite is unlikely to exceed 4–5Gbps. Therefore, to provide a total throughput of 85Gbps, more than 20 conventional FSS may be required.

We believe it would be much more expensive to procure 20 conventional FSS than the two high-throughput satellites that NBN Co proposes, even if sufficient orbital slots could

be found. On this basis, we find NBN Co's choice of technology to be efficient.

As discussed in Section 5, we are aware of nine commercial high-throughput satellites in operation at present out of a total of around 300 communications satellites in orbit. The high-throughput satellites have been launched over a period of around eight years and have proved to be largely problem-free in terms of their launch, deployment and operation. On this basis, we find NBN Co's choice of technology to be prudent.

8.2.2 Satellite frequency band

Critical decision and related issues

NBN Co needs to decide in which satellite frequency band (or bands) its satellites should operate. The factors which influence this decision are the amount of spectrum that can be secured in a particular band and the acceptable CPE antenna size.

The C band and the Ku band are already heavily used with many satellites in orbit. This makes it difficult to obtain co-ordination for a new satellite and limits the amount of spectrum that can be used, which in turn increases the number of gateways required. There are as yet few Ka-band satellites in orbit and it is therefore much easier to obtain co-ordination and secure a large amount of spectrum.

A number of recent high-throughput satellites operating in the Ka band – such as Avanti's HYLAS-1, Eutelsat's KA-SAT and ViaSat's ViaSat-1 – are designed to operate with CPE antennas in the range 75-85cm. The minimum diameter of the CPE is determined not only by data rate requirements, but also by interference limitations to neighbouring satellites. To obtain a comparable performance in the Ku-band, an antenna with a diameter in the range of 1.2–1.8m is likely to be required, while C-band operation is likely to require 1.8–2.4m diameter antennas.

NBN Co's position

NBN Co has selected a Ka-band network. It states that the Ku-band was deemed unsuitable for its high-throughput satellites due to:

- the limited availability of spectrum, which would have increased the number of required gateways beyond what would have been practical (in terms of available geographical location to place gateways) and affordable
- a desire to ensure that the majority of user installations could be completed with an antenna less than 1m across.

The same considerations would have applied to an even greater extent in the case of a C-band system.

Analysys Mason's assessment

We understand that NBN Co is in the process of securing, and obtaining co-ordination for, an allocation of 1.5GHz of spectrum in the Ka band. In our opinion, it is very unlikely that NBN Co would have been able to secure an allocation of anywhere close to 1.5GHz in a lower frequency band. Consequently, we consider that the choice of the Ka band maximises the performance of the proposed satellites, minimises the number of gateways needed (and thus the cost of the ground segment), and minimises the size of the CPE antennas (which in turn makes them more acceptable to end users and minimises the cost and complexity of installation). We therefore conclude that the approach is efficient.

Although the Ka band is subject to greater rain fade than lower frequency bands, the documents that we have reviewed indicate that this factor has been correctly incorporated into NBN Co's CPE and gateway link budget calculations. Consequently, the availability of the Ka band network is unlikely to be materially worse than the availability of an alternative Ku band network. This leads us to conclude that the selection of the Ka band is also prudent.

8.2.3 Layer 2 protocol

Critical decision and related issues

As per the requirements set out in its *Statement of Expectations*, the Australian Government has declared its choice of wholesale service provision at Layer 2. In particular, the *Statement of Expectations* provides that NBN Co “will offer open and equivalent access to wholesale services, at the lowest levels in the network stack necessary to promote efficient and effective retail level competition, via Layer 2 bitstream services”.

The provision of wholesale access at Layer 2 usually refers to providing access seekers with access to the electronic layer of the network (i.e. the data link layer of the open systems interconnection (OSI) model).⁹⁸

Notwithstanding that NBN Co has been required to supply Layer 2 wholesale services, NBN Co is required to take a critical decision regarding the Layer 2 protocol that will underpin the supply of wholesale services.

Ethernet is now the ubiquitous Layer 2 protocol, not only for local area networks but also for metropolitan and national area networks. Ethernet has been prescribed and recommended by a number of standards bodies (e.g. the Broadband Forum and the Metro Ethernet Forum) and regulators around the world as the preferred Layer 2 broadband access technology.

⁹⁸ If additional background on Layer 2 service delivery is needed, a full discussion of the impact of providing wholesale services at different layers in the OSI model can be found in the following report: Analysys Mason, *GPON Market Review – Competitive Models in GPON: Initial Phase*, Report for Ofcom, Ref: 15340-512, 26 October 2009. See, http://stakeholders.ofcom.org.uk/binaries/research/technology-research/Analysys_Mason_GPON_Market_1.pdf.

NBN Co's position

NBN Co plans to adopt Ethernet as the Layer 2 protocol to deliver its wholesale services for the satellite network, as well as its fibre and fixed wireless networks which will use the same Points of Interconnect (PoIs).

Analysys Mason's assessment

Analysys Mason considers that NBN Co's choice of Ethernet as a Layer 2 protocol is both efficient and prudent, as the choice of Ethernet aligns with global standards and the Layer 2 protocol to be used on NBN Co's fibre and fixed wireless networks.

8.3 Satellite network architecture and regulatory assessment

In this section Analysys Mason considers the network architecture options available to NBN Co which mainly affect the topology of the network. It is structured as follows:

- Section 8.3.1 discusses the amount of spectrum which NBN Co plans to use for its satellite network
- Section 8.3.2 discusses the number of satellites and throughput per satellite
- Section 8.3.3 discusses the approach to securing orbital positions for the satellites
- Section 8.3.4 discusses the number, size and distribution of the beams on each satellite
- Section 8.3.5 discusses the number of gateways and frequency mapping of gateway channels to satellite service beams
- Section 8.3.6 discusses the terrestrial network architecture.

8.3.1 Target amount of spectrum

Critical decisions and related issues

The critical decision that NBN Co faces is whether the system should be designed so that the spectrum bandwidth used for the service links is limited to the 500MHz which is already available for use with class-licensed terminals or whether to seek an expansion in the amount of spectrum that can be used by class-licensed terminals in order to improve system performance.

The ITU has allocated up to 2.5GHz of spectrum in the FSS uplink band (27.5–30.0GHz) and an equal amount in the FSS downlink band (17.7–20.2GHz).

In order to facilitate FSS use of these bands, most national administrations have identified at least 500MHz of spectrum which is available to very small aperture terminals (VSATs), a category which includes satellite broadband CPE, on a class-licensed basis (i.e. terminals which meet defined technical standards can be installed anywhere in the country without the need to apply for an individual licence). Much of the remaining spectrum is available to satellite services on a shared basis with terrestrial fixed services (typically point-to-point microwave links). To avoid

interference with terrestrial fixed services, the default position is that satellite terminals operating in the shared parts of the bands require individual licences.

All high-throughput satellites to date have exploited the available class-licensed bands for their service links, as it is impracticable to seek individual licences for large numbers of installation, but in terms of satellite design, there would be three benefits from having the increased spectrum:

- more users can be supported in the most heavily-used beams
- fewer beams are required to achieve the necessary frequency reuse, making the satellite less complex and less expensive
- fewer different types of frequency converter are required on the satellite with a further reduction in complexity and cost.

For these reasons satellite operators in other regions have also been seeking larger amounts of class-licensed spectrum.⁹⁹ Since broadband services are asymmetric it would be particularly beneficial to obtain additional class-licensed spectrum on the forward link.

NBN Co's position

NBN Co decided very early on to work with ACMA with a view to enabling class-licensed terminals to operate with 1500MHz of spectrum on the forward link and 600MHz on the return link.

As a result of this work, on 16 August 2011, ACMA approved a set of changes enabling the band 28.5–28.6 GHz to be used for CPE return links and the band from 19.7–20.2GHz to be used for CPE forward links under a class licence. These actions create a 600MHz wide class-licensed return link and an additional 500MHz wide class-licensed downlink for CPE for use by all satellite operators in Australia.

Further action from ACMA applies to the 17.7–18.8GHz band which changes this to a class-licensed band for satellite CPE shared with fixed links. However, before this change could be implemented ACMA asked NBN Co to commission a study on the impact of band sharing with fixed links. Ultimately this study produced a favourable outcome and ACMA has proceeded with the change to the licensing of this band.

The class licence changes for the CPE are therefore now complete and implemented ahead of the NBN Co satellite network deployment.

⁹⁹ See, for example, the submission of the European Satellite Operators Association (ESOA) to the UK regulator, Ofcom, relating to its spectrum review, *A review of the management of the spectrum currently used for point to point fixed links and other services that share this spectrum* published in January 2012 (available at <http://stakeholders.ofcom.org.uk/consultations/spectrum-review/?showResponses=true>)

Analysys Mason's assessment

Given the target bandwidth requirements, we believe that it is efficient and prudent for NBN Co to strive to make use of additional spectrum for CPE links beyond the two 500MHz bands already available on a class-licensed basis. NBN Co took a calculated risk in developing a plan for its satellite network on the basis that class licensing of the additional spectrum would be possible, which was recognised as such in the NBN Co risk register. Working closely with ACMA from the outset was prudent and a satisfactory outcome has now been achieved.

8.3.2 Number of satellites and target throughput per satellite*Critical decisions and related issues*

NBN Co needs to decide how many satellites to procure. Given the target throughput established for the satellite network (which we estimated at up to 64.2Gbps for the forward link and 21.4Gbps for the return link – see Section 8.2.1), this is determined by:

- the maximum total throughput that can be obtained from each satellite
- the throughput that can be obtained in the most heavily used spotbeams, and
- considerations of in-orbit redundancy.

We discuss each of these issues in turn below.

► *Maximum total throughput per satellite*

The maximum throughput is a function of the amount of spectrum available, the spectral efficiency (measured in bits per Hz) and the number of gateways. NBN Co has access to 1.5GHz of spectrum in the Ka band for the forward link, which can be used simultaneously with two different polarisations. Potential ground segment suppliers indicated a spectral efficiency of around 3 bits per Hz. Assuming a total of eight to ten gateways, and assuming a 10% bandwidth loss due to implementation margins, these parameters imply that a single high-throughput satellite should be able to deliver 65–80Gbps on the forward link.

On the return link, 0.6GHz is available on two polarisations. Potential ground segment vendors indicated a spectral efficiency of around 2 bits per Hz (the spectral efficiency on the return link is typically lower due to a combination of limited peak power at the CPE, reducing the ability to support high order modulation and smaller carrier bandwidths unable to support the most efficient coding schemes). With the same assumptions, the return link parameters imply that a single high-throughput satellite should be able to deliver 17–22Gbps on the return link.

These estimates would imply that NBN Co may have been able to meet its total target throughput with a single high-throughput satellite.

► *Throughput in most heavily-used spotbeams*

The density of premises to be served by satellite varies greatly across the country. The proposed network addresses this issue to some extent by using a combination of large and small spotbeams (as shown in Figure 5.3 in Section 5.2 above) but antenna size considerations (which are discussed in Section 8.3.4 below) place a lower limit on the diameter of the small spotbeams. NBN Co's modelling shows that the expected user density in the 'hottest' (i.e. the most heavily-used) spotbeams means that the total throughput will exceed the capacity of a single high-throughput satellite, even though the total throughput across the country is less than the capacity of a single satellite.

► *In-orbit redundancy considerations*

Satellites are extraordinarily reliable with very few major failures occurring after the first year in orbit until close to the end of their scheduled life. Because of this, a number of high-throughput satellite operators have begun service with no planned spare satellite (e.g. Avanti with HYLAS-1, Thaicom with IP Star and Eutelsat with KA-SAT).

However, given the lead time for satellite procurement, it would take two years or more to replace a satellite which fails in orbit so if NBN Co were to rely on a single satellite and it did fail in orbit, the impact on users would be high.

If an operator procures two or more satellites, a decision then needs to be made as to whether they are placed in the same orbital position or in different orbital positions. If two satellites are placed in the same orbital position, then in the unlikely event of failure of one satellite users can be switched easily to the remaining satellite. However, the available spectrum must be shared between them, so twice as many beams are needed to achieve the same capacity as with two orbital slots. Growth is also more complex to manage and both satellites may have to be replaced at the same time.

With two orbital positions users are split between the two satellites. This makes more efficient use of spectrum but in the event of total failure of one satellite, the users of that satellite would need to have their antennas repointed to use the other satellite instead.

Assuming that the satellite network serves 3% of Australian premises with 65% penetration, the number of antennas to be repointed would be around 146 000 (and since the two satellites together are likely to provide sufficient capacity to serve more than 3% of premises this number could potentially be higher). While repointing this number of antennas is clearly a far-from-trivial task, it could still be undertaken in far less time than it would take to procure a replacement satellite.

NBN Co's position

NBN Co intends to procure two identical satellites to be installed in different orbital locations. The target throughput for the satellite solution is in excess of 70Gbps on the forward link and in excess of 20Gbps on the return link. NBN Co's calculations show that this arrangement will provide

sufficient capacity to support the expected number of users in all of the large spotbeams and a large majority of the small spotbeams. In a few of the hottest small spotbeams there may still be excess demand. NBN Co plans to address this by selectively installing additional fixed wireless sites as the demand for satellite capacity in particular spotbeams approaches the limit available from two satellites.

Analysys Mason's assessment

Since demand in the hottest spot beams exceeds the capability of a single satellite, a minimum two satellite procurement is the most efficient option available. Given the low probability but serious consequences of procuring a single satellite which then fails in orbit, we conclude that NBN Co's approach of procuring two satellites is also prudent.

Moreover, since NBN Co is planning an integrated satellite and terrestrial network, any 'excess' capacity from having two satellites in different orbital positions could potentially be used to serve additional users, thus reducing the size and cost of the terrestrial wireless network. However, until further information is available to NBN Co about the actual demand and take-up of services in the wireless and satellite footprints, it may not be prudent for NBN Co to make these trade-offs until after the wireless network is substantially complete.

If two satellites are to be procured, placing them in different orbital positions is clearly more efficient than placing them in the same position, given the low probability of in-orbit failure. If NBN Co arrange for there to be equal numbers of users on each satellite, the impact of either satellite failing would be that half of the user antennas would need to be repositioned. We therefore consider that this arrangement is prudent.

8.3.3 Approach to securing orbital positions

Critical decision and related issues

NBN Co needs to decide a strategy for securing two orbital positions for its Ka-band satellite network from the ITU, to proceed prior to network definition or later with a more definite design.

The main issues are:

- The large number of prior notifications from Asian and Global operators
- Seven year expiry if no network in place
- Complex design and procurement process before network design became certain

The ITU can only be approached through advanced publication information (API) submitted by a recognised administration authority which is ACMA in this case. This generally contains an envelope of all options for frequency band and orbital slot since the network is at a pre contract stage and some orbital slots may prove more difficult than others. This is then checked by ACMA.

Once the API submission is forwarded from ACMA to the ITU Radio Bureau, the seven year period begins. If no satellite is in orbit at the end of seven years then the application is removed. There is a period of at least six months before the operator can submit a Co-ordination Request (CR). The ITU then publishes details in one of the next available International Frequency Information Circulars. Informal discussions with other operators can commence at any time but once the information is published in a Co-ordination Request, operators who think they may be subject to interference from the new network may request co-ordination via their own administration.

Only after publication will it become clear which administrations have a problem with a particular orbital slot. Only after co-ordination meetings will it become clear if a resolution can be found which allows both to proceed. It may be possible to change the design to avoid interference if this is understood at an early stage. If issues arise later then it may not be so easy to change a contract for a satellite.

Coordination Requests, which are detailed technical documents, were prepared in early 2011 for the 135°E, 140°E, 145°E and 150°E positions. All these were published together by the ITU in IFIC #2702 dated 6 September 2011.

NBN Co's position

NBN Co proceeded early with an API for four orbital positions (130° East, 135° East, 140° East and 145° East) and three frequency bands including the Ka band using outline parameters for the satellite network. These reached the ITU via ACMA in August 2010 and, following initial discussions with other administrations, it was decided to add 150° East in December 2010 to replace 130° East.

Analysys Mason's assessment

The decision to proceed early with preliminary information has proven prudent as indicated by the need to submit a later application for 150° E. Once this was decided the submission process was efficient.

It is prudent for NBN Co to keep options open by submitting four applications rather than just two and NBN Co has been prudent in completing co-ordination with a number of administrations and setting dates for meetings with others.

NBN Co has been prudent in recruiting specialist support to administer the liaison through ACMA to the ITU.

8.3.4 Number, size and distribution of satellite service beams

Critical decision and related issues

NBN Co needs to decide whether its satellite network should be based on an even distribution of similar-sized beams or one with two different sizes of beam for low- and high-demand areas of Australia.

The main issue surrounding this decision is the large land area to be completely covered and the wide range in the density of predicted demand between remote areas and city surrounds.

Most existing high-throughput satellites (e.g. WildBlue) have an approximately even distribution of beams and all beams are approximately the same size. This initial design decision was made in light of predictions that the majority of the market serviced by these satellites would be in rural areas. In practice, take-up in North America has occurred in the hinterlands of the cities. Many of WildBlue's beams were left with underused capacity and thus the useful capacity of the satellite was less than its headline capacity until it became part of the ViaSat network.

The operator of a high-throughput satellite subdivides the channels for the service links into a number of carriers, each compatible with the CPE capability. Users are then allocated to each carrier. This process is transparent to the satellite, which typically is designed to provide equal amounts of spectrum to each service beam regardless of demand. An ideal design would allow individual carriers to be switched independently to the needed service beam, but this is not yet achievable using cost-effective technology with a proven heritage.

The number of beams is a key indicator of satellite complexity. In very rural areas even one carrier in a small beam would have more capacity than needed. For this reason, a mix of small and large beams as proposed by NBN Co provides increased efficiency in matching geographical variations.

With one reflector a single microwave feed produces a single spotbeam. Additional neighbouring feeds can be added and each produces a nearby spotbeam. Unfortunately, there are gaps left in this single feed per beam antenna design with only one antenna available. These are then filled by adding three more identical antennas, each slightly offset in angle from the first. Thus, four antennas of the same size are required to produce a single carpet of spotbeams with no gaps.

The total number of beams provided by the satellite is a good indicator of its complexity, and its payload mass will rise approximately linearly with this number. The size of the spotbeam produced by a satellite antenna is inversely proportional to the diameter of the reflector which is used.

Using only small beams would have required approximately 280 beams in total to cover all of Australia. Producing a satellite with 280 beams is beyond the current industry capability.

Using only the large beams approximately 40 beams would be required to cover all of Australia. This would not have provided sufficient capacity overall due to limited frequency reuse, nor would it have

been able to deliver the density of capacity that NBN Co expects to require in the most densely-populated areas.

Satellites are limited in the size and number of large antennas that they can fit inside the launcher, so accommodating three or more different beam sizes would be extremely challenging.

Even so, larger diameter reflectors of this type have flight heritage, and this is an area of continuing progress through industrial research and development, as discussed in Section 5.4 above.

NBN Co's position

NBN Co has chosen to cover Australia with 101 service beams comprising 75 small beams and 26 large beams, distributed as shown in Figure 5.3 in Section 5.2 above. The diameter of the beam is about 700km for the large beams and 260km for the small ones.

Analysys Mason's assessment

Given the demanding coverage requirements and the technology constraints, Analysys Mason believes that NBN Co has selected an efficient beam coverage plan by mixing large and small beams.

The total number of beams is at the high end of the industry's proven capability and the small beams are 10% smaller than on those high-throughput satellites already in orbit (i.e. those listed in Figure 5.4 in Section 5.3 above). This means that the reflectors necessary to produce the smaller beams are slightly larger than those on previous satellites. The issues surrounding antenna size are further discussed in Section 8.4.3 below. However, Analysys Mason believes that this is a manageable stretch for an experienced manufacturer such as Space Systems/Loral, following standard industry development and qualification practices. Analysys Mason considers that NBN Co has been prudent in finding a beam coverage plan that is well aligned with the industry's antenna capabilities.

8.3.5 Number of gateways and frequency mapping of gateway channels to satellite service beams

[C-I-C]

8.3.6 Terrestrial network architecture

Critical decision and related issues

NBN Co faces two critical decisions with regard to the terrestrial network architecture:

- where to place the data processing centres (DPCs)
- how to connect the ten gateways to the PoIs and the DPCs, and the DPCs to the PoIs.

NBN Co's satellite network design requires a number of components of the baseband system and network management system (NMS) to be housed in a DPC environment. These components are as follows:

- baseband system
 - service control subsystem (SCS)
 - transparent performance enhancing proxy (TPEP)
 - NBN Co's Layer 2 software package
- NMS
 - central management subsystem (CMS)
 - administration provisioning subsystem (APS)
 - element management subsystems (EMS).

This equipment could either be distributed around the gateways, or located centrally, away from the gateways.

The connections from the gateways to a fibre backbone network could in principle comprise a single link or dual redundant links. Within the fibre backbone network the data traffic and the management and control traffic for the satellite network could use dedicated capacity or shared capacity.

NBN Co's position

NBN Co decided to adopt a centralised DPC architecture with DPCs housed in shared NBN Co facilities with other telecoms and data centre equipment, located in large, environmentally managed buildings close to Australian capital cities.

NBN Co decided that the centralised DPC architecture was the best fit for its requirements, for the following reasons:

- lower operating expenditure (opex) (estimated savings of AUD3 million per annum) due to
 - ease of maintenance of TPEP and SCS servers/switches – these are sophisticated items of equipment and will be more accessible for maintenance purpose if they are located in close proximity to the satellite network operations centre than if they were housed in extremely remote, unmanned gateway sites
 - few virtual data links to PoIs and gateways – due to the PoIs being located in the connectivity serving area (CSA), fewer virtual data links are required with a centralised architecture than if all equipment were to be located in the gateways
 - reduction in the rack space and power requirements at each gateway
- simpler and quicker failover scheme for major TPEP and SCS failures (DPC failover versus gateway failover).

As a consequence of adopting the centralised DPC architecture, all data traffic between the gateways and the PoIs will flow via one of the data centres.

NBN Co decided to connect the ten gateways to the DPCs and the PoIs reusing existing fibre, DWDM and MPLS infrastructure to provide resilient connectivity. Each DPC and gateway will be connected using redundant provider edge routers co-located within the same facility. The data path will traverse the MPLS network, while the management and control path will traverse the national connectivity network (NCN) which is run on separate MPLS infrastructure. One of main reasons for separating the data traffic from the management and control traffic is to prevent fault conditions on the data network affecting the management and control network and vice versa. Use of an MPLS network provides increased resiliency for the satellite network and reduces the cost of connectivity between the gateway and POI sites as compared to other architecture.

NBN Co states that the final architecture of the terrestrial communications network catering for the satellite network is still being formalised, and the list of standards to be used has not been finalised yet.

Analysys Mason's assessment

Although we have not seen detailed calculations showing the relative cost of a centralised versus a distributed DPC architecture, it seems intuitively reasonable that a centralised architecture would be more cost-efficient and would simplify maintenance, making it a prudent approach as well. The use of a centralised DPC architecture results in a very slight increase in latency on the terrestrial part of the network compared to a distributed architecture (since all data traffic needs to be routed via one of the DPCs) but we do not consider this to be material in comparison to the inherent latency on the satellite part of the network. The centralised architecture also results in a requirement for slightly more capacity on the MPLS network but given the amount of capacity available on the network we believe that this will not have a material impact on costs.

It is clearly more prudent to connect each gateway back to the DPCs using a fully resilient MPLS network with underlying resilient DWDM infrastructure rather than a single link and, given that the gateway sites are being chosen in part based on their proximity to NBN Co's planned network sites, this approach should be reasonably efficient as well. The same argument applies to the DPCs. We also believe that is prudent for NBN Co to separate the data traffic from the management and control traffic.

8.4 Satellite network infrastructure assessment

Here we present our assessment of choices regarding the infrastructure used in NBN Co's satellite network. We have reviewed the following network elements:

- CPE
- gateways
- spacecraft

- terrestrial network

We discuss each of these in turn below.

8.4.1 CPE

Critical decision and related issues

Since NBN Co has been given the target of enabling broadband satellite coverage with peak speeds of at least 12Mbps and availability that is consistent with, or better than, current satellite broadband networks (which NBN Co has assumed to be 99.5%), the critical decision that it faces with regard to CPE is what combination of outdoor unit (i.e. satellite dish) diameter and transmission power offers the best trade-off between cost, performance and ease of installation.

A more powerful outdoor unit will offer better performance, but will cost more to manufacture and install and may consume more electrical power. Moreover, the law of diminishing returns applies: in order to double the spectral efficiency, the power must be increased by a factor of four. Similarly, a larger dish will offer higher gain and thus increase the effective transmit power and receive sensitivity (as well as producing a more tightly-focused beam which helps to reduce interference), but will cost more to manufacture and will be more difficult to install (as well as being more obtrusive once installed).

We also note that there are relatively few mass-market manufacturers of Ka-band satellite CPE, (ViaSat and Hughes Network Systems being the largest), so NBN Co had a relatively narrow choice of CPE.

NBN Co's position

NBN Co has decided that CPE initially procured for the satellite network should provide a data rate of 12Mbps under good atmospheric conditions (i.e. clear skies). It has selected ViaSat as its exclusive supplier of CPE for the satellite network. The CPE to be provided by ViaSat is based on the company's second-generation SurfBeam 2 product, which is currently in production, and has been deployed in Europe and the USA (ViaSat recently reported passing a total of one million shipped units across all of its models). The SurfBeam 2 product will be enhanced for NBN Co through the addition of new low-power modes, higher data rates, and the ability to make use of a wider downlink spectrum band. However, we understand that the product's fundamental design – including the tuner, demodulator and media access control layer processing – remain unchanged from the design that is already in production.

The VSAT is composed of an indoor unit and an outdoor unit. The indoor unit consists of a modem and a power supply (see Figure 8.2). All DC connections on the modem and alternative current (AC) power source are locking connectors to prevent accidental removal.



Figure 8.2: Satellite indoor unit [Source: NBN Co, 2012]

The outdoor unit consists of an antenna with transmit receive integrated assembly (TRIA) (see Figure 8.3) and a mount (see Figure 8.4).



Figure 8.3: Satellite outdoor unit with 80cm antenna [Source: NBN Co, 2012]



Figure 8.4: Satellite outdoor unit mounts (pole mount on the left, universal mount for walls, flat and angle roofs on the right) [Source: NBN Co, 2012]

Four antennas of nominal sizes of 80, 120, 180, and 240cm have been offered to NBN Co in accordance with its Request for Proposal (RFP) requirements. The 80cm antenna has a metal reflector, while the larger antennas have a glass fibre reinforced composite reflector. Each antenna has an offset-fed prime focus design for high efficiency and excellent sidelobe characteristics. Precision surface tolerances assure high gain at Ka-band frequencies. All antennas comply with the rigorous antenna sidelobe pattern envelope defined in ITU-R S.580-6. Larger sizes will facilitate operation in areas with local interference to and from fixed links, but are more expensive. Two versions of the TRIA are offered: a 3W and 6W version. We understand that most installations will use the 3W version.

Each antenna includes an azimuth/elevation mounting head. This head utilises an integral clamping feature called a 'canister' clamp. The canister clamp is a standard pipe interface which provides the flexibility to mount the antenna in a wide variety of installation scenarios. The azimuth/elevation mounting head includes fine adjustment in both azimuth and elevation to assure precise pointing to the satellite.

The interface between the SurfBeam 2 indoor unit and the SurfBeam 2 Modem outdoor unit is a single coaxial cable (some other satellite CPE uses separate transmit and receive cables). Use of a single cable simplifies installation and reduces the probability of an improperly installed or damaged connector.

Analysys Mason's assessment

In our opinion, the CPE design is efficient in terms of the trade-off it provides between cost, performance and ease of installation. NBN Co's selection of ViaSat as its CPE provider is prudent since ViaSat is one of the leading suppliers of Ka-band satellite CPE. It is proposing a design which represents a relatively modest evolution of its existing product. Moreover, ViaSat has a large installed base of equipment and although the majority of its equipment has been installed as part of the company's own WildBlue service, it has also been chosen by other leading Ka-band satellite operators, such as Eutelsat.

8.4.2 Gateways

Critical decisions and related issues

Having decided how many gateways to build and what electronic equipment should be installed at the gateways and in the DPCs as part of its satellite network architecture, the critical decisions faced by NBN Co are the location of the gateways, the choice of gateway supplier and the size of the gateway antennas.

The optimisation of the locations of the gateways is dependent on a number of factors, including the need to:

- avoid areas with large amounts of atmospheric attenuation, ACMA exclusion zones and other locations which could face restrictions
- have good access to power and NBN Co's fibre network
- be amenable to a generic approach to site construction
- be able to recruit maintenance personnel within a reasonable travelling time to each gateway
- have good gateway carrier to interference (C/I) isolation from neighbouring shared users of the band
- accommodate any limitations on location imposed by the spacecraft payload design, e.g. be sufficiently well separated to avoid intra-system interference with other gateways
- find sites with no environmental or local authority impediments including:
 - being situated above the 100-year flood level

- being free of soil contamination
- having clear line of sight to the 130 to 150 degree orbital locations.

Given that the CPE has to interact with the electronic equipment at the gateway, and the relative lack of standards in satellite equipment design compared to other branches of telecoms equipment design, it is standard practice for operators of satellite broadband networks to choose the same vendor to supply their CPE and gateways.

NBN Co's position

NBN Co started by eliminating ACMA exclusion zones such as cities with a population over 25 000 people and known exclusion zones including a 700km radius around Alice Springs.

NBN Co then used the system capacity tool to eliminate areas with large amounts of atmospheric attenuation (the tropical north of Australia).

NBN Co states that from this point onwards the process became more complex and iterative, taking inputs from multiple aspects such as gateway design requirements, C/I, payload limitations, real-estate availability, fibre backhaul and power availability, personnel logistics of getting to sites during times of emergencies (e.g. frequency of flights, accommodation needs, flood and emergency access routes). The process started with a list of about 25 different sites and ended with a final list of 12 locations from which the ten required sites could be selected.

The satellite contract was signed first, then the CPE and gateway contract (awarded to ViaSat), and the final parcels of land are now being purchased

We understand that ViaSat was able to offer gateway antennas 7, 9.1 or 13.5m in diameter. Although ViaSat has built 13.5m antennas in other bands, we understand that NBN Co is one of the first customers for 13.5m Ka-band antennas (7m and 9.1m Ka-band antennas are in operation in other countries).

Analysys Mason's assessment

Analysys Mason believes that this complex decision on the location of gateways has proceeded efficiently and prudently. It is a complex trade across technologies, commercial and external factors. It was necessary to proceed step by step and check on the way.

We believe it is efficient and prudent for NBN Co to choose a single supplier for gateways and CPE.

Moreover, we believe that the improvement in link performance and availability associated with choosing large gateway antennas, combined with the limited cost differential and low risk associated with the development, makes this a prudent and efficient choice.

8.4.3 Spacecraft

The design of any telecoms satellite is a truly iterative process between the manufacturer and the operator.

Critical decisions and related issues

We consider that the critical decisions that NBN Co faces in relation to the spacecraft are as follows:

- choice of manufacturer
- size of antenna reflectors
- position of gateway beams within the antenna
- choice of launch service provider.

We discuss each of these decisions in turn.

► *Choice of manufacturer*

The design of any telecoms satellite is a truly iterative process between the manufacturer and the customer (i.e. the operator) as the customer seeks to exploit the full capability of the platform to maximise revenues. The process is well documented in a paper jointly authored by EADS Astrium and Eutelsat describing *a posteriori* the way in which KA-SAT was designed.¹⁰⁰

As Figure 5.4 shows, three satellite manufacturers have a track record of building Ka-band broadband satellites of comparable size and complexity to those proposed by NBN Co, and thus there are three obvious candidates for the task of designing and building NBN Co's spacecraft: Boeing, EADS Astrium and Space Systems/Loral.

Satellites are sold in small numbers, typically 20–30 per annum for the whole industry. The satellite bus is somewhat standardised by each supplier, which places orders for parts for a handful of satellites at a time. Changes happen gradually and the products evolve over time. New features and technologies are treated with caution until they have been proven in orbit for several years, whereupon they are almost universally adopted.

In the last decade improvements in the power subsystem have reduced battery mass and increased solar array power. Most recently, the use of electric propulsion on station has reduced the mass of fuel necessary to provide the required lifetime. This has allowed heavier payloads to be considered without dramatically affecting launch mass. The proposed beam layout and bandwidth of the NBN Co satellites leads to a large payload mass and power, but one which is within the capabilities of the industry.

► *Size of antennas*

[C-I-C]

¹⁰⁰ Performance optimization of multibeam broadband payloads, Gidney, Jones, Paullier and Fenech, 2008

► *Position of gateway beams within the antenna*

[C-I-C]

► *Launch strategy*

The decision on launch strategy is made early in the design phase of a satellite programme. High-throughput satellites with the amount of capacity proposed by NBN Co typically have a mass of 6–6.5 tonnes at launch and NBN Co currently sits in the middle of this range. Until June 2009 there were three available launch service providers: Arianespace, ILS and Sea Launch. The launch is the highest risk element of the programme: if a design fault has to be rectified following a failure, this can lead to the launcher being unavailable for a long period. With three launch service providers, competition is maintained even when one is unavailable

In June 2009, Sea Launch sought Chapter 11 protection and did not emerge until July 2010 causing an interruption in operations. Recent events show the delicacy of this situation:

- On 31 May 2012, Intelsat 19 was launched by Sea Launch using its Zenit3SL launch vehicle. This was its first launch since emerging from Chapter 11 and was apparently successful. The satellite platform failed to deploy one of its solar arrays but is now in orbit with reduced power. The precise cause is still under investigation. Sea Launch is due to launch Intelsat 21 on 17 August 2012.
- On 2 August 2012, Intelsat 20 (6.09 tonnes) together with Avanti's HYLAS-2 (3.3 tonnes) was successfully launched by Arianespace.
- On 6 August 2012, Roscosmos launched two satellites on Proton (the same launcher marketed in the West by ILS). The Briz M upper stage failed and both satellites were lost. Roscosmos (and ILS) has suspended all launches of this model until an investigation is completed.

All three service companies are very likely to be available to support future 6-tonne class missions. They may be joined by a fourth option at the end of 2013 when SpaceX's Falcon Heavy is due to start services. This should be capable of launching 12 tonnes and so could in theory carry two 6-tonne class satellites.

NBN Co's position

NBN Co has selected Space Systems/Loral as its satellite manufacturer following a competitive procurement process. It has decided to proceed with four large diameter reflectors for the small beams. Loral is obliged to manage its mass budget to maintain compatibility with the three available launch vehicles. [C-I-C]

Analysys Mason's assessment

NBN Co has selected a prudent satellite design consistent with the industry's capabilities and one which brought bids from the experienced suppliers.

The use of large reflectors allows NBN Co to procure an efficient satellite able to meet its needs for useful capacity. On balance, this is a prudent decision provided the manufacturer is able to manage any resultant growth in the mass of the spacecraft.

[C-I-C]

We consider that it would be prudent to retain compatibility with the maximum possible number of launch vehicles at this stage in the design process. However, we recognise that it may be more efficient from a technical perspective to reduce the number of different constraints on the satellite design and thus restrict the choice of launch vehicles.

8.4.4 Terrestrial network*Critical decisions and related issues*

As explained in Section 8.3.6 above, NBN Co will carry the satellite data traffic on a dedicated virtual private network running over an MPLS fibre network, while the management and control traffic will be run over the national connectivity network, a separate MPLS network on NBN Co's fibre network.

Having decided on the network architecture, the remaining critical decisions relating to the terrestrial network are the capacity of each link and the protocols to be used. The capacity should be sufficient to accommodate the expected level of traffic on each link at all times but should not be over-dimensioned to the extent that significant cost is added to the network.

NBN Co's position

NBN Co states that each of the terrestrial links has been dimensioned to accommodate the expected volume of traffic but that the size of any of the links can be quickly and inexpensively increased if necessary since there is plenty of additional capacity available on the MPLS fibre network.

NBN Co states that the final architecture of the terrestrial communications network catering for the satellite network is still being formalised, and the list of standards to be used has not been finalised yet.

Analysys Mason's assessment

We believe that NBN Co's approach to dimensioning the terrestrial links is efficient and

prudent and that the initial capacities proposed are reasonable.

8.5 Conclusion

Analysys Mason considers that NBN Co's design of its satellite network reflects an efficient and prudent network design.

In particular:

Technology decisions

- NBN Co's decision to procure high-throughput satellites rather than conventional FSS satellites is efficient given the amount of capacity required to meet the Government's expectation that the satellite network should be capable of providing service to 3% of Australian premises at a peak speed of at least 12Mbps, and prudent given the track record of the commercial high-throughput satellites in orbit.
- Again given the amount of capacity required it is efficient for NBN Co to procure Ka-band satellites and NBN Co appears to have been prudent in the way it has allowed for the increased level of rain fade that occurs in the Ka band.
- NBN Co's choice of Ethernet as a Layer 2 protocol is both efficient and prudent, as the choice of Ethernet aligns with global standards and the Layer 2 protocol to be used on NBN Co's fibre and fixed wireless networks.

Architecture-related and regulatory decisions

- Given the bandwidth that was likely to be required to achieve the target overall capacity and peak throughput per user of at least 12Mbps, we believe that it is efficient and prudent for NBN Co to strive to make use of additional spectrum for CPE links beyond the two 500MHz bands allocated exclusively for FSS use by the ITU.
- Given that the expected number of users in certain spotbeams exceeds the capacity that could be provided by a single satellite, we believe that it is efficient for NBN Co to procure two satellites. A network based on two satellites is also more prudent than use of a single satellite since, in the unlikely event of the single satellite failing, service would have been lost for an extended period (possibly several years).
- Having decided to order two satellites it is efficient to place them in separate orbital positions as this doubles the capacity that can be obtained from a given amount of spectrum. This decision means that in the event of one satellite failing totally, it will be necessary to re-point half of the user terminals. Given the expected number of users this would clearly be a significant undertaking but we consider that the time required would be far less than the lead time for a replacement satellite. Consequently, we believe that this approach is prudent.

- NBN Co has prudently made four applications for orbital positions in case problems arise in co-ordinating the use of the two preferred positions. NBN Co appears to have proceeded efficiently with co-ordination activities to date.
- Analysys Mason believes that NBN Co's beam coverage plan, involving a combination of small and large beams, is efficient. The total number of beams specified is at the high end of the industry's proven capability, but we believe that this is a manageable stretch for an experienced satellite manufacturer, so the decision should be regarded as prudent.
- While the size of the reflector necessary to produce the smaller beams is slightly larger than on previous high-throughput satellites, larger diameter reflectors of this type have flight heritage, and this is an area of continuing progress through industrial research and development. Analysys Mason therefore considers that this development is manageable following standard industry developments and qualification practice.
- Again, given the capacity requirement we believe that it is efficient and prudent to construct nine primary gateway locations with a tenth gateway location for disaster recovery. We believe that adjusting the amount of bandwidth allocated to each of the smaller beams to match the expected level of demand is efficient since it should increase the proportion of installed capacity that is ultimately usable. The approach is also prudent since there is some margin to manage uncertainties in the predictions and to implement the channel plan in the satellite network.
- NBN Co has adopted a centralised approach to the architecture for data processing centres (DPCs) required to support the satellite network. Although we have not seen detailed calculations showing the relative cost of a centralised versus a distributed DPC architecture, it seems intuitively reasonable that a centralised architecture would be more cost-efficient and would simplify maintenance, making it a prudent approach as well.
- We believe that the arrangements for connecting the gateways and the DPCs to the NBN Co fibre network using dual redundant links are prudent and efficient. We also believe that it is prudent to transport the data traffic in a separate virtual private network from the management and control traffic since this minimises the risk of a fault condition on the data network affecting the management and control network, and vice versa.
- If the satellite network were being used as a back-up for NBN Co's terrestrial services, then it may have been prudent to use a different fibre transit network altogether to carry the traffic from the satellite network. However, since it is intended that different users should either have satellite or terrestrial service, we see no particular benefit in terms of prudence (but a significant loss of efficiency) by carrying the satellite traffic separately.

Infrastructure-related decisions

- In our opinion, the CPE design is efficient in terms of the trade-off it provides between cost, performance and ease of installation. NBN Co's selection of ViaSat as its CPE provider is prudent since ViaSat is one of the leading suppliers of Ka-band satellite CPE.
- We believe it is efficient and prudent for NBN Co to choose a single supplier for both gateways and CPE given that there is a lesser degree of standardisation in satellite terminals and gateways than in the terminals and network equipment for fibre and terrestrial wireless networks.
- Analysys Mason believes that this complex decision on the location of gateways has proceeded efficiently and prudently. It is a complex trade across technologies, commercial and external factors.
- We believe that the improvement in link performance and availability associated with choosing the largest gateway antenna available, combined with the limited cost differential and low risk associated with the development, makes this a prudent and efficient choice.
- Based on Space Systems/Loral's track record of supplying high-throughput satellites, we believe that NBN Co's choice of manufacturer is prudent. We have not had access to the evaluation of the different proposals received, but have no reason to doubt that Space Systems/Loral was chosen on the grounds that it offered the most efficient approach.
- [C-I-C]
- We consider that NBN Co has been prudent to retain compatibility with three launch vehicles at this stage in the design process. However, we recognise that it may be more efficient from a technical perspective to allow the satellite mass to grow and restrict the choice of launch vehicles to two.
- We believe that NBN Co's approach to dimensioning the terrestrial links is efficient and prudent and that the initial capacities proposed are reasonable.

Degree of future-proofing in the satellite network

- Once launched the total amount of capacity in each spotbeam provided by the satellites will essentially be fixed. Some marginal improvement may be possible by adjusting the transmission parameters. It may also be possible to increase the maximum speed for individual users by upgrading their CPE (for example, by installing a larger or more powerful outdoor unit or a higher-speed indoor unit).
- Nevertheless, since the satellite network is being used as one component of a national broadband network then it should be possible to meet evolving bandwidth demand by substituting terrestrial capacity for satellite capacity – for instance, if clusters of satellite broadband users are causing congestion in a particular spotbeam, it may be possible to serve

some of the clusters with a new terrestrial wireless base station instead, freeing up satellite bandwidth to continue serving the most remote users.

- We also note that the spacecraft are being designed for a 15-year working life (the standard approach in the satellite industry) while other components of NBN Co's network are being designed for a 30-year working life. Consequently, there is an opportunity to revisit the requirement for the satellite network, and potentially implement a significant upgrade, approximately half way through the working life envisaged for the network as a whole.

Annex A FTTP network benchmarking

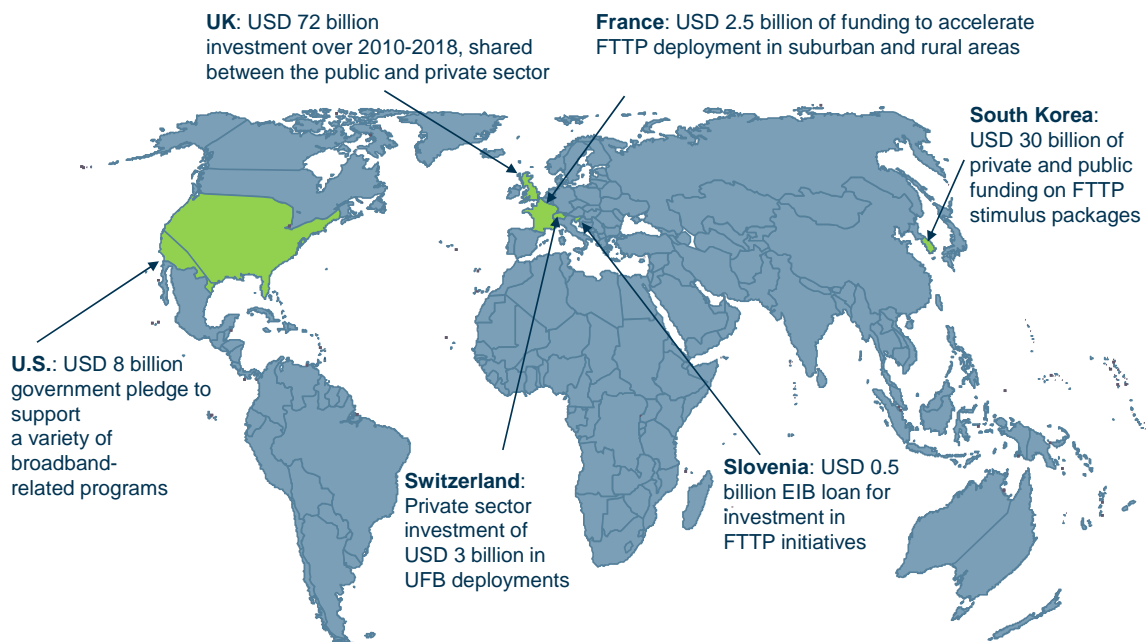
In this annex, we present six case studies of FTTP deployments around the world to assist us in benchmarking NBN Co's technical solution against other national broadband solutions. The design of each solution reflects the unique situations and objectives of individual countries and network operators.

In order to draw lessons from these different deployments, each case study follows a common structure to describe the factors that could potentially influence the technical solution chosen for a broadband access network. The factors examined include: an overview of the market and regulatory situation; any insights into network architecture and cost; and any issues identified from operational experience.

A.1 National broadband schemes

Public investment in FTTP varies significantly across markets, but it is increasingly included as part of larger, national economic stimulus packages. Here we describe a selection of national stimulus packages. These are typically joint public-private projects involving government investment in partnering, setting up and/or subsidising a private company to roll out fibre-based access networks and/or broadband services.

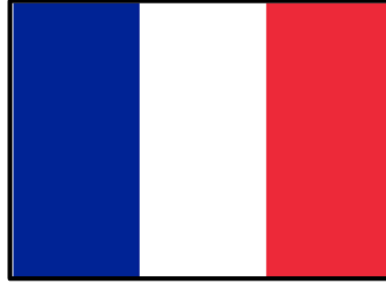
Figure A.1: Map showing FTTP case studies examined [Source: Analysys Mason]



A.1.1 France

Market and regulatory overview

The French broadband market is dominated by the incumbent France Telecom (FT, 42.8% market share) and alternative DSL operators Iliad (Free) (21.8%) and SFR (22.8%). Numericable, the single cable operator, has a 4.2% share of the broadband market. Smaller operators, including Bouygues Telecom, share the remaining 7.3% of broadband subscribers. The three main operators – FT, Iliad and SFR – have launched fibre-based services in the last three years.¹



The regulator, ARCEP, has published a number of rulings relating to the FTTx market. It has granted alternative operators equal access rights to FT's duct network, and has also mandated the provision of a shared access point in buildings, which is available to all operators.

UFB architecture:
FTTH (GPON and P2P)
Planned bandwidth (assured):
100Mbps download, 100Mbps upload

The aim is to allow fair infrastructure competition among fibre access operators without duplication of the in-building/terminating segment. Volume-based access pricing is also enforced in densely populated areas, and ARCEP is also considering access regulation of overhead infrastructure such as poles. In less populated areas, flat-based pricing has been implemented.

Any operator may request, by the start of a fibre project, that the 'building operator' (i.e. the telecoms operator appointed by the landlord to install fibre infrastructure) installs an additional dedicated fibre to each unit. ARCEP has stated that an operator that requests additional fibre must share the installation costs with the building operator². This multi-fibre obligation applies to populous areas (Zone 1 cities).

In December 2009, the French Government announced its National Ultra-Fast Broadband Programme that is proposed to deliver 100Mbps broadband to 70% of homes by 2020 and universal coverage by 2025³. The Government has pledged USD2.7 billion to help achieve this target. As commercial operators will target the densely populated regions, the Government has focused its funds on the less populated areas. It has committed the USD2.7 billion to local authorities and operators for FTTH roll-out, and provides advisory support.

As a result of the high deployment costs, co-funding agreements have been established among the operators. FT, Iliad and SFR have agreed to co-finance roll-out in moderately populated areas (Zone 2). In July 2011, FT and Iliad also agreed to co-fund the roll-out in less densely populated areas. More recently, in November 2011, FT and SFR agreed to share the deployment of fibre to the areas that are not very densely populated. This is a significant move, since 9.8 million of the 11 million households in these areas were to be served by fibre networks from both FT and SFR. Under the November 2011 agreement, SFR will serve 2.3 million households and FT the remaining 7.5 million, thereby removing the network duplication. As per ARCEP regulations, access to both networks must be provided to all other market players.

Current and planned FTTx deployments

France Telecom conducted a successful FTTH GPON pilot which ran from June 2006 to February 2007, and covered 14 000 homes across six districts of Paris and five provincial cities. FT acquired 1000 customers, representing a population penetration of 7%. With the subsequent commercial launch, FT plans to deploy FTTH to 3600 communes (10 million households) by 2015 and to 15 million households by 2020, in conjunction with other operators (see above). By June 2011, FT had passed 819 000 homes with FTTH⁴.

Leading altnet Iliad (Free) is rolling out FTTH using Ethernet over a P2P fibre architecture. It has plans to connect 4 million homes by 2012, and had passed 450 000 by June 2011⁵.

SFR has launched FTTH services using both GPON check and P2P architectures: "Rather than adopting a blanket approach to fibre, we have chosen to make our deployment decisions on a local, case-by-case basis, alternating between GPON and P2P Ethernet."⁶ By June 2011, fibre was available to 550 000 homes⁷. SFR intends to expand its fibre coverage to 30 cities by the end of 2011 and SFR has made agreements with FT extend its fibre roll-out to less densely populated areas (see above).

Architecture, configuration, equipment and costs

FT is using two 1:8 splitters (or a 1:8 splitter followed by a 1:4 splitter), giving a maximum split ratio of 1:64. FT will also consider the use of 1:32 individual splitters. Each FT OLT laser has the capability to supply 64 subscribers.

FT's 2006–7 trial incurred total capex of less than USD6 million, an average of USD430 per home passed⁸. To achieve its 10 million household coverage by 2015, FT plans to invest around USD2.68 billion^{9,10}. This budget is expected to be enhanced by partnerships to an actual total investment budget of EUR4 billion (USD5.35 billion)¹¹. This suggests a capex per home of USD535.

SFR intends to spend EUR250 million per year until 2014 on its fibre roll-out, including expansion to 30 French cities.

Iliad (Free) plans to spend USD1.3 billion on its FTTH roll-out by 2012, by which time it expects to have connected 4 million homes. This equates to an average capex of USD325 per home passed.

A.1.2 Slovenia

Market and regulatory overview

In June 2011, Slovenia had a broadband penetration rate of 60.7% of households. There are three major broadband providers, led by Telekom Slovenije (TS) (42.7%), T-2 (18.9%) and Telemach (16.3%). Tus Telekom, Amis and other smaller broadband providers make up the remaining 22% market share. At the end of September 2010, 62.1% of broadband connections were provided over DSL, with 22.3% delivered via cable and 15% via FTTx¹². In 2010, Slovenia had 55% and 51% household coverage of FTTH and FTTC respectively, and had the third-highest percentage of homes passed by FTTH/B across Europe (44%). However, take-up of fibre was low. APEK has included fibre in Market 4 and has enforced mandated access on in-house wiring, dark fibre, manhole and concentration points and ODF. A long-run incremental cost (LRIC) approach to costing has been adopted¹³.



UFB architecture:
FTTH (P2P)
Planned bandwidth (assured):
100Mbps download, 100Mbps upload

More than EUR82 million (USD110 million) of public funding has been allocated to broadband development in Slovenia, with a focus on "white spots", areas where there is no commercial interest in deploying broadband. To date, funds have been used in areas that were chosen via two competitive funding activities – GOŠO 1 and GOŠO 2. GOŠO 1 saw the coverage of 15 921 households in white spots by December 2010 at a total project value of EUR60.8 million (USD81.4 million). GOŠO 2 will enable five projects to be undertaken, which are expected to provide high-speed broadband connectivity to 13 497 households in white areas, at a cost of EUR36.8 million (USD49 million).

Current and planned FTTx deployments

TS and T-2 are both deploying PTP FTTH infrastructure. In contrast to the position in the overall broadband market, T-2 is leading the deployment of FTTH: it had covered 300 000 sites by mid-2010, compared to 110 000 sites from TS¹⁴.

TS switched on a pilot VDSL network in 2007 and by December 2009, 335 locations had been upgraded on the VDSL network. Though only 110 000 sites were passed with FTTH by mid-2010, TS aims to cover 560 000 households (70% household coverage) by 2015.

T-2 began its roll-out of FTTH in January 2007. It is investing heavily in a nationwide IP network that combines VDSL2 and FTTH. By January 2010, T-2's FTTH connections were live in 11 cities, with work ongoing to expand availability in each of these and to extend to 21 other cities.

With investment by these two operators, FTTH/FTTB coverage has reached over 40 out of 210 municipalities in Slovenia by the end of 2011.

Architecture, configuration, equipment and costs

TS and T-2 are deploying P2P networks. TS is focusing on scalability, adaptability for new services and QoS¹³, while TS prefers P2P as it provides a simple end-to-end Ethernet architecture with mass-market CPE availability. T-2 is also focusing on scalability and QoS, and the benefit of guaranteed bandwidth levels¹⁵.

TS has chosen Iskratel to supply equipment for the FTTH roll-out¹⁶. T-2 has chosen Extreme Networks to provide core and edge switching for the P2P network¹⁵.

TS is deploying two fibre cables to each customer premises. One cable is for IP connectivity (broadband, VoIP, IPTV) and feeds into the FTTH modem at the customer premises. The other cable is used to transport the cable-TV signal. T-2 is also providing each customer with a pair of fibre cables.

TS is investing EUR450 million (USD602 million) to achieve its target coverage of 560 000 households¹⁷. This indicates a cost per household of USD1075. Generally, TS has quoted several costs per household of FTTH deployment: EUR970 (USD1299) (without civil works, 2007), EUR1310 (USD1754) (urban, including some civil works, 2008), EUR1860 (USD2490) (rural, including some civil works, 2008).

More recent indications of per-household cost can be obtained from the publicly-funded projects within GOŠO 1 and GOŠO 2, although these relate to deployments in rural areas. Two case studies, Krško and

Mozirje, saw an average connectivity cost of EUR2500 (USD3347) per household for these rural areas.

A.1.3 South Korea

Market and regulatory overview

The South Korean high-speed broadband market is one of the most advanced in the world, with 95% of households having access to 100Mbps since the end of 2009¹⁸. Since 2007, FTTB has been the dominant broadband technology¹⁹. FTTx services had been taken up by approximately 58% of the broadband population by June 2011²⁰.

An important driver of this high penetration is that, in common with many other Asian countries, a much larger proportion of people live in high-density accommodation than is the case in Europe and North America.

Also, the regulator has not introduced any particular obligations or restrictions on the deployment of fibre networks, and so operators are not obliged to provide access to their competitors. This has helped drive the penetration rate²¹.

The South Korean Government has played a vital role in broadband development through both direct funds and tax incentives. Since 1999, the Government has operated a certification scheme for buildings with over 20 households and floor area of 3300m², to give potential householders a clear indication of the standard of the in-building cabling, and the likely broadband speeds that it can support. This scheme now covers over 3.2 million households in over 5500 buildings.

Furthermore, Government programmes such as u-Korea (USD2.086 billion of public funds), which plans to deliver 1Gbps to 20% of households and 100Mbps to all by 2015, has motivated the deployment of fibre networks by operators, while the MIC's Broadband convergence Network (BcN) initiative of 2004 increased the popularity of FTTH. This has gradually encouraged operators to migrate from FTTB to FTTH. The latest ultra-fast broadband (UFB) initiative III for UFB fibre network has USD1 billion in Government funding and USD27 billion in private investment for a last-mile FTTH deployment in urban and rural areas. It aims to deliver speeds of 1Gbps to households by 2012²².



UFB architecture:
FTTH (EPON/GPON and P2P)
Planned bandwidth (assured):
100Mbps download, 100Mbps upload

Current and planned FTTx deployments

Incumbent KT is in the process of updating its FTTB network to FTTH (i.e. extending the fibre to individual dwellings within each block) with the objective of providing nationwide coverage. While it has largely used EPON, it is experimenting with GPON and is also at the forefront of WDM-PON developments. It reached its one-millionth FTTH subscriber in July 2008 and provided a 90.1% coverage of 100Mbps service by June 2011.

Alternative operator SKT (formerly known as Hanaro Telecom) has opted for a GPON architecture for its transition from FTTB to FTTH, having previously used Ethernet LAN and FTTx/VDSL. By the end of 2008, it had 2.3 million subscribers for its 100Mbps service – almost two thirds of its broadband customer base – and 3.6 million FTTH subscribers by March 2011.

A second alternative and cable operator, LG U+, is also deploying FTTH. By June 2011, 1.76 million of its 2.82 million broadband subscribers had taken up its FTTH service.

Architecture, configuration, equipment and costs

KT invested USD1 billion from 2006–10, including USD540 million in 2008 alone. 90% of South Korean households are connected to the broadband network – approximately 19 million – giving an average cost per home passed of approximately USD53²³. This is significantly lower than in many other countries, but this reflects the fact that 81% of South Korea's population lives in urban and suburban areas, and a large proportion lives in high-density apartment buildings, which reduces roll-out costs. KT's equipment vendors include Dasan Networks, Ubiquoss, Corecess, Dongwon Systems, Comtec Systems, Auvitek and Samsung.

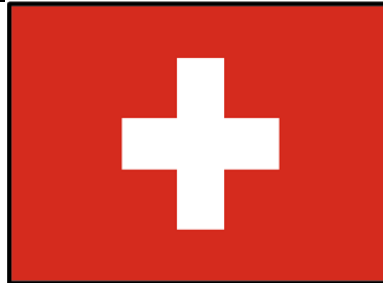
In 2007, SKT spent USD105.3 million to upgrade parts of its network, to add a further 8.3 million households to the 4.3 million households that already had 100Mbps connectivity. This represented an investment of just USD13 per household passed. However it should be noted that this was an upgrade of its existing

infrastructure rather than a new fibre deployment *per se*, so much of the infrastructure will already have been in place. SKT uses Alcatel-Lucent GPON equipment.²⁴

A.1.4 Switzerland

Market and regulatory overview

With a household penetration of 83.4%, the Swiss broadband market is dominated by the incumbent, Swisscom, which had a market share of 54.4% at June 2011. Cable operator, Cablecom, held a 17.3% share while Sunrise (formerly TDC) served 12% of broadband subscribers. Smaller operators made up the remaining 16.3% market share. Fibre penetration is high in Switzerland, with 62 000 connections at June 2011.



In 2009, the Swiss regulator (ComCom) developed a policy that set out a co-ordinated roll-out of FTTH, with multiple fibres to every building and open access to all providers under the same terms and conditions for both dark fibre (non-illuminated, Layer 1) and the network transport level (Layer 2)²⁵.

UFB architecture:
FTTH (P2P)
Planned bandwidth (assured):
100Mbps download, 10Mbps upload

ComCom has ruled that fibre installation into buildings should be done by operators but the vertical networks will belong to the building owners. In return, the operators will obtain long-term exploitation rights.

In September 2011, ComCom approved a proposal for multi-fibre deployment with a shared-cost model between operators and utility companies. However, ComCom was reluctant to give Swisscom control over the pricing structure. Since then, Swisscom has declared that it needs to re-think its partnership proposal and may have to 'go it alone'²⁶.

As a result of the active participation of the incumbent and private-sector investors, the Swiss Government has taken a 'hands-off' approach to providing public support for fibre deployment.

Current and planned FTTx deployments

In 2006, incumbent Swisscom initially deployed an FTTC architecture due to the long distance between its central offices and its customers (sometimes over 5km). In 2008, it launched its 'Fibre Suisse' FTTH plan, to lay multiple fibres (typically four) to every home. With an aim of covering 24.4% of households with 50Mbps by 2015, Swisscom is attempting to partner with infrastructure owners, such as utility companies and cable operators to reduce its costs, and offer wholesale models. Although Swisscom is not using GPON for its FTTH customers, the multi-fibre architecture that it is deploying will enable alternative operators to do so. By April 2011, 230 000 homes had been connected.

Alternative operator Sunrise has partnered with the Zurich-based electricity supplier Ewz to offer FTTH services in the city, over Ewz's fibre network.

Ewz launched its fibre-based network (Zurinet) in Zurich in June 2008. The network was initially rolled out to St. Gallen, Fribourg, Winterthur and Berne²⁷. A consortium of seven other local electricity networks also plans to roll out an FTTH network in Switzerland, but it is advocating a single-fibre architecture rather than Swisscom's multi-fibre model.

Architecture, configuration, equipment and costs

Swisscom is using a fully P2P architecture for its FTTH customers, but the nature of its multi-fibre architecture means that other operators using it will be able to deploy a wide variety of FTTH architectures. It is offering handover through co-location in its central offices, as well as in distribution points (manholes). This means that it is feasible for alternative operators to use a similar P2P architecture to that used by Swisscom, or a PON architecture with splitters installed at distribution points, or any other type of structure.

Swisscom is planning to spend USD2.2 billion on its deployment to over 1 million households over a six-year period up to 2015, an investment that, on average, equates to less than USD2200 per household connected²⁸.

A.1.5 UK

Market and regulatory overview

The UK has a highly developed and competitive broadband market, with broadband take-up at 80% in rural areas and 74% in urban areas²⁹ in March 2011. There are six³⁰ significant broadband operators and several smaller players.

The current NGA policy of the regulator (Ofcom) recognises that wholesale local access (WLA) on both active and passive products are important components of NGA, but suitable in different circumstances. For active access, Openreach, the wholesale access subsidiary of BT, offers a VULA-type Generic Ethernet Access (GEA) product (Layer 2 Ethernet unbundling product) in areas where BT has already upgraded its access network to fibre. BT maintains control of the active electronics.



UFB architecture:
FTTC / FTTH (GPON and P2P)
Planned bandwidth (non-assured):
100Mbps download, 30Mbps upload

For passive access, which is encouraged in areas where operators plan to deploy NGA before BT, physical infrastructure access (PIA) obligations are enforced. Openreach issued its most recent PIA offer in November 2011 but this has been met with some objection from industry. There are claims that Openreach's offer is 'fatal to competition' because of its high price and tight restrictions on the points of network access³¹.

Ofcom has set out specific expectations for new-build developers (who are most likely to deploy FTTH), to encourage: offering open access where there is only one network, making use of open standards, installing spare duct capacity, sub-loop unbundling and offering Active Line Access (ALA) -type wholesale bitstream products³².

After its election in 2010, the UK's Conservative-Liberal Democrat coalition Government pledged GBP530 million (USD826 million) for broadband roll-out: GBP300 million (USD465 million) from the BBC's licence fee and the remaining GBP230 million (USD360 million) from the digital switchover underspend³³. Distribution and delivery of the broadband strategy has been assigned to the Broadband Delivery UK (BDUK), a team within the Department for Culture, Media and Sport³⁴. BDUK is in the process of allocating the funds to various regions.

In May 2010, BT announced that it was increasing its investment in fibre roll-out to around GBP2.5 billion (USD3.9 billion) over the next five years, with 25% of the roll-out being FTTH. BT's investment will not rely on public-sector funding and the network will pass around two-thirds of UK homes by 2015, providing open access to all service providers on an equal basis. BT had previously undertaken to invest GBP1.3 billion (USD2.03 billion) in making super-fast download speeds available to 40% of homes by 2012³⁵.

Current and planned FTTx deployments

BT operates a GPON FTTH pilot at Ebbsfleet, with plans to connect a total of 10 000 homes³⁶. Through its BT Infinity programme, the incumbent had 4 million homes passed with FTTH/C at December 2010, and a subscriber base of over 200 000 at June 2011³⁷. In Cornwall and the Isles of Scilly, BT had provided FTTH/C to over 14 000 homes (50 subscribers) by April 2011.

Cable operator Virgin Media is deploying DOCSIS 3.0 cable to pass over 12 million homes³⁸. By June 2011, Virgin Media's 100Mbps service was available to 6 million homes.

Other planned FTTx deployments include: Thales (FTTC, 586 000 premises passed in the 'Digital Region'), IFNL (GPON, 6000 homes in Corby) and i3 group (formerly H2O, PTP, 158 000 premises in Bournemouth and Dundee), Redstone (P2P Active Ethernet, 15 000 homes in Belfast³⁹), and Velocity1 (P2P Active Ethernet, 4200 homes in Wembley^{40,41}).

Architecture, configuration, equipment and costs

BT is aiming for commonality across FTTC/H by offering its GEA wholesale product on both architectures (but with different data capacities). For FTTH, BT is using GPON with a 32-way split. Communication providers interface via a 1Gbps Ethernet optical interface at a flexibility point at the 'handover node' (local exchange)⁴². BT is using Huawei as technology vendor for both its FTTC plans⁴³ and the FTTH deployment at Ebbsfleet⁴⁴.

Based on a 2008 Broadband Stakeholders Group report, the cost per household for FTTC was originally estimated to be about GBP200 (USD312), compared with GBP1000 (USD1558) for GPON. However, deployment costs would be relatively constant across higher density areas, which are the areas that private operators would prioritise in order to secure a faster return on their investment⁴⁵. A more recent estimate of GPON deployment cost is GBP867 per household (USD1351)⁴⁶.

IFNL is using Alcatel Lucent for its GPON system with a 64-way split at Corby⁴⁷ but notes that increasing the split requires higher laser power and therefore increases the cost⁴⁷. IFNL has adopted an agnostic approach to technology, choosing P2P or GPON, depending on the scale of the deployment and the available space at the ODF⁴⁸. It will be offering access to the infrastructure via an ALA-type active interconnect interface⁴⁹.

i3 says that it will cost just over GBP30 million (USD47 million) to provide P2P (with two fibres) in Dundee (although this involves just 70 000 homes, so limited economies of scale will be realised).

A.1.6 USA

Market and regulatory overview

The household penetration of broadband in the USA stood at 66.8% at June 2011⁵⁰. This market was shared by Comcast (21.3%), AT&T (20.1%), Time Warner Cable (12.2%), Verizon Communications (10.4%), CenturyLink (6.6%) and other smaller players (29.4%)⁵¹.

Fibre penetration was reported to be 18% of households in April 2011⁵². Verizon and AT&T offer widespread FTTx services, while CenturyLink (formerly Qwest) has deployed fibre in a small number of greenfield sites, with future plans for rural coverage.

The US regulator, the FCC, has chosen to rely on infrastructure-based competition in the high-speed broadband market, rather than mandating wholesale access.

This regulatory forbearance approach to NGA deployment means unbundling obligations are not enforced. Rather, operators can choose to withhold access or sell it at a price that is not constrained by regulation. However, this only applies to new fibre networks, not the replacement of legacy networks with fibre.

Incumbent operators (Verizon, AT&T and the then Qwest) effectively did not start to install fibre until the FCC exempted them from having to provide wholesale access. The FCC's policy was therefore to rely on competition from cable operators. As a result, cable operators have historically led the telecoms operators in broadband provision, and are providing high-speed services using DOCSIS 3.0.

In March 2010, the US Government announced its National Broadband Plan. The plan aims to provide 100Mbps broadband to at least 100 million households (87% household coverage), at least 4Mbps to all households and 1Gbps to all community schools, hospitals and Government buildings by 2020. Public funding of USD15.5 billion has been provided, but only to support the universal service target.



UFB architecture:
FTTC / FTTH (GPON)
Planned bandwidth (assured):
150Mbps download, 35Mbps upload

Current and planned FTTx deployments

The country's leading telecoms operator, AT&T (which is the incumbent in 22 US states), offers FTTx services under its U-verse brand. By the end of June 2011, 29 million homes had been passed by FTTx, leaving only 1 million to be covered by the end of the year in order for AT&T to achieve its target.

Branded as FiOS Internet, Verizon's high-speed broadband service reached 16.1 million homes at June 2011. The operator failed to meet its initial 2010 year-end target of 18 million homes, and extended this to 2012. In October 2010, Verizon trialled a PON service, achieving 10Gbps upstream and downstream, and in November 2010 the operator launched a 150Mbps service.

The third fibre operator, Qwest, had 4 million units covered by its network by August 2010 and provided 40Mbps download speeds to greenfield areas. The operator finalised its merger with CenturyLink in April 2011. The merged company will focus its coverage on rural areas.

Architecture, configuration, equipment and costs

Verizon originally implemented a BPON architecture, and started a comprehensive upgrade to GPON in early 2008, after successful trials of its FiOS high-speed service in 2007⁵³. Verizon originally named Alcatel Lucent, Motorola and Tellabs as GPON vendors, although Tellabs decided to cease its GPON activity for Verizon in April 2008⁵⁴. Verizon reported that its cost per home passed fell from USD1220 in January 2006 to USD880 in December 2006⁵⁵. The operator expected a reduction to USD700 in 2010, due to simplified in-home wiring and installation processes as well as a move towards remote service activation and maintenance. However, the 2010 cost is still relatively high compared to other benchmarked countries due to the long loop lengths that are typical in the USA.

Unlike Verizon, AT&T and Qwest/CenturyLink have elected to use FTTN/VDSL2 and FTTC/VDSL2 respectively. However, AT&T is also implementing FTTH for greenfield deployments.

CenturyLink expects to spend over USD300 million annually on the fibre roll-out.

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Annex B Analysys Mason LTE link budgets

Figure B.1: Analysys Mason LTE link budget for 12/1 service [Source: Analysys Mason, 2011]

Downlink link budget		Uplink link budget	
BS power	60 W	UE power	0.2 W
BS power	47.8 dBm	UE power	23.0 dBm
BS gain	15.6 dBi	UE gain	13 dBi
BS loss	0 dB	UE loss	0 dB
RS power boost correction	-0.7 dB	UE ERP	36.0 dBm
BS ERP	62.7 dBm	Lognormal fade margin (95% area prob)	9.7 dB
Lognormal fade margin (95% area prob)	9.7 dB	Fast fade margin	0 dB
Fast fade margin	0 dB	Building penetration loss	0 dB
Building penetration loss	0 dB	Interference margin	2 dB
Interference margin	2 dB	Body loss	0 dB
Body loss	0 dB	Total margins	11.7 dB
Total margins	11.7 dB	BS antenna gain	15.6 dBi
UE antenna gain	13 dBi	BS loss	0 dB
UE loss	0 dB	No. of resource blocks allocated	95
No. of resource blocks allocated	100	Modulation scheme	QPSK 1/2
Modulation scheme	64QAM 3/4	SINR	2.0 dB
SINR	17.5 dB	Implementation loss	2.5 dB
Implementation loss	4 dB	BS noise figure	5 dB
UE noise figure	7 dB	Thermal noise per resource block	-121.5 dBm
Thermal noise per resource block	-121.5 dBm	BS reference sensitivity	-95.2 dBm
UE reference sensitivity	-76.0 dBm	Rx level at BS antenna	-99.0 dBm
Rx level at UE antenna	-77.2 dBm	Uplink path loss	131.2 dB
Downlink path loss	138.6 dB	Downlink path loss	138.6 dB
Downlink path loss	138.6 dB	Uplink path loss	131.2 dB
Uplink path loss	131.2 dB	Maximum path loss	131.2 dB
Maximum path loss	131.2 dB	BS antenna height	40 m
BS antenna height	40 m	UE antenna height	5 m
UE antenna height	5 m	Operating frequency	2,300 MHz
Operating frequency	2,300 MHz	Clutter class	suburban rural
Clutter class	suburban rural	Propagation model	Extended Hata model
Cell range (km)	3.2 12.4		

Annex C Description of the NBN Co satellite payload

The NBN Co payload has been designed to operate 26 large service beams, 75 small service beams and 10 gateway beams

It is built on the Space Systems/Loral 1300 platform which offers antenna and payload equipment accommodation and power capabilities which are among the best available. Weighing approximately 6.3 tonnes at launch, and designed for a 15 year mission life, it will be equipped with a high throughput payload consisting of eight multi-feed deployable antennas with enhanced pointing accuracy and key repeater components such as high power amplifiers and low noise amplifiers. Each spacecraft will deliver more than 16 kW total power.

Space Systems/Loral has adapted its platform to implement this large all Ka-band broadband mission using its experience from delivering Ka-band and spot-beam satellites and payloads over more than 30 years. In particular, SS/L has designed and built many of the leading “High Throughput Satellites” such as Wildblue-1, ViaSat-1 and Echostar XVII (Hughes Jupiter), and the IPSTAR satellite launched in 2005 which is currently being used to deliver 6Mbps services to NBN First Release Satellite Service customers.

The NBN Co design features four small and four large antennas. The small antennas work as a set to produce the required honeycomb pattern of 26 large beams sized to cover the continent. The large antennas work together in the same way to produce the honeycomb pattern of 75 small beams, sized and pointed to cover selected zones where higher capacity is required due to population density. The large antennas also provide the 10 gateway beams. This use of different sized service spot beams to align satellite capacity with population density has been designed by SS/L to meet the specific needs of the NBN.

In the following sections the path through the repeaters from low power receive to high power transmit is described.

The payload functions as an analogue repeater which performs frequency translation from uplink to downlink signals and provides amplification of downlink signals prior to transmission back to the ground. This payload does not process the signals at the bit level.

The low noise receive section consists of input waveguide, input filtering, and low noise amplification. All active units are provided with sufficient redundancy, to meet 15 year mission specifications. Low-noise amplifiers (LNAs) are utilised for both the gateway receive and user receive functions.

After low-noise amplification the signals from gateways are fed into the forward repeater and signals from user CPEs are fed into the return repeater.

Different frequency translations are required to map each block of spectrum on the uplink to the correct block on the downlink.

Each of the downlink blocks of spectrum contains a different number of channels of tailored bandwidth destined for different user beams according to the detailed frequency plan. The individual channels are separated using an input multiplexer (IMUX). The IMUX is individually tailored to the number and bandwidths of the channels that it is required to separate. Once separated each channel is routed to the specific high-power amplifier (HPA) to which it has been allocated.

In practice, HPAs are required to provide a highly linear amplification. Any nonlinearity would lead to the production of unwanted copies of the analogue carriers in one channel at frequencies designated for use by other channels. These copies would manifest themselves as additional interference. Where signals are using higher order modulation schemes these are more sensitive to non linearity than signals using lower order schemes.

The HPAs used on satellites are highly efficient but intrinsically non linear. Great care has to be taken to achieve linearity through active power control, variable gain channel amplifiers and specially designed linearisers. The amplifier is also operated below its nominal highest power rating which is known as output back-off. The output back-off can be changed in orbit. The thermal subsystem is designed to manage heat dissipation from the operation of these amplifiers. The amplifiers need to be shared with the 101 beams. After signal amplification, all channels are first routed to the output filtering section and then routed to their respective designated antenna for transmission to the ground.

The signals in the return repeater pass through the same functional blocks as for the forward repeater. The return repeater is designed to accommodate the many small carriers originating from the end-user CPE.

The payload contains many passive and active items of equipment and switches to be positioned on the payload panels. There are many interconnects to be implemented in coaxial cable or waveguide as performance dictates. Careful consideration must be given to the payload power, dissipation and mass budgets. Panel layouts are optimised so that excessively long cable and waveguide runs between equipment are avoided, minimising associated losses.

Annex D Principal authors

<p>AMRISH KACKER</p> <p>Position: Senior Partner, Head of Asia–Pacific Operations, Analysys Mason</p> <p>Project role: Project Director</p> <p>Qualifications: MBA, B.Eng.</p>	<p>Amrish leads the Asia–Pacific operations of Analysys Mason and is based in Singapore. He has worked across the region, specialising in the support of board-level investment and strategy decisions. He was the Project Director for the efficiency and prudency review that Analysys Mason is undertaking of the FTTP network that NBN Co is deploying.</p> <p>Amrish has successfully delivered a number of projects involving NGA/government interventions in the Asia–Pacific region. Projects of note include the following:</p> <ul style="list-style-type: none"> • Support to a wireless operator in developing its TD-LTE migration strategy and a board-level assessment of NGN investment for a multi-play operator. • Advice to a quad-play operator in the Asia–Pacific region on its strategic approach to a new FTTH network. Amrish conducted an industry workshop on NGA, on behalf of the Malaysian Access Forum Berhad. The objective of the workshop was to provide the industry with an overview of NGA architectures as a basis for understanding potential wholesale products. • Support to a large mobile operator in a South-East Asian market on developing its regulatory strategy for wholesale broadband access. We developed a detailed understanding of the building blocks of wholesale broadband access, both for legacy, DSL-based networks and for next-generation, fibre- or VDSL-based networks planned in the country. We also conducted a thorough review of the terms proposed by the incumbent in its wholesale offer, and developed a negotiating position for our client to put forward. Finally, we provided some high-level insight into the economics of the portfolio of wholesale products available to our client, and recommended a strategy to reach a positive negotiation outcome, engaging with the regulators and policy makers as well as other operators in the market. • Strategic consultancy support on Singapore’s next-generation national broadband network (NGNBN), for the IDA. We developed a cost model for deploying the NGNBN, looking at different technologies and network architectures. We considered a range of operational structures for the NGNBN and the possible procurement strategies to deliver the network. Amrish was responsible for assessing the role for wireless technologies in the NGNBN.
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	<p>Amrish has also successfully delivered a number of NGA/government interventions in Europe. Projects of note include:</p> <ul style="list-style-type: none"> • directed the development of a regional broadband intervention strategy in the UK • managed the development of a transformation roadmap for a European incumbent to migrate to an NGN • worked closely with the UK Cabinet Office in developing a proposal for the aggregation of public-sector demand for broadband over a 10 to 15-year period • managed the development of a framework for an intervention plan to extend broadband availability in a rural English country; the framework provided a basis for costs as well as potential benefits • managed the development of a roadmap for a European incumbent operator to migrate its current legacy system to an NGN. <p>Amrish has and M.B.A. from the Indian Institute of Management and a B.Eng. Degree in Computer Science from the Birla Institute of Technology and Science (Pilani).</p>
<p>DR. FRANCK CHEVALIER</p> <p>Position: Manager, Analysys Mason</p> <p>Project role: Project Manager and fibre network review lead</p> <p>Qualifications: Ph.D., B.Eng. (Honours), IET Chartered Engineer</p>	<p>Franck was the Project Manager for the efficiency and prudence review of the FTTP network that is being deployed by NBN Co. As such, he was responsible for the day-to-day running of the project and for preparing the deliverables.</p> <p>Franck has 12 years of experience in telecoms, designing multi-million-pound optical networks and providing specialist strategic and technical advice to regulators, operators and governments. Projects of note include the following:</p> <ul style="list-style-type: none"> • Managed a project for Chorus in New Zealand (TNZ) to review its FTTH network design to ensure it was cost-effective and met the Crown's objectives, for both the ultra-fast broadband (UFB) network and the rural broadband initiative (RBI) network. • Worked on a number of relevant projects for Ofcom (the UK regulator) including one on GPON competition models. He also managed a highly technical report on the capacity of future optical access networks, which was used by Ofcom to inform its review of wholesale local access. He also managed the duct survey projects commissioned by Ofcom in 2008 and in 2009, and the development of operational models in shared infrastructure, which resulted in Ofcom mandating duct and pole access in the UK to remove entry barriers for NGA alternative operators. • In the past three years, Franck has been involved in over five

	<p>technical reviews of national fibre networks and three technical due diligences of mobile networks, throughout the world.</p> <p>Franck is regularly invited to speak and chair at international conferences on the subjects of broadband, NGA, backhaul and duct access.</p> <p>Prior to joining Analysys Mason in 2005, Franck was the design authority for optical networks in the UK, France, the Middle East and Africa, while working for Nortel Networks.</p> <p>Franck has a Bachelor of Engineering (Honours) and a Ph.D. in Optical Transmission from the University of Strathclyde (UK). He is an IET Chartered Engineer and a member of the Ofcom Advisory Committee for Scotland.</p>
<p>KHOOSHIRAM OODHORAH</p> <p>Position: Consultant, Analysys Mason</p> <p>Project role: Wireless network review lead</p> <p>Qualifications: M.Sc., B.Sc.</p>	<p>Khooshiram joined Analysys Mason in 2007. He is a specialist radio planner and has a comprehensive knowledge of mobile wireless technologies, including LTE, WiMAX, HSPA, TETRA, UMTS and GSM. He has delivered a number of radio planning and coverage projects and interference analyses, including performing technical due diligences and technical reviews of wireless networks. In particular, Khooshiram was the technical lead for the due diligence of wireless broadband proposals for the National Broadband Scheme in the Republic of Ireland, and carried out a technical due diligence on a proposed digital terrestrial television (DTT) plan on behalf of a major European operator.</p> <p>Khooshiram has worked on a number of public-sector projects:</p> <ul style="list-style-type: none"> • undertook several cost modelling exercises of aggregated wide area networks and NGB networks • developed in-depth capex, opex and revenue modelling for fibre (FTTC and FTTP) and wireless (WiMAX and LTE) next-generation broadband technologies for a number of local authorities in the UK as part of grant funding applications from the UK Government and the European Commission • supported a number of UK local authorities to obtain public-sector funding by developing cost-benefit analysis of next-generation broadband – for instance, Cornwall received GBP53.5 million from the European Commission through the European Regional Development Fund (ERDF); the UK Government granted GBP31 million and GBP57 million to Somerset & Devon County Councils and to the Welsh Government, respectively. <p>Khooshiram is an accomplished user of MapInfo, Matlab, Mentum</p>

	<p>Planet and ICS Telecom radio planning tools. He has run several cell planning and interference analysis (including cross-border co-ordination) simulations for public-sector organisations, national regulators and mobile network operators worldwide.</p> <p>Prior to joining Analysys Mason, he worked as a software engineer at Ceridian Ltd and Infosys.</p> <p>Khooshiram holds a first-class B.Sc. (Honours) in Information and Communications Technologies from the University of Mauritius and a Master in Modern Digital and Radio Frequency Wireless Communications from the University of Leeds (UK). He is a member of the Institution of Engineering and Technology and has completed a detailed LTE cell planning course from Wray Castle Ltd. He is also a qualified PRINCE2 practitioner.</p>
<p>DR. TRICIA RAGOOBAR</p> <p>Position: Associate Consultant, Analysys Mason</p> <p>Project role: Consultant</p> <p>Qualifications: Ph.D., M.Sc., B.Sc.</p>	<p>Tricia joined Analysys Mason in 2011. She has a comprehensive knowledge of the regulatory and socio-economic impact of fixed NGA network deployment in both Europe and on an international scale, and a deep understanding of the market factors that influence the development of NGA.</p> <p>Tricia has conducted interviews with key operators and regulators across Europe in order to enhance her knowledge of the NGA situation in these countries, and to provide recommendations for accelerating the development of the NGA markets. She has also investigated the options for financial support for NGA deployment. She has presented her work at various international telecoms conferences (Tokyo, Copenhagen and Budapest) and has also published her research on NGA regulation and development in well-recognised telecoms journals, such as <i>Telecommunications Policy</i>.</p> <p>Tricia has also contributed to the delivery of several major broadband projects within Analysys Mason, including a proposal for fibre network deployment in Africa and a market analysis of communications options for the oil and gas sector in the UK. She has also undertaken work on spectrum availability, DTT market analysis and frequency (digital dividend) allocation techniques for the Greek regulator.</p> <p>Tricia holds a Ph.D. in NDA development and regulation. She also has an M.Sc. Degree in Communications Technology and Policy from the University of Strathclyde (UK), and a B.Sc. (Honours) in Electrical and Computer Engineering from the University of the West Indies.</p>
<p>PHILIP BATES</p> <p>Position: Senior</p>	<p>Philip has worked in the telecoms and data networking industry for nearly 30 years. He has extensive experience in the satellite industry, having successfully delivered a wide variety of projects for multiple</p>

<p>Manager, Analysys Mason</p> <p>Project role: Project Manager</p> <p>Qualifications: M.B.A., M.A.</p>	<p>satellite companies such as SES and Inmarsat. Projects of note include the following:</p> <ul style="list-style-type: none"> • For a global fixed satellite operator, managed a study to forecast the addressable market for satellite broadband services in Europe taking account of the current status of DSL, cable and mobile broadband roll-outs, and the expected improvements in the coverage and speed of terrestrial technologies in the next decade. • For the same client, managed a study to forecast the demand for satellite capacity for telecoms applications in developing regions (Middle East, North Africa, sub-Saharan Africa and Latin America) over ten years, and estimate the extra demand that may result from the introduction of next-generation capacity offering greater performance at a lower cost per bit. • For a leading satellite operator, managed a major primary research programme on the future demand for direct-to-home (DTH) satellite broadcasting capacity in Europe. • Managed a project for the UK Broadband Stakeholder Group to look at the comparative costs of delivering next-generation broadband services in the UK by wireless and satellite means. • Managed the due diligence of a company providing IP satellite capacity to mobile operators, Internet service providers (ISPs) and public- and private-sector end users in sub-Saharan Africa. <p>Prior to joining Analysys Mason in 2008, Philip held management positions with the mobile satellite venture ICO Global Communications, British Telecom, and a number of technology start-ups. At ICO Global Communications:</p> <ul style="list-style-type: none"> • Was responsible for negotiating interconnection contracts with telecoms operators in 12 countries (ICO aimed to provide global mobile phone service using satellites, and raised over USD3 billion in funding from leading telecoms operators worldwide). • Subsequently, worked on ICO's wholesale service proposition and distribution strategy. • Was promoted to head of regional development, where he led a small team which acted as the main interface between the head office in London and ten international offices, and managed the company's relationship with investors in Japan, Korea, Malaysia and Indonesia. <p>Philip holds an M.B.A. from Warwick Business School in the UK),</p>
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	and an M.A. in Engineering from the University of Cambridge, also in the UK. He is a Chartered Engineer and a member of the Institution of Engineering and Technology (IET).
<p>DAVID ROBSON</p> <p>Position: Associate, Analysys Mason</p> <p>Project role: Satellite Expert</p> <p>Qualifications: Ph.D., M.A., B.A.</p>	<p>David has over 30 years' experience in the satellite industry. He started his career as an AOCs Engineer at BAE Systems within the Skynet 4 Project Office before transferring to the Communications Satellite software team, where he was responsible for the development of around one million lines of design code. He became expert in the use of this software and in the design of antennas and communications payloads, and has a number of key patents to his name.</p> <p>Since then, David has held several positions within leading satellite companies, including Inmarsat, SES and Astrium. He has particular expertise in the design of broadband and broadcast satellite services and their position with respect to terrestrial fixed-line and wireless systems. Projects of note include the following:</p> <ul style="list-style-type: none"> • supported the UK Space Agency (UKSA) in completing the Innovation and Growth Strategy actions on broadband and green credentials of satellites • was responsible for collaboration with Hughes Network Systems on Project 21, which then became ICO Global Communications • led the UK Ministry of Defence (MOD) Skynet 5 pre-feasibility study • co-ordinated the mobile systems R&D programme, which led to the funding and development of the Astrium Digital Signal Processor • led a series of mobile satellite proposals before becoming Account Manager responsible for the success of Inmarsat 4 – at over USD700 million, this was the largest commercial contract ever awarded at the time • became the lead interface to the UK Government and interfaced at Ministerial level in arguing the case for UK contributions to the ARTES programme • led Astrium's payload development and led industry efforts to seek the UK public contribution to the HYLAS and Alphasat projects • led the UK Case 4 Space team on behalf of the Space Industry and helped draft the Space IGT final report. <p>In 2007, David founded Fell Systems, a company specialising in the provision of consultancy services to the satellite industry. He has supported work in building a case for increased use of space infrastructure to help meet political and economic objectives in the UK.</p>

	<p>He is now also working with partners to develop and demonstrate next-generation TV networks using Ka-band satellite capacity. He has completed a feasibility study of satellite-based video on demand (VoD) services and a pilot being developed in partnership with a European broadband satellite operator is now nearing the demonstration stage.</p> <p>He is also a member of the GEO Satellite Development team at Surrey Satellite Technology Ltd (SSTL) working on satellite systems and communications payload designs, product positioning and sales support.</p> <p>David has a M.A. and a B.A in Physics from Oxford University in the UK, and a Ph.D. in Theoretical Particle Physics from Liverpool University, also in the UK.</p>
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Annex E Declaration

E.1 Declaration

Analysys Mason has made all the inquiries that Analysys Mason believes are desirable and appropriate and that no matters of significance that Analysys Mason regards as relevant have, to Analysys Mason's knowledge, been withheld from the ACCC or the Court.

Analysys Mason declares that each of the opinions expressed in this report is wholly or substantially based upon Analysys Mason's specialised knowledge.

Amrish Kacker for Analysys Mason Pte Ltd



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26 September 2012

E.2 Disclosure of previous work undertaken for NBN Co

Analysys Mason has undertaken previous work for NBN Co. Analysys Mason believes that there is no conflict of interest with the assessment undertaken in this report for the following reasons:

- the scope of the technical review of NBN Co's fibre, fixed wireless and satellite networks did not include any work of the kind previously undertaken by Analysys Mason
- the team that led the present assessment was not involved in the previous work
- information provided by NBN Co and the work delivered in the context of the previous project is securely stored in Analysys Mason's Project Repository and the team involved in the present project does not have access to this information
- the team that led the previous project has now left Analysys Mason to form an independent company known as Implied Logic Ltd.¹⁰¹

¹⁰¹ <http://www.impliedlogic.com/Company/>.

Annex F Glossary

The acronyms given here are those principally used in this report. Where an acronym is defined in another entry, it is given in italics.

10G	10 Gigabit
3G	Third generation
3GPP	3G Partnership Project
AAR	Access aggregation region
ABHT	Average busy-hour throughput
AC	Alternating current
ACCC	Australian Competition & Consumer Commission
ACMA	Australian Communications and Media Authority
ADSL	Asymmetric digital subscriber line
AG-EVC	Aggregation <i>EVC</i>
ALA	Active line access
AN	Aggregation node
APEK	Agencija za pošto in elektronske komunikacije
APON	ATM PON
APS	Administration provisioning subsystem
ARCEP	Autorité de Régulation des Communications Électroniques et des Postes
ATA	Analogue telephone adapter
ATM	Asynchronous transfer mode
AUD	Australian dollars
AVC	Access virtual circuit
BDUK	Broadband Delivery <i>UK</i>
BPON	Broadband passive optical network
BPSK	Binary <i>PSK</i>
BS	Base station
BT	British Telecommunications plc
CBD	Central business district
CCA	Competition and Consumer Act 2010
CCTV	Closed-circuit television
CDMA	Code division multiple access
CIR	Committed information rate
CMS	Central management subsystem
CoS	Class of service
CPE	Customer premises equipment
CRA	Customer relationship agreement
CSA	Connectivity serving area
CVC	Connectivity virtual circuit

CWDM	Course <i>WDM</i>
DA	Distribution area
dB	Decibel
DC	Direct current
DCN	Data communications network
DECT	Digital enhanced cordless telecommunications
DFN	Distribution fibre network
DHCP	Dynamic host configuration protocol
DL	Downlink
DNS	Domain name system
DPC	Data processing centre
DSCP	Differentiated services code point
DSL	Digital subscriber line
DT	Deutsche Telecom
DTH	Direct to home
DTV	Digital television
DVB-RCS	Digital video broadcasting – return channel via satellite or (return channel over system)
DWDM	Dense wavelength division multiplexing
EDGE	Enhanced data rates for <i>GSM</i> evolution
EFMA	EFM Alliance
EIR	Equipment identity register
EIRP	Effective isotropic radiated power
EMS	Element management system
eNodeB	Enhanced node B
EPON	Ethernet passive optical network
ESA	Exchange serving area
ESOA	European satellite operators' association
E-UTRAN	Enhanced <i>UTRAN</i>
EVC	Ethernet virtual connection
EV-DO	Evolution data-optimised
FAN	Fibre access node
FCC	Federal Communication Commission
FD	Frequency division
FDA	Fibre distribution area
FDD	Frequency division duplexing
FDH	Fibre distribution hub
FD-LTE	FD LTE
FDMA	Frequency division multiple access
FE	Fast Ethernet
FSA	Fibre serving area
FSAM	Fibre serving area module
FSAN	Full service access network
FSS	Fixed services satellite

FT	France Telecom
FTTB	Fibre to the building
FTTC	Fibre to the cabinet
FTTH	Fibre to the home
FTTP	Fibre to the premises
FTTx	Fibre to the x
FY	Financial year
GBE	Government business enterprise
GBP	Great Britain pounds
Gbps	Gigabits per second
GE	Gigabit Ethernet
GEA	GE Access
GEPON	GE PON
GNAF	Geocoded national address file
GPON	Gigabit PON
GPRS	General packet radio service
GRE	Generic routing encapsulation
GSM	Global system for mobile communications
GTO	Geostationary transfer orbit
HD	High definition
HDTV	High-definition television
HFC	Hybrid fibre coaxial
HOM	Higher order modulation
HSDPA	High-speed downlink packet access
HSPA	High-speed packet access
HSS	Home subscriber server
HSUPA	High-speed uplink packet access
HTS	High throughput satellites
ICO	Interconnection Offer
IEEE	Institute of Electrical and Electronic Engineers
IET	Institution of Engineering and Technology
IMS	IP multimedia system
IMT	International Mobile Telecommunications
IP	Internet protocol
IPTV	Internet protocol television
ISP	Internet service provider
ITU	International Telecommunications Union
ITU-T	ITU Standardization
L0	Layer 0
L1	Layer 1
L2	Layer 2
L3	Layer 3
LAN	Local area network

LFJ	Local fibre joint
LFN	Local fibre network
LIFD	Low impact facilities determination
LTE	Long term evolution
MBMS	Multimedia broadcast multicast service
Mbps	Megabits per second
MDU	Multi-dwelling unit
MGCP	Media gateway control protocol
MIMO	Multiple-input multiple output
MME	Mobility management entity
MOD	(UK) Ministry of Defence
MPLS	Multi-Protocol Label Switching
NBN	National broadband network
NC	Nucleus Connect
NCN	National connectivity network
NFAS	NBN Co fibre access service
NG PON	Next generation PON
NGA	Next-generation access
NGN	Next generation network
NGNBN	Next generation national broadband network
NGNBN	Next generation NBN
NMS	Network management system
NNI	Network-network interface
NTD	Network termination device
OCR	Optical consolidation rack
ODF	Optical distribution frame
OFDF	Optical fibre distribution frame
OFDMA	Orthogonal FDMA
OLT	Optical line terminal
ONT	Optical network terminal
ONU	Optical network unit
OSI	Open systems interconnection
OTA UE	Over-the-air user equipment
OTT	Over-the-top
P2P	Point-to-point
PCP	Primary connection point
PCRF	Policy charging rule function
PDN-GW	Packet data network gateway
PIA	Physical infrastructure access
PIR	Peak information rate
PoI	Point of interconnect
PON	Passive optical network
POP	Point of presence

PoP	Provide or pay
PSK	Phase shift keying
PSTN	Public switched telephone network
PTP	Point to point
QAM	Quadrature amplitude modulation
QoS	Quality of service
QPSK	Quadrature phase shift keying
RB	Resource block
RF	Radio frequency
RFP	Request for proposal
RGW	Residential gateway
SAE	System architecture evolution
SAU	Special Access undertaking
SC-FDMA	Single carrier FDMA
SCS	Service control subsystem
SDU	Single-dwelling unit
S-GW	Serving gateway
SINR	Signal-to-interference noise ratio
SIP	Session initiation protocol
SKT	SK Telecom
SME	Small/medium-sized enterprise
SNR	Signal-to-noise ratio
SP	Service provider
SSTL	Surrey Satellite Technology Ltd
TC_1	Traffic class 1
TC_2	Traffic class 2
TC_3	Traffic class 3
TC_4	Traffic class 4
TC-MC	Traffic class multi-cast
TD	Time division
TDD	Time division duplexing
TD-LTE	Time division-Long Term Evolution
TDM PON	Time division multiplexing PON
TDM	Time division multiplexing
TEBA	Telstra equipment building access
ToP	Take or pay
TPEP	Transparent performance enhancing proxy
TRIA	Transmit Receive Integrated Assembly
TS	Telekom Slovenije
TV	Television
UFB	Ultra-fast broadband
UK	United Kingdom
UKSA	United Kingdom Space Agency
UL	Uplink

ULLS	Unconditioned local loop service
UMTS	Universal mobile telecommunications system
UNI	User-network interface
UNI-D	Data UNI
UNI-V	Voice UNI
US	United States
USA	United States of America
USD	US dollar
USIM	Universal subscriber identity module
UTRAN	UMTS radio access network
VDSL	Very-high-bit-rate digital subscriber line
VLAN	Virtual LAN
VoD	Video on demand
VoIP	Voice over internet protocol
VPN	Virtual private network
VSAT	Very small aperture terminal
VULA	Virtual unbundled local access
WBF	Wavelength blocking filter
W-CDMA	Wideband CDMA
WDM PON	Wavelength division multiplexing PON
WDM	Wavelength division multiplexing
WiMAX	Worldwide interoperability for microwave access
WSA	Wireless serving area
WSAM	Wireless serving area module
XG PON	10G PON
XG	10th generation
XPIC	Cross-polarisation interference cancellation