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Report for Webb Henderson

Review of the efficiency and prudency of NBN Co's fibre and wireless network design

2 March 2012

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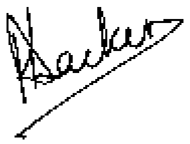
Acknowledgement

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



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2 March 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 and wireless 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 prudency of NBN Co's design.

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

- in reviewing the 'prudency' 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 and fixed wireless network design has focussed on the following areas, which we consider to be key to an assessment of efficiency and prudency:

- 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 network and fixed wireless network. This has included:

- the Network Design Rules, which serve as the basis for establishing the efficiency and prudency of NBN Co's initial network design during the SAU approval process and which provide the baseline for the operation of the prudency provisions in Schedule 8 (Prudency) of the SAU[2]

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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 prudency and efficiency perspective. In practice, this has meant that our analysis of some design decisions has, depending on the subject matter, focused on the prudency or efficiency of the particular choice, but not both. Accordingly, where an assessment in our report only refers to the efficiency or the prudency 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.

2 http://www.nbnco.com.au/assets/documents/nbn-network-design-rules.pdf.

- other publicly available NBN Co documents, as further described in Section 2.5[3]
- 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 and wireless networks reflects an efficient and prudent network design*."

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

Efficiency and prudency 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.

3 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 prudency 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% 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.

- 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.

Efficiency and prudency 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:

► *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.

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

- 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.

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, and speeds of up to 12Mbps to the remaining 7% of Australian 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 ongoing 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 prudency of NBN Co's design of its fibre and wireless networks.

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 and wireless networks reflects an efficient and prudent network design*."

Our instructions specifically state that, in undertaking our assessment of whether, and the extent to which, NBN Co's design for its fibre and wireless 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 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 our 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*.

Where elements of NBN Co's network design have been specified at a policy level, Analysys Mason has:

- sought to explicitly identify the relevant elements as being specified by the Australian Government in its analysis, and
- either:
  - where no substantive design decision has had to be made by NBN Co in fulfilling that policy requirement, not assessed these elements, or
  - where a substantive design decision has had to be made by NBN Co in fulfilling that policy requirement, limited its 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.

Accordingly, Analysys Mason has focused its analysis on the choices or decisions that have had to be made by NBN Co itself in relation to the design of its networks.

For each major decision in respect of the design of NBN Co's fibre and fixed wireless networks, 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 prudency and/or efficiency perspective.

2.3 Our approach

From our perspective, we consider that the key decisions that influence the efficiency and prudency 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 and wireless 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 and fixed wireless networks in other leading jurisdictions.

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

- in reviewing the 'prudency' 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 prudency 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 practically possible to evaluate all design decisions from both a prudency and efficiency perspective. In practice, this has meant that our analysis of some design decisions has, depending on the subject matter, focused on the prudency or efficiency of the particular choice, but not both. Accordingly, where an assessment in our report only refers to the efficiency or the prudency 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 prudency 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 30 years. The purpose behind this line of inquiry is to ensure that our analysis of NBN Co's key technology decisions are 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 prudency 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 prudency 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 or 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 prudency 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 network 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 prudency and efficiency of NBN Co's design of its fibre and fixed wireless 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 prudency and efficiency analysis have regard to this fact. For example, while an operator may deploy a fixed wireless 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 National Broadband Network, NBN Co's design decision for its fixed wireless network 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 and fixed wireless network in an integrated manner would not otherwise be considered and would result in a situation where NBN Co's network design would be held to a lower prudency 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 and fixed wireless networks in a collective manner, where relevant.

2.4 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 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
- **Section 6** 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.

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 prudency of NBN Co's fixed wireless network design
- **Annex C** describes the expertise and experience of the principal authors of this report
- **Annex D** 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 E** provides an explanatory list of the acronyms used throughout this report.

2.5 Documents reviewed in the preparation of this report

In undertaking our assessment of the efficiency and prudency 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:

- NBN Co's Network Design Rules[5] which serve as the baseline for the network design contemplated within the prudency provisions in Schedule 8 (Prudency) of the SAU
- NBN Co's Product and Pricing Overview for Service Providers, dated December 2011 (and the preceding version)[6]
- NBN Co's Consultation Paper: Proposed Business and Enterprise Fibre Access Services, dated 23 December 2011[7]
- NBN Co's Network Availability Discussion Paper[8]
- NBN Co's Network-Network Interface Discussion Paper[9]
- NBN Co's Traffic Class Performance Paper for the NBN Co Fibre Access Service[10]
- NBN Co's Wholesale Broadband Agreement[11]
- NBN Co's Facilities Access Product overview paper[12]
- NBN Co's Multicast: Feature, Technology and Pricing overview for multicast over fibre[13]
- NBN Co's Fair Use Policy[14]

5 http://www.nbnco.com.au/assets/documents/nbn-network-design-rules.pdf.

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

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

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

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

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

11 http://www.nbnco.com.au/getting-connected/service-providers/wba.html.

12 http://www.nbnco.com.au/assets/documents/facilities-access.pdf.

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

- NBN Co Points of Interconnect documentation on the ACCC website.[15]

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.

Our assessment reflects the documentation and position taken by NBN Co as at 2 March 2012. Any modifications (if any) to the architecture, product roadmap or product construct made by NBN Co after 2 March 2012 may not be reflected in this report.

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

15 http://www.accc.gov.au/content/index.phtml/itemId/952292.

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').[16]

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.

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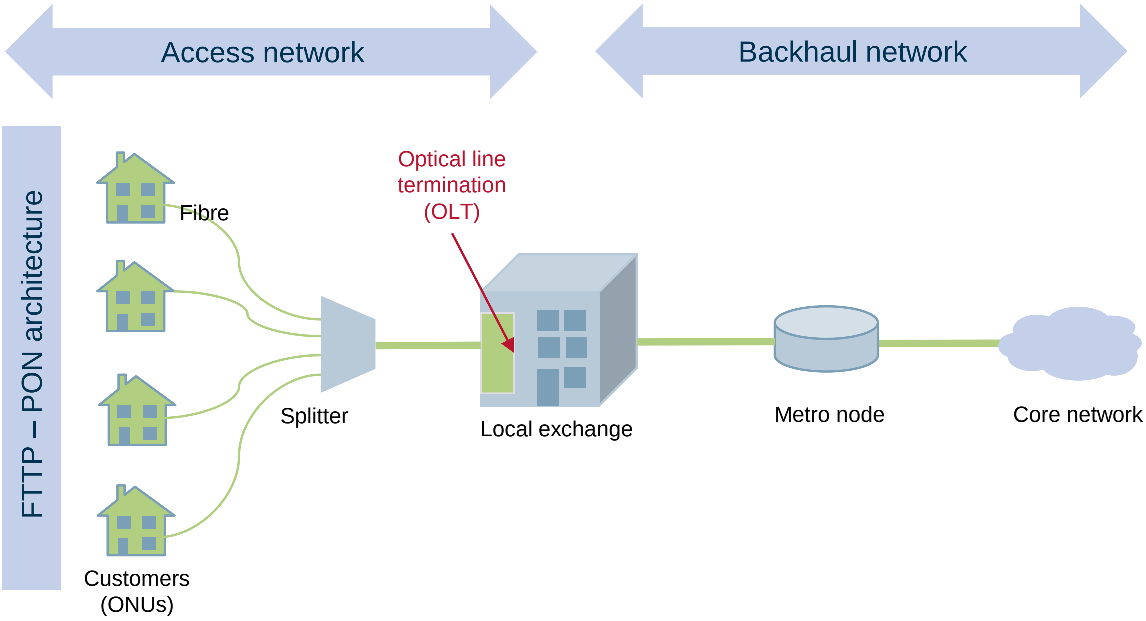
16 Analysys Mason for Ofcom (2009), *Fibre Capacity Limitations in Access Networks. Available at: http://www.ofcom.org.uk/research/technology/research/emer_tech/fibre/.*

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:

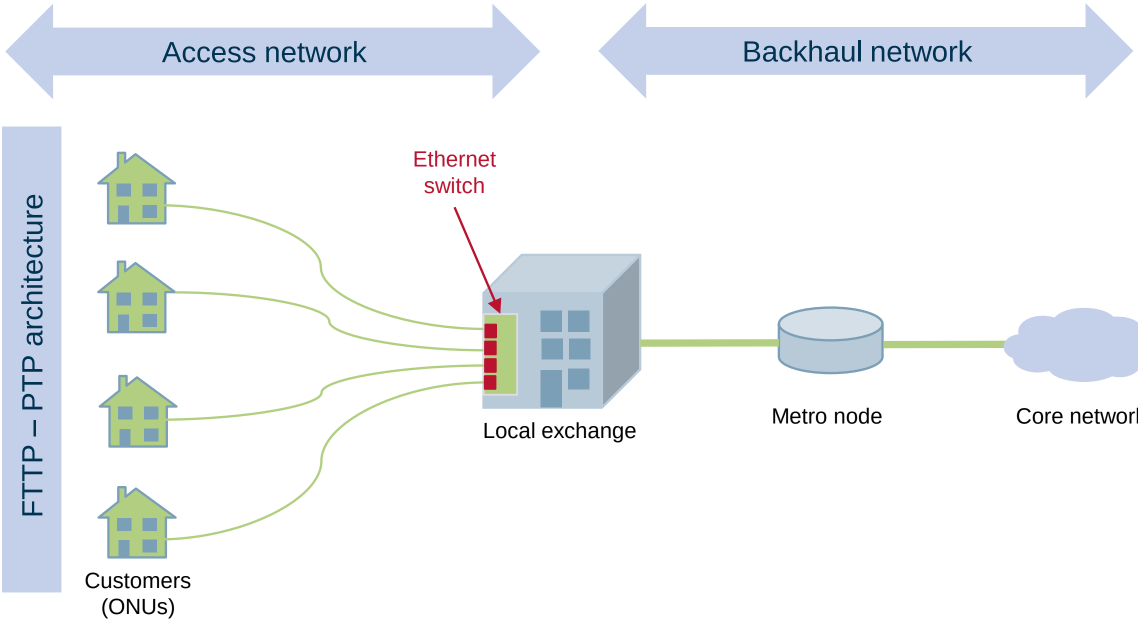
- **Ethernet PON (EPON)** is an IEEE/EFM standard for using Ethernet in the last mile (IEEE 802.3ah). EPON is applicable for data-centric networks, as well as full-service voice, data and video networks. It is less popular in Europe and the USA than in Japan and South Korea, where it dominates. The current 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 below.

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),[17] which provides 10Gbps downstream and 2.5Gbps upstream (four times the download speed of the previous generation of GPON).

[17] 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 EPON[18] ports have been deployed worldwide.

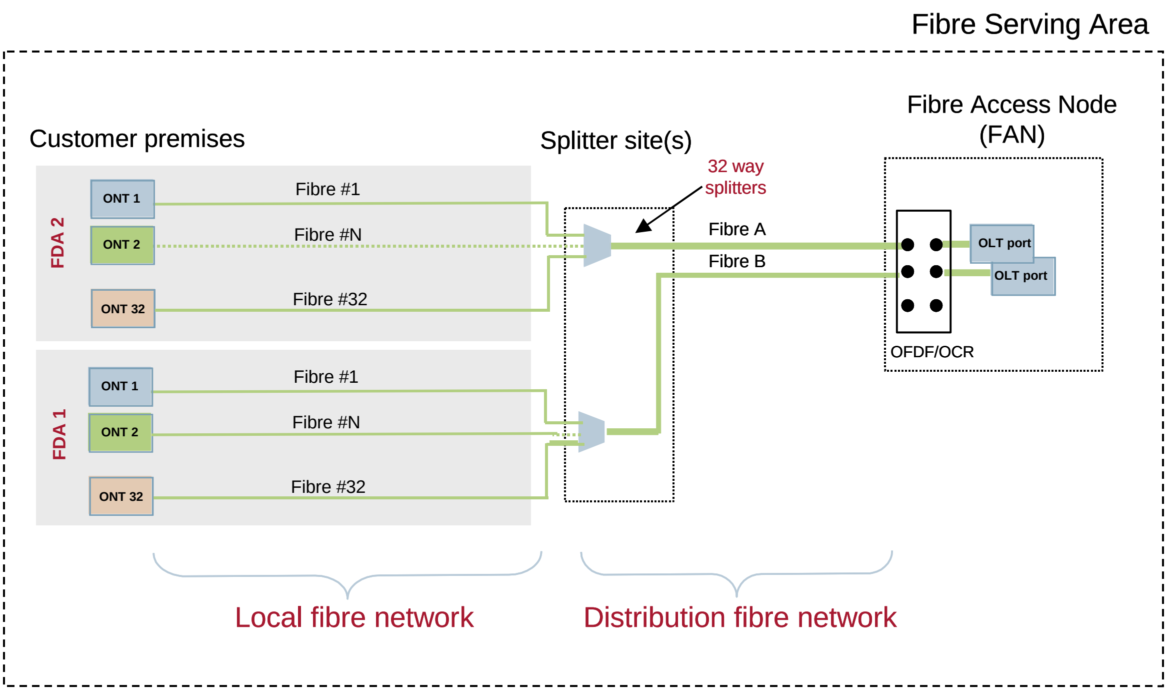
The next generation of the IEEE family of PON is the 10 GEPON (Gigabit Ethernet PON). This was standardised by the IEEE P802.3av task force in September 2009 and is backwards-compatible with IEEE 802.3ah EPON.

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]



18 Analysys Mason FTTx Forecast, 2011.

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

- **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:

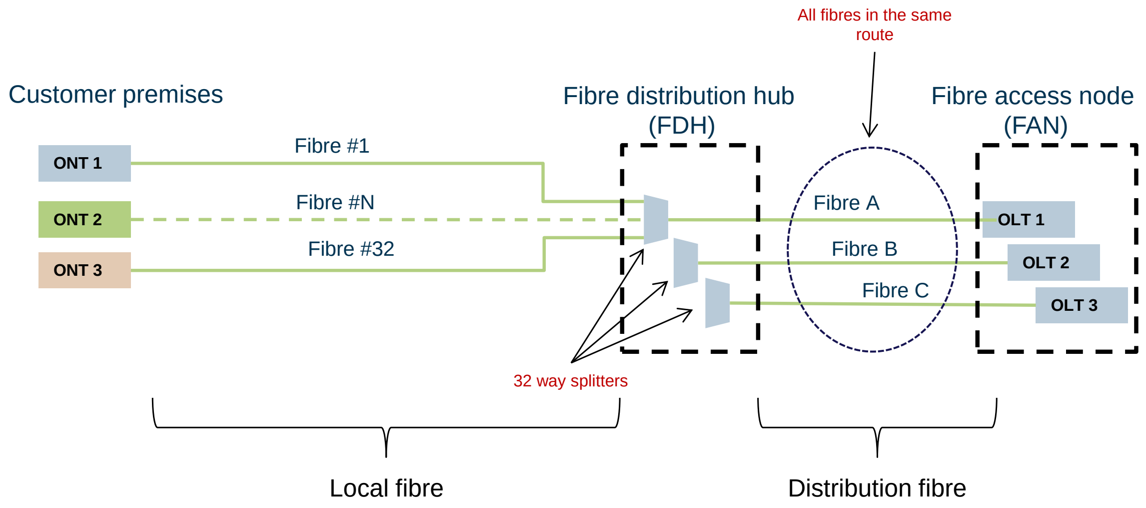
- centralised architecture
- distributed architecture
- cascaded architecture.

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.[19]

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]

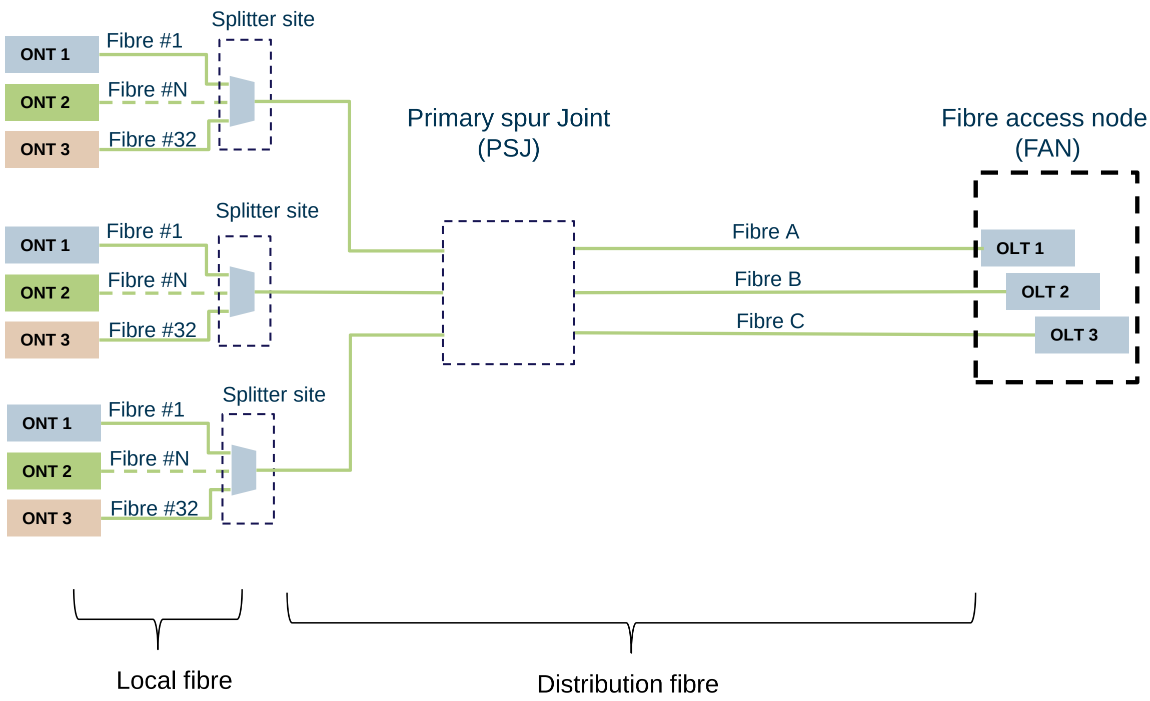
19 Please note that, in this report, a centralised architecture does not refer to the case where all splitters are hosted in the FAN site, but refers to an architecture where all splitters are centrally located in a remote cabinet.

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 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]

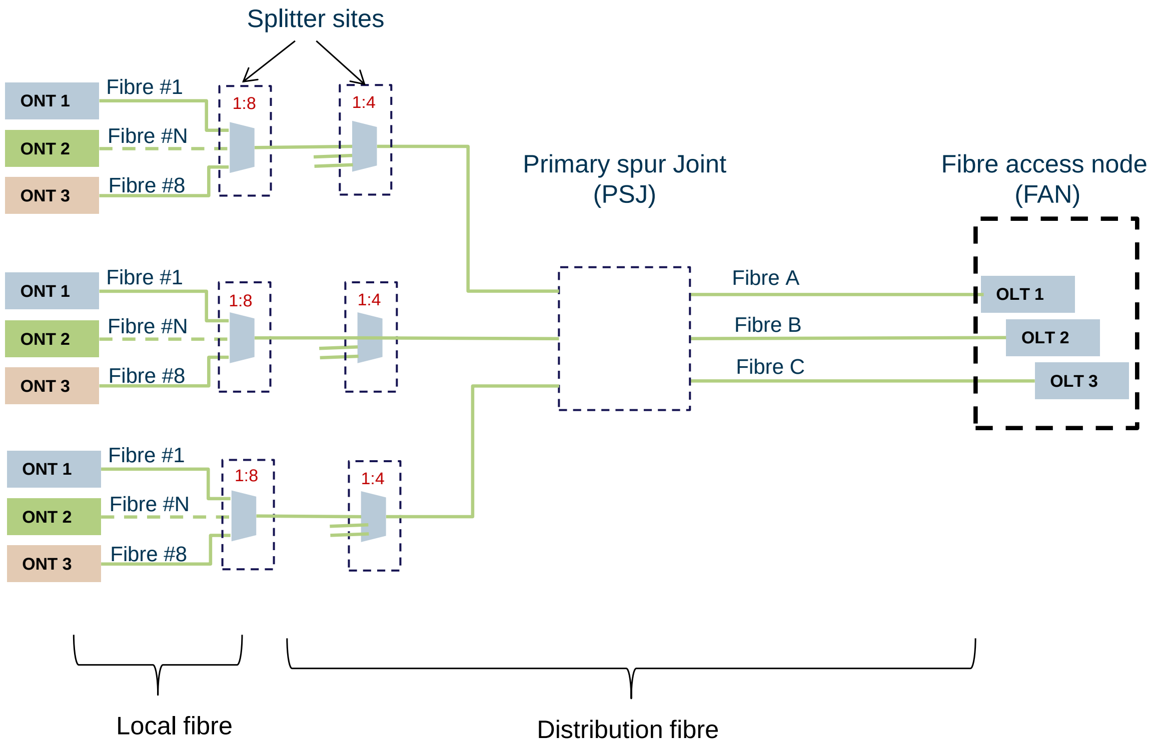


A distributed architecture uses a single level of split (a 1×32 splitting scheme is illustrated above) with the splitters distributed in the field, closer to the end users. In a distributed architecture, splitters are usually located in either underground footboxes/manholes or in enclosures on poles (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.

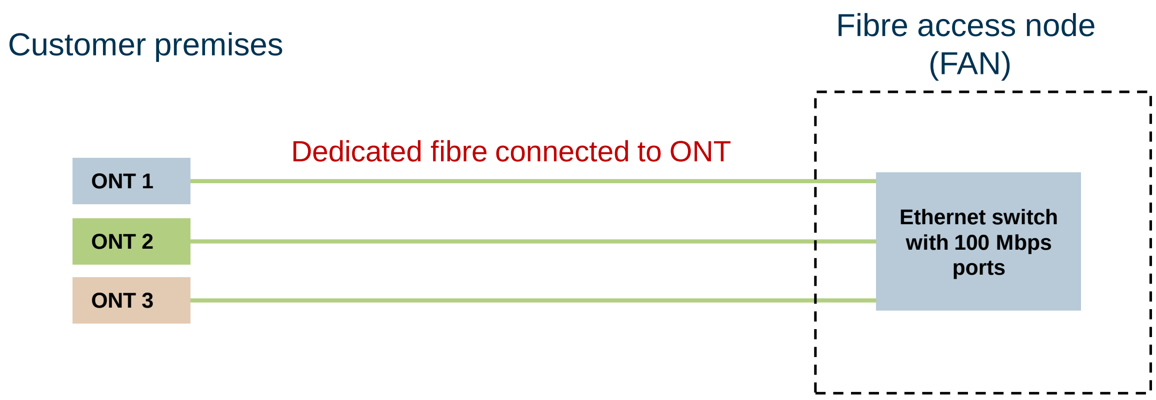
- **1000BASE-BX10**, the Gigabit Ethernet equivalent of 100BASE-BX10, also specified to operate over 10km.

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 below, 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,[20] 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,[21] 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%.[22] Furthermore, Verizon trialled an XG PON 2 service in October 2010, and achieved 10Gbps both upstream and downstream.[23]

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,[24] 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.[25] However, this trend is slowly changing now that many European incumbents are starting to heavily invest in GPON technology to address the residential market.

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

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

22 Analysys Mason NGA Tracker, 2011.

23 Analysys Mason NGA Tracker, 2011.

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

25 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.

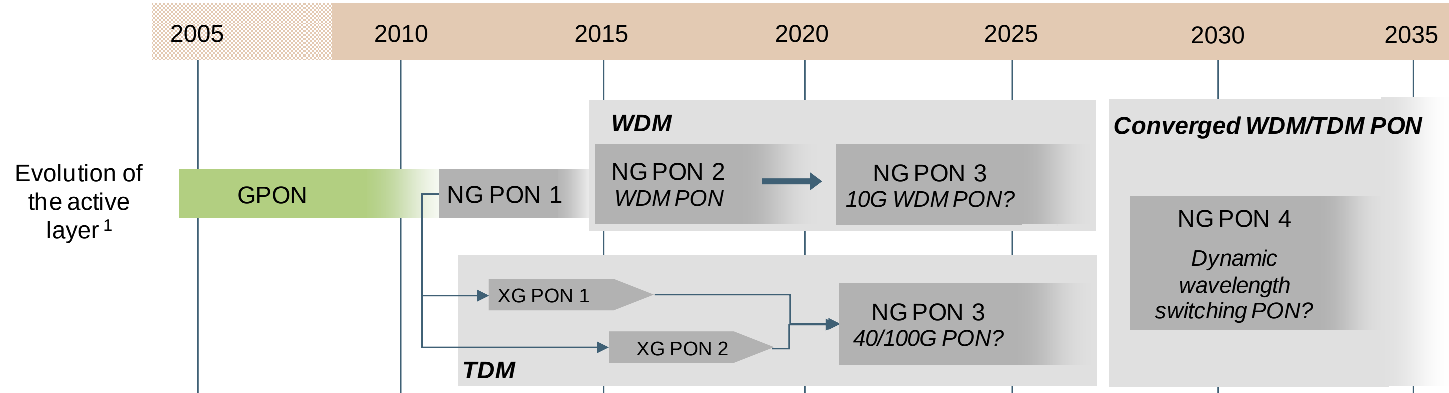
It is important to note that developments beyond 2015 are difficult to predict with any certainty and should therefore be considered as indicative only.

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]

Expected deployment



	2005–2010	2010–2015	2015–2020	2020–2025	2025–2035
Max capacity per user [2]	DL 2.5Gbit/s UL 1.25Gbit/s	DL 10Gbit/s UL 2.5Gbit/s	DL 10Gbit/s [3] DL 1Gbit/s [4] UL 10Gbit/s [3] UL 1Gbit/s [4]	DL 40 or 100Gbit/s [3] DL 10Gbit/s [4] UL 10Gbit/s [3] UL 1–10Gbit/s [4]	DL 100Gbit/s UL 10Gbit/s
Guaranteed capacity per user [2]	DL 40–80Mbit/s UL 20–40Mbit/s	DL 160–320Mbit/s UL 40–80Mbit/s	DL 160–320Mbit/s [3] DL 1Gbit/s [4] UL 160–320Mbit/s [3] UL 1Gbit/s [4]	DL 310–780Mbit/s [3] DL 10Gbit/s [4] UL 160–320Mbit/s [3] UL 1–10Gbit/s [4]	DL >10Gbit/s UL >1Gbit/s
Reach	20–30km	60km	80km	100km	>100km
Spilt	32/64:1	64:1	64/128:1	>128:1	=1024:1 [5]

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),[26] 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.

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.

26 Where XG PON is synonymous with 10G PON.

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.

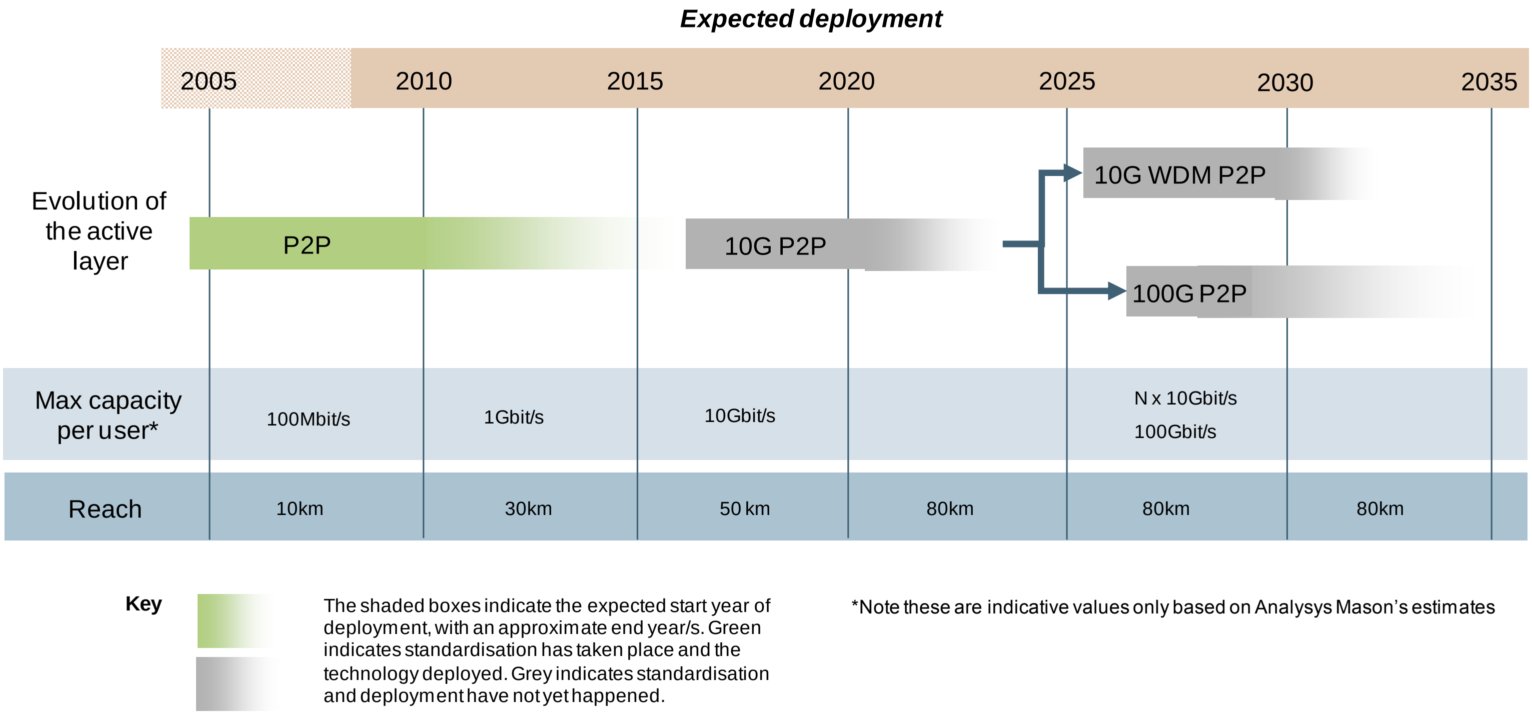
Please refer to Section 7.2.4 of the Analysys Mason report on access networks for Ofcom for a detailed discussion on the barriers to PON evolution.

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.[27] 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.

27 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.

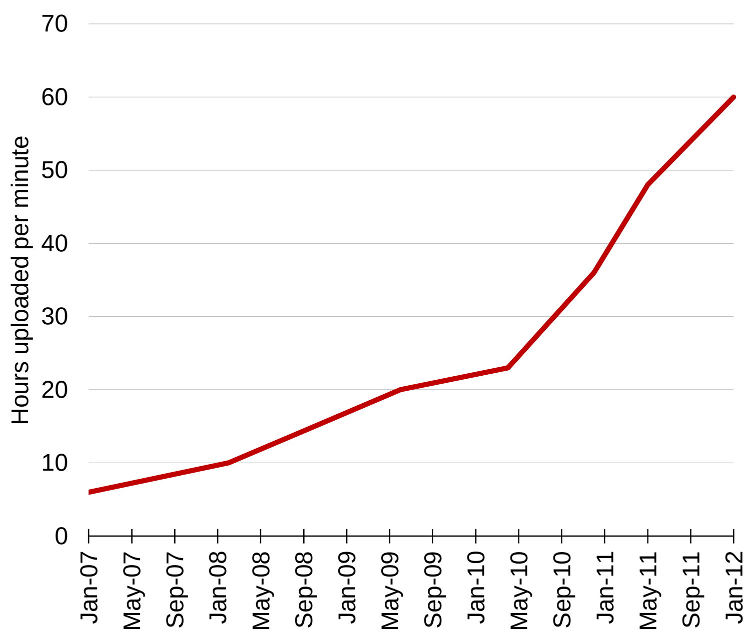


Figure 3.12: Hours of video uploaded to YouTube every minute [Source: YouTube]

► *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[28]

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

Timescale	Upload type	Upstream bandwidth requirements
2015	• Upload 3D video • Upload large file (50MB in 1 minute)	• 30Mbps • 10Mbps
2025	• Upload HD 3D video • Upload large file (300MB in 20 seconds)	• 100Mbps • 120Mbps
2035	• Upload ultra-HD 3D video • Upload large file (1GB in 20 seconds)	• 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.

28 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.

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 show the downlink and uplink bandwidth requirements.

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

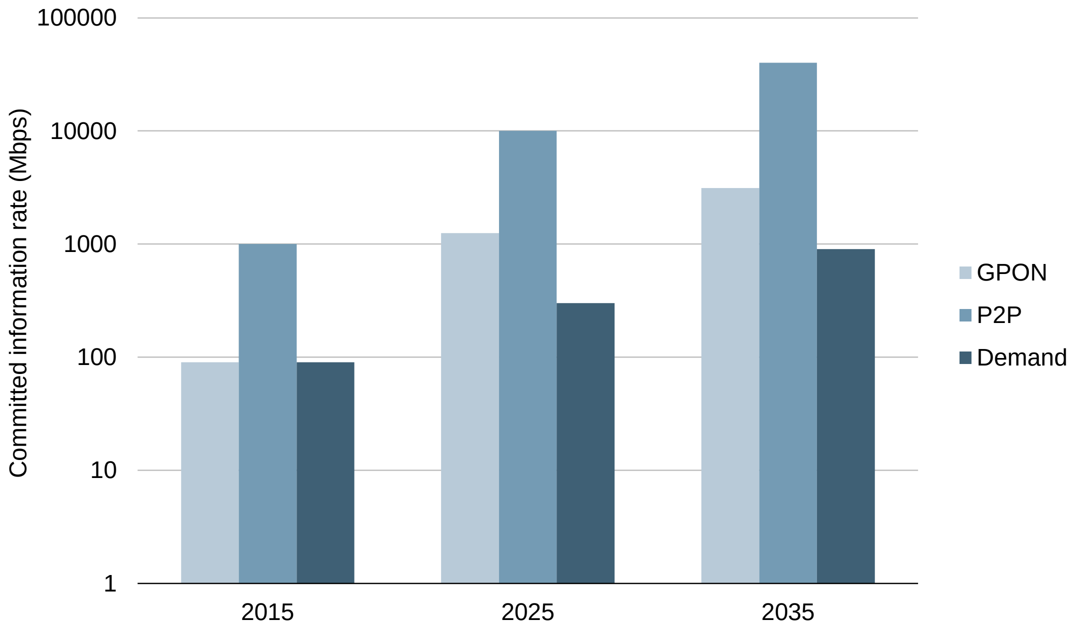
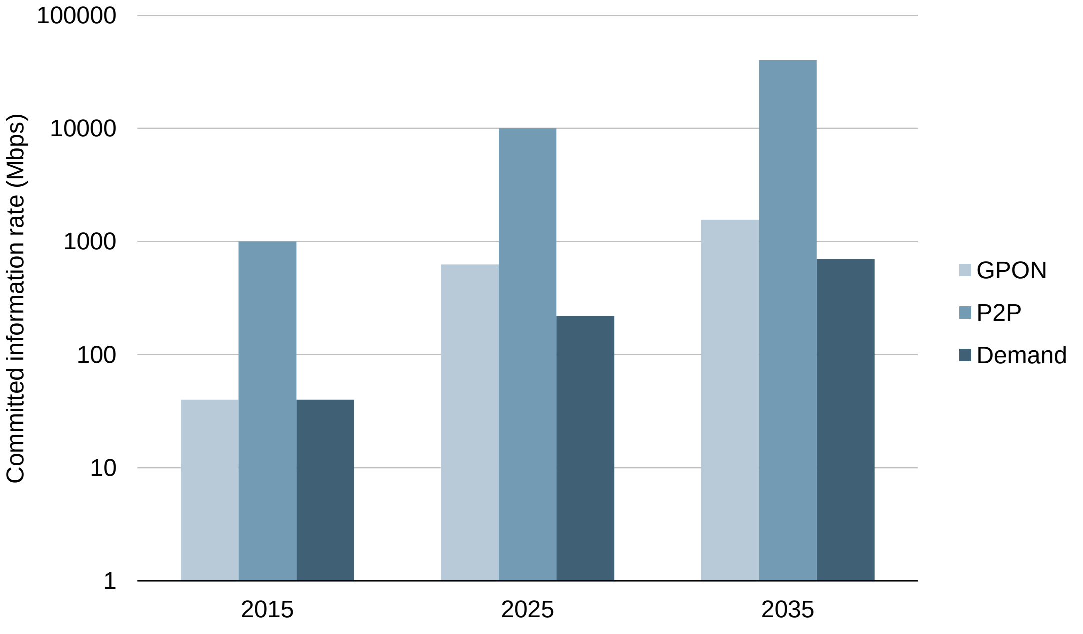


Figure 3.16: Uplink bandwidth requirements vs. evolution of technology bandwidth [Source: Analysys Mason]



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

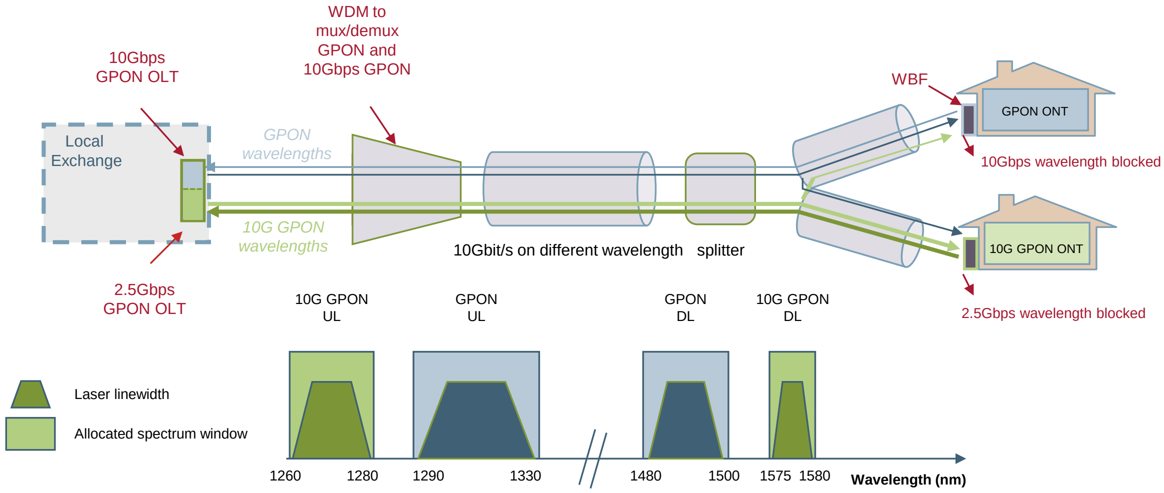
3.8.1 P2P upgrades

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 below. 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

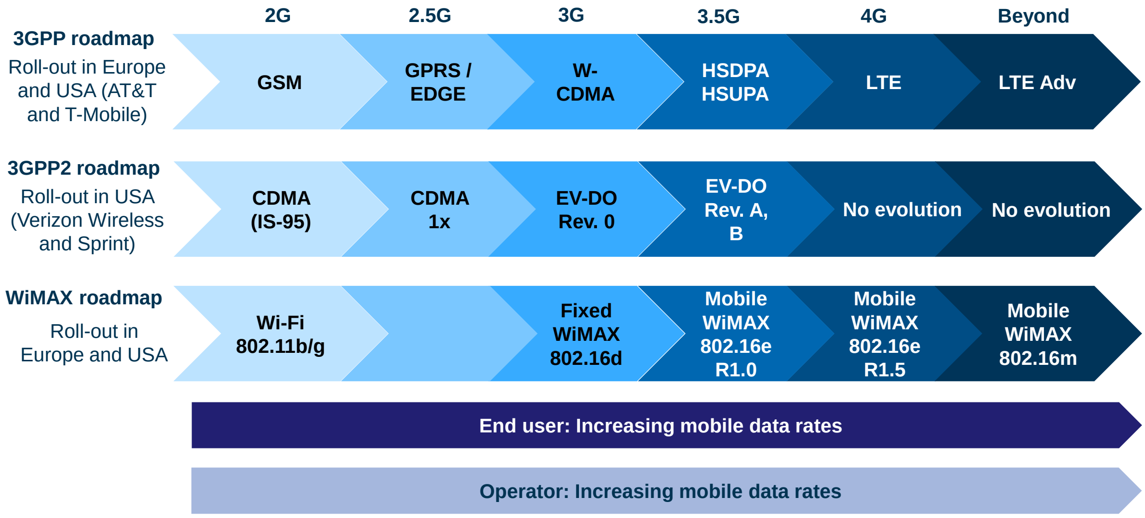
Fixed wireless access networks are becoming increasingly popular to connect end users. This is especially the case in emerging economies where wireline access infrastructure is not well developed, and also in the rural areas of developed countries where it is very costly to roll out this kind of infrastructure. 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

802.16m[29] 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.

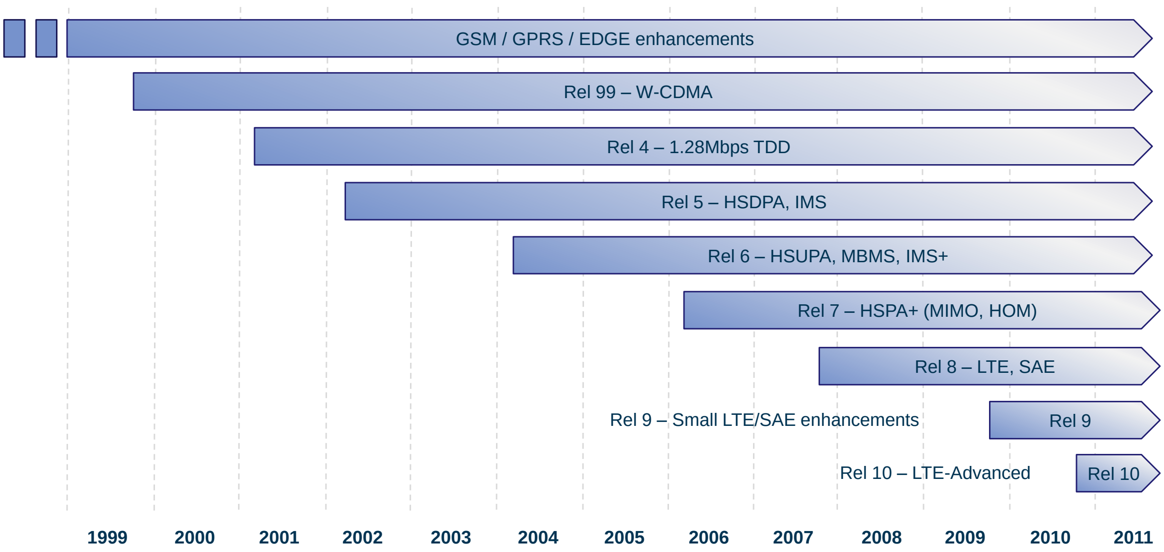
4.3 Overview of 3GPP LTE technology standards

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.[30] 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 below.

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



29 802.16m (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.

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

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.

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.

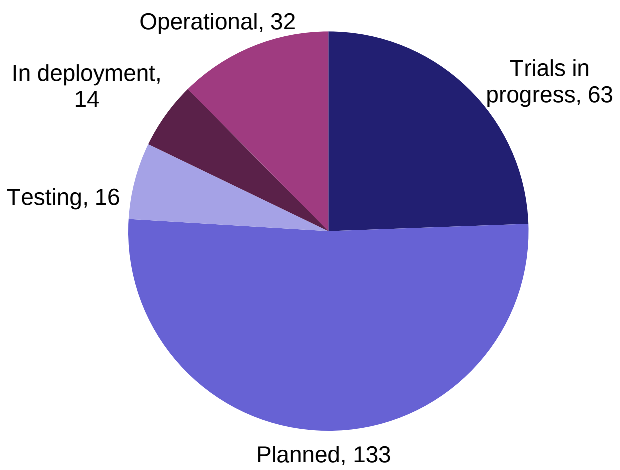


Figure 4.4: Network status of FD-LTE [Source: Analysys Mason]

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.

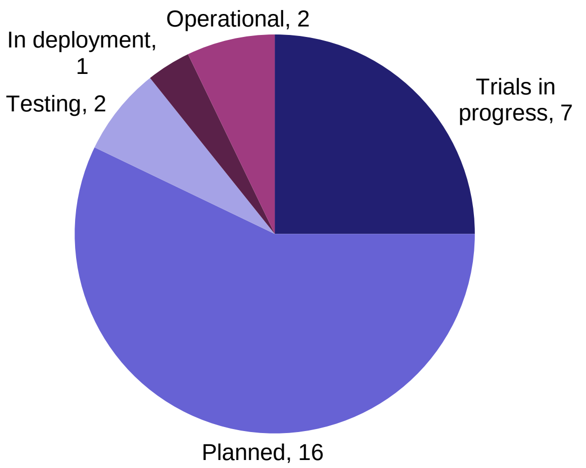


Figure 4.5: Network status of TD-LTE [Source: Analysys Mason]

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]

	Uplink		Downlink		
E-UTRAN band	$F_{ul\ Low}$ (MHz)	$F_{ul\ High}$ (MHz)	$F_{dl\ Low}$ (MHz)	$F_{dl\ High}$ (MHz)	Duplex mode (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: 2×2, 2×4, 4×2, 4×4 UL: 1×2, 1×4, 2×2, 2×4
MIMO models	Spatial multiplexing Transmit diversity (Alamouti, CDD) UE specific beam-forming
Sector throughput (capacity) (10MHz)	15.7Mbps (2×2)[31]
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.

31 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.

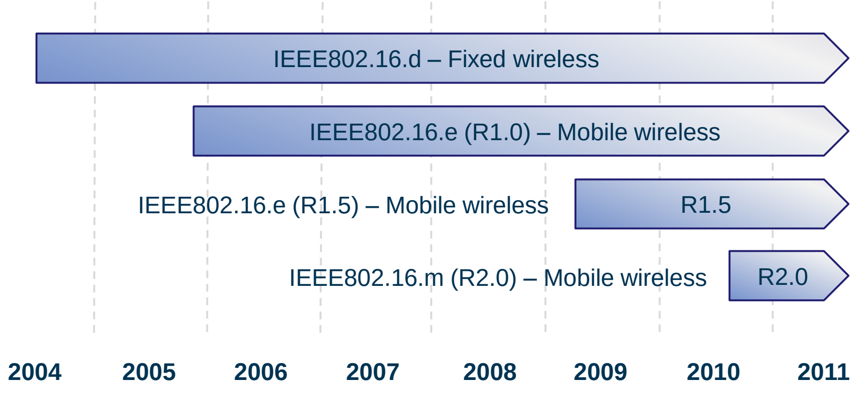


Figure 4.8: Timeline for release of IEEE 802.16 specifications [Source: Analysys Mason]

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).

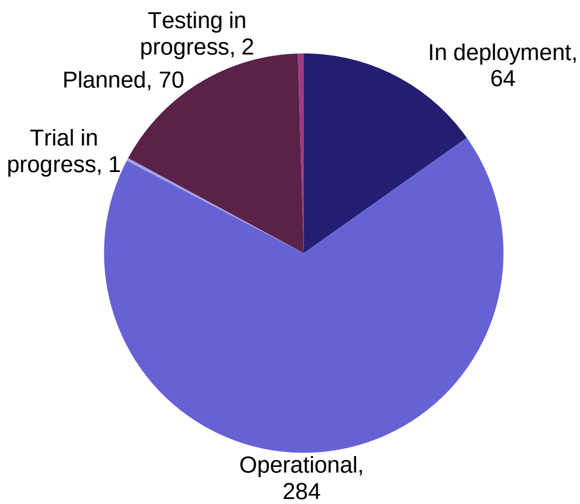


Figure 4.9: Status of fixed WiMAX networks [Source: Analysys Mason]

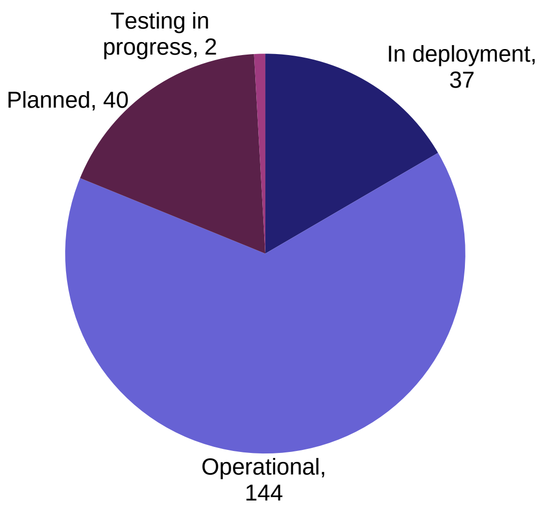


Figure 4.10: Status of mobile WiMAX networks [Source: Analysys Mason]

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.

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: 2×2, 2×4, 4×2, 4×4 UL: 1×2, 1×4, 2×2, 2×4	DL: 2×2, 2×4, 4×2, 4×4 UL: 1×2, 1×4, 2×2, 2×4
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 (2×2 and 3:1 downlink uplink ratio)[32]	
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
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)
- internetworking between W-CDMA and LTE or between HSPA and LTE is easier than with mobile WiMAX.

[32] *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.

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

5.1 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 prudency 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 prudency of the design of FTTP networks:

- technology:
  — GPON[33] or P2P technology, or a combination of both
  — Layer 2 protocol[34]
- 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

33 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*".

34 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.

- infrastructure:
  - — approach to fibre dimensioning
  - — the extent of re-use of existing passive infrastructure[35]
  - — customer premises, including the number of fibres to each premises, the demarcation point for the wholesale service and number of UNI ports on the NTD[36]
  - — 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.[37]

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

It is also important to note that our analysis has sought to analyse each of these design choices from an efficiency and prudency 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 prudency 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 5.1 summarises the critical decisions faced by NBN Co in respect of the design of its FTTP network from a technology, architecture and infrastructure perspective.

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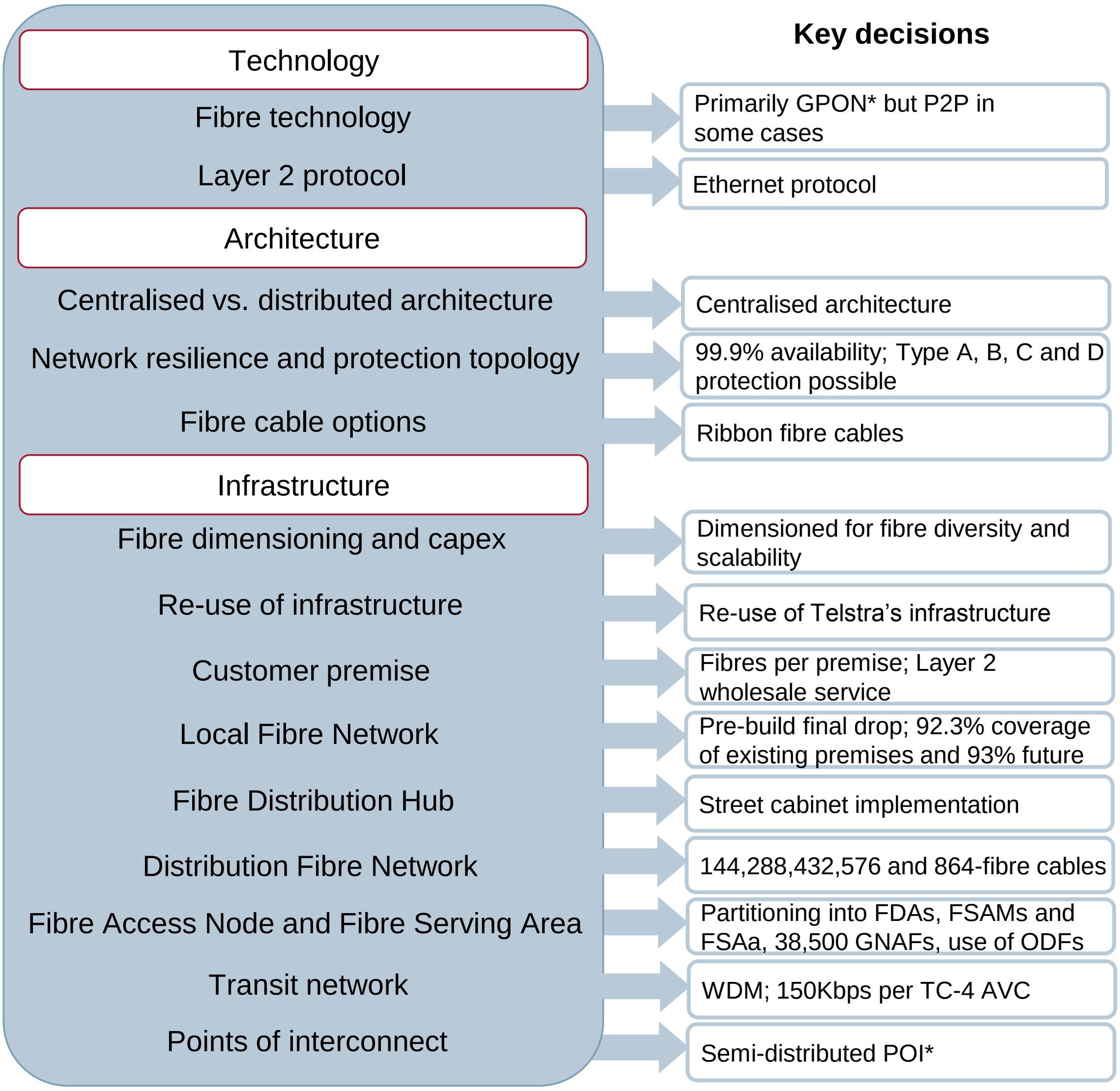
35 The *Statement of Expectations* provides that the Australian Government "*requests NBN Co to provide this network and expects NBN Co to use existing infrastructure in providing this service, where efficient and economic to do so*".

36 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.

37 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 5.1: 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 prudency 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*.

5.2 Fibre technology assessment

5.2.1 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*,[38] 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.

5.2.2 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).[39]

38 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.

39 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.

5.3 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.

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

Critical decision and related issues

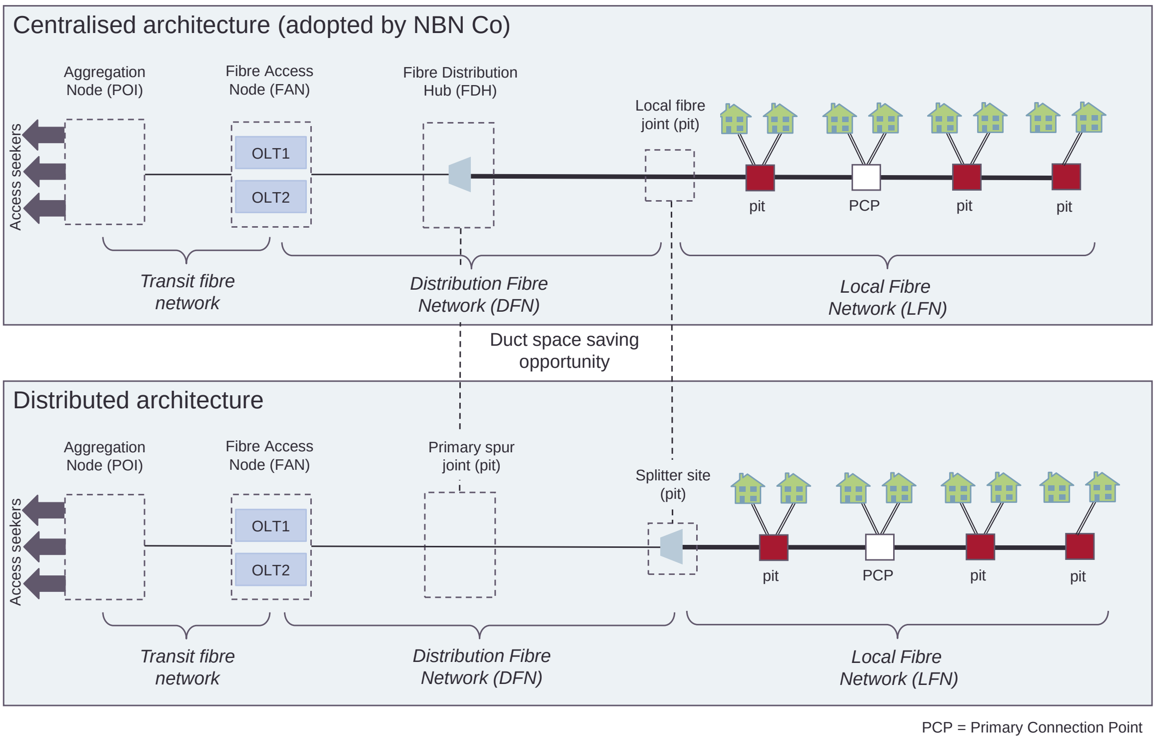
NBN Co needs to assess whether implementing a centralised or a distributed architecture[40] represents the optimal choice in view of its objectives (refer to Section 3.3.2 for definitions of centralised and distributed architectures). The choice of architecture is a function of many parameters such as capex, opex and network evolution. Below we discuss the impact of NBN Co's choice on each of these parameters.

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

► *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 5.2.

Figure 5.2: 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.

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

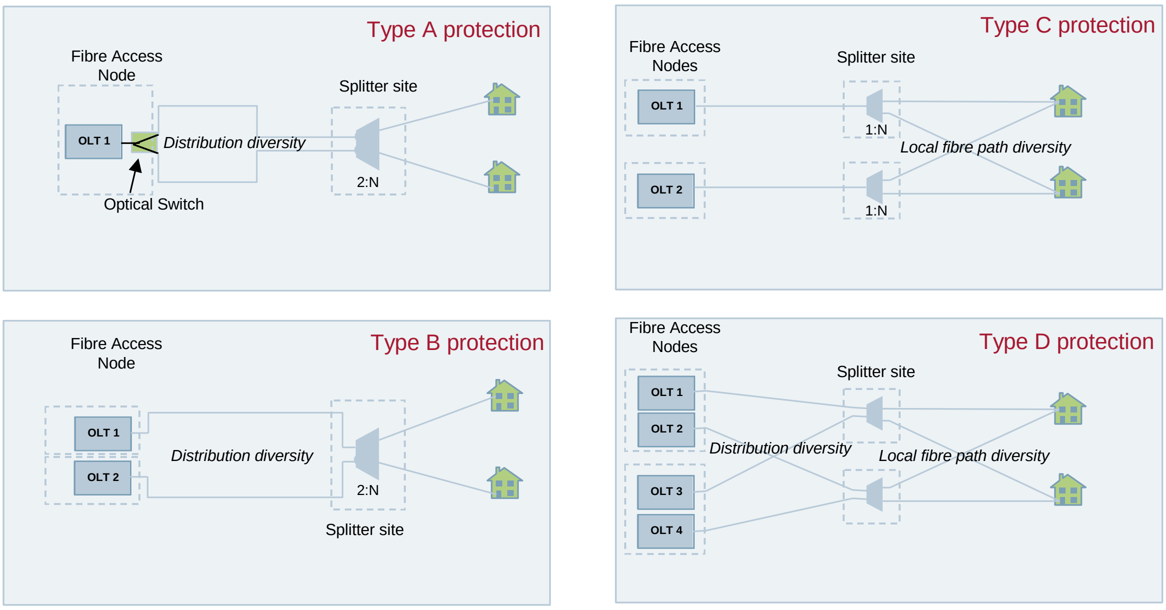
Critical decision and related issues

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 5.3.

Figure 5.3: 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.[41]

To meet and exceed this availability target for particular services, NBN Co has designed its network to provide path diversity in the transit network[42] 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 5.4.

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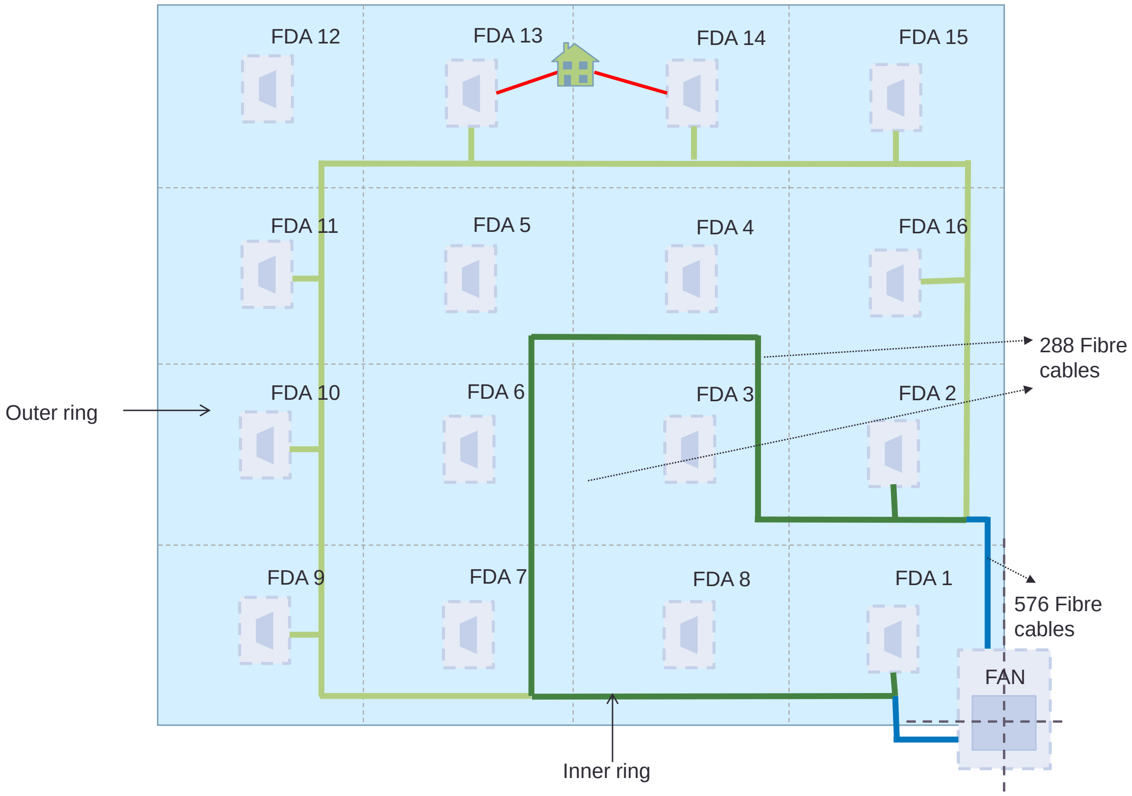
41 http://www.nbnco.com.au/our-network/industry-consultation/network-availability-discussion-paper.html.

42 See assessment of infrastructure network in Section 5.4.

Figure 5.4: 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 extent[43]. 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

[43] Different operators include different elements in this calculation.

- 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 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).

5.3.3 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:

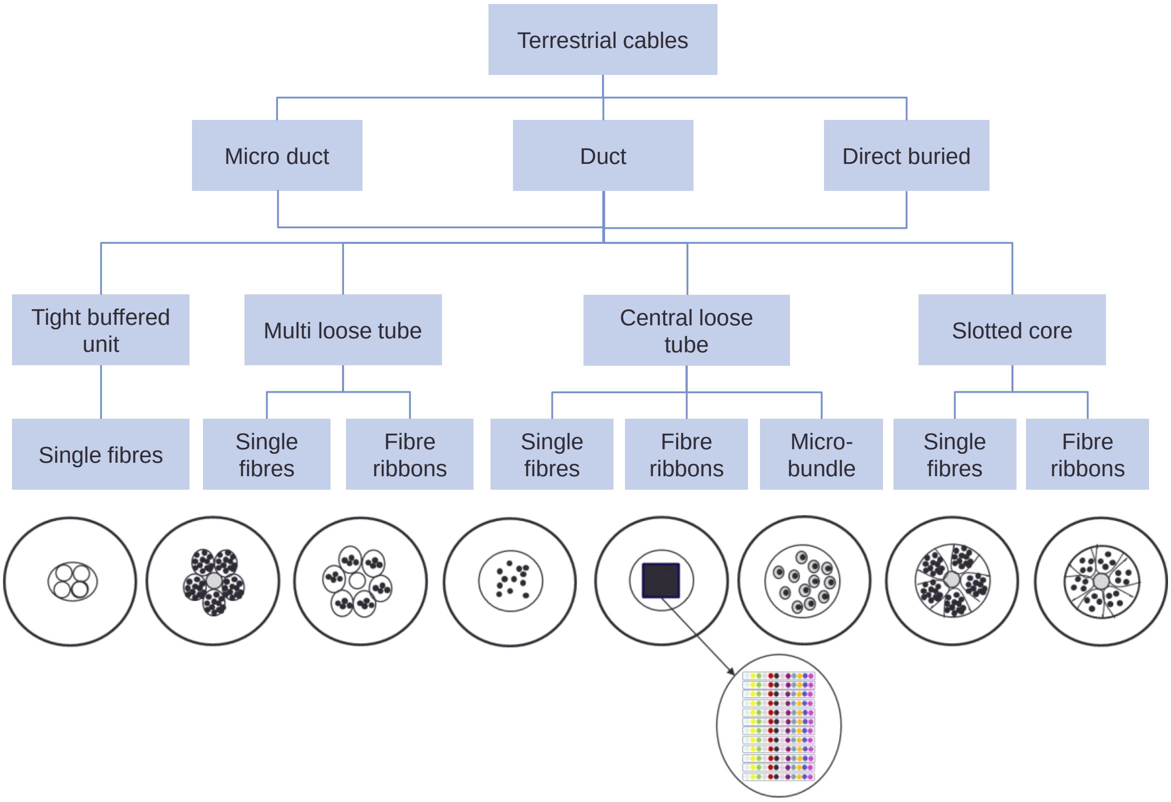
- number of fibres in the cables
- overall diameter of the cable
- cable design and protection specifications

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 5.5) 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 5.4.1, 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 5.5.

Figure 5.5: 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 works[44] and therefore reduce the overall capex for the solution.

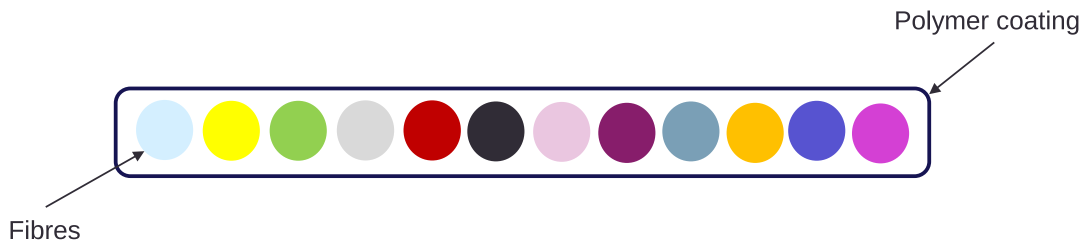
Note that in Figure 5.5 a relatively new type of fibre cable, based on fibre bundles or 'ribbons', is increasingly popular for its operational properties. This is because, in such cables, fibres are grouped into bundles of 12 fibre strands, which can be all spliced at once.

[44] In areas where underground infrastructure already exists.

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 5.6.

Figure 5.6: Ribbon of 12 fibres [Source: NBN Co, 2011]



As shown in Figure 5.6, 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 5.7.

Figure 5.7: 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 5.7 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 below in Figure 5.8

Figure 5.8: 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.

5.4 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.

5.4.1 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 5.9 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 5.9: Illustrative breakdown of capex for FTTP networks [Source: Analysys Mason, 2011]

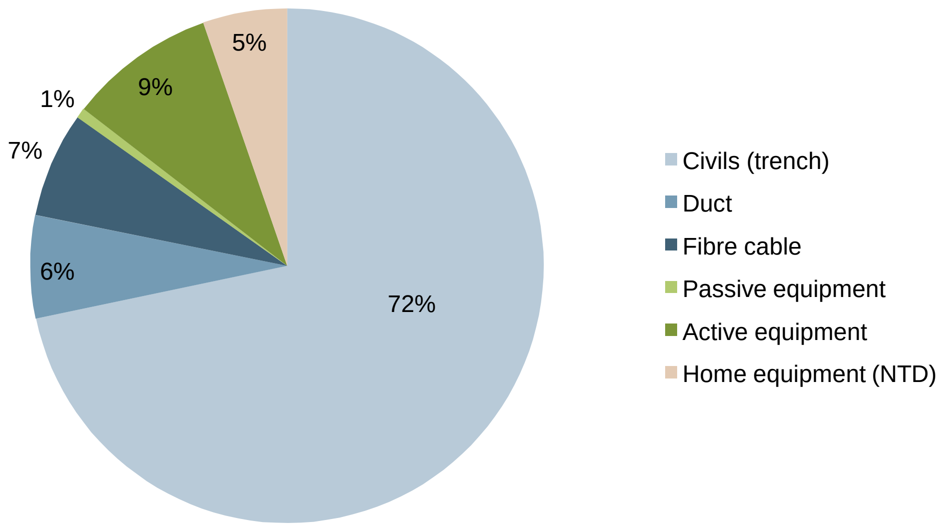


Figure 5.9 does not represent NBN Co's capex but an illustrative benchmark based on our experience with real deployment throughout the world. This breakdown will vary depending on the amount of infrastructure that the operator can re-use (e.g. duct utilisation) and on the architecture used to implement the network.

Figure 5.9 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 5.7.

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 fibre[45]
- 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.

45 See Figure 5.7 for cable size.

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).

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 5.3) in the event of a doubling of the number of fibre strands in the cable.

5.4.2 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.[46]

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

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.

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.[47]

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

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

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.

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.

5.4.3 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 fibre[48] could potentially be sufficient to provide access to a number of service providers.

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

[48] 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.

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 5.18 for more detail) for non-addressable connections or extra connections that may be required per SDU.

► *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 5.10.

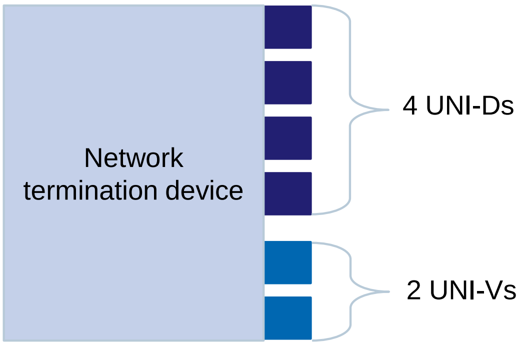


Figure 5.10: Proposed UNI configuration for premises served by fibre [Source: NBN Co]

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.[49] 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.

5.4.4 Local fibre network

Critical decision and related issues

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

- coverage

49 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.

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

► *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 5.11 summarises the four ULLS bands used in Australia.

Figure 5.11: 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 5.11, the geotypes and their associated DA characteristics are illustrated in Figure 5.12 for the case of Australia.

Figure 5.12: 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 5.12, 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%[50] 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, depending on the contract terms with Telstra, NBN Co may have no alternative but to use aerial infrastructure. In general, aerial infrastructure is more cost-effective than underground infrastructure from a capex perspective. However, it is widely accepted that underground infrastructure is more reliable, as it is not subject to external conditions (e.g. bad weather) and so is more cost-effective than aerial infrastructure from an opex perspective.

In the particular case of NBN Co, it would make sense to use the underground infrastructure wherever this exists and only consider the use of aerial infrastructure where no Telstra

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

infrastructure is available or where NBN Co would otherwise need to construct its own ducting infrastructure, which would be significantly more expensive than an equivalent aerial deployment.

► *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 5.3 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%[51] and the agreement between NBN Co and Telstra, we consider that it is appropriate for NBN Co to expect high take-up. This is because, as the copper is de-commissioned, end users who wish to retain a fixed-line service will need to migrate 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 device[52] 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.[53] 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 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.[54]

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

[51] Australia profile, TeleGeography, September 2011.

[52] See Figure 5.8 for an illustration of a multiport device.

[53] Due to the increase in frequency of fault repair.

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

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 5.13.

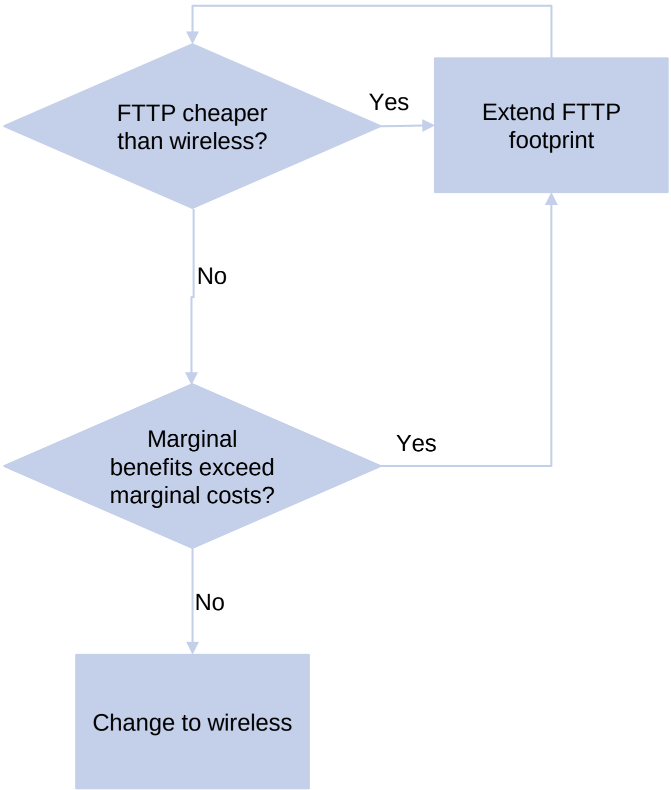


Figure 5.13: NBN Co's methodology for defining FTTP coverage [Source: NBN Co, 2011]

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,[55] and hence cost, were high) were excluded. Coverage: 89.7%.

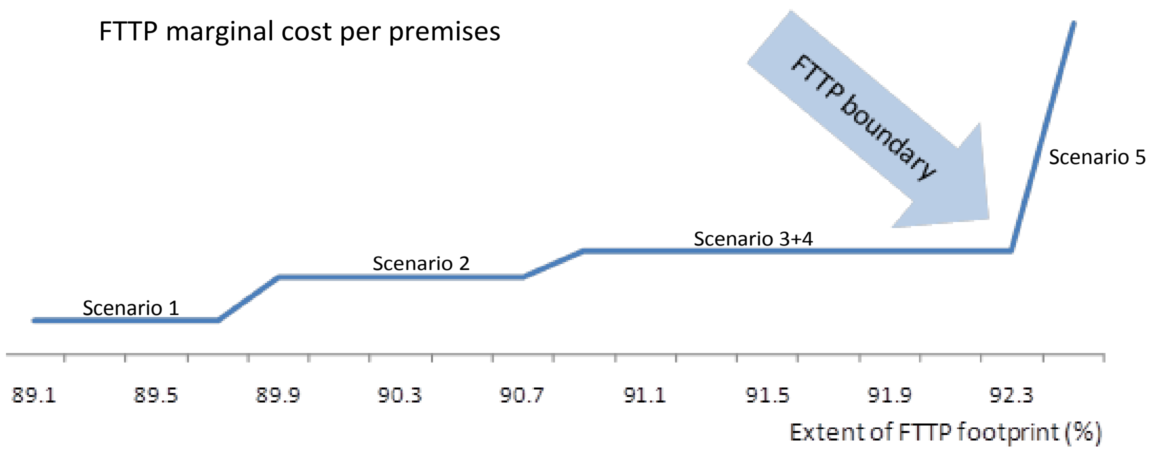
2. Transit backhaul necessary to serve 8 satellite earth stations was added, and communities of over 1000 premises near these additional routes were added. Coverage: 90.8%.

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 5.14.

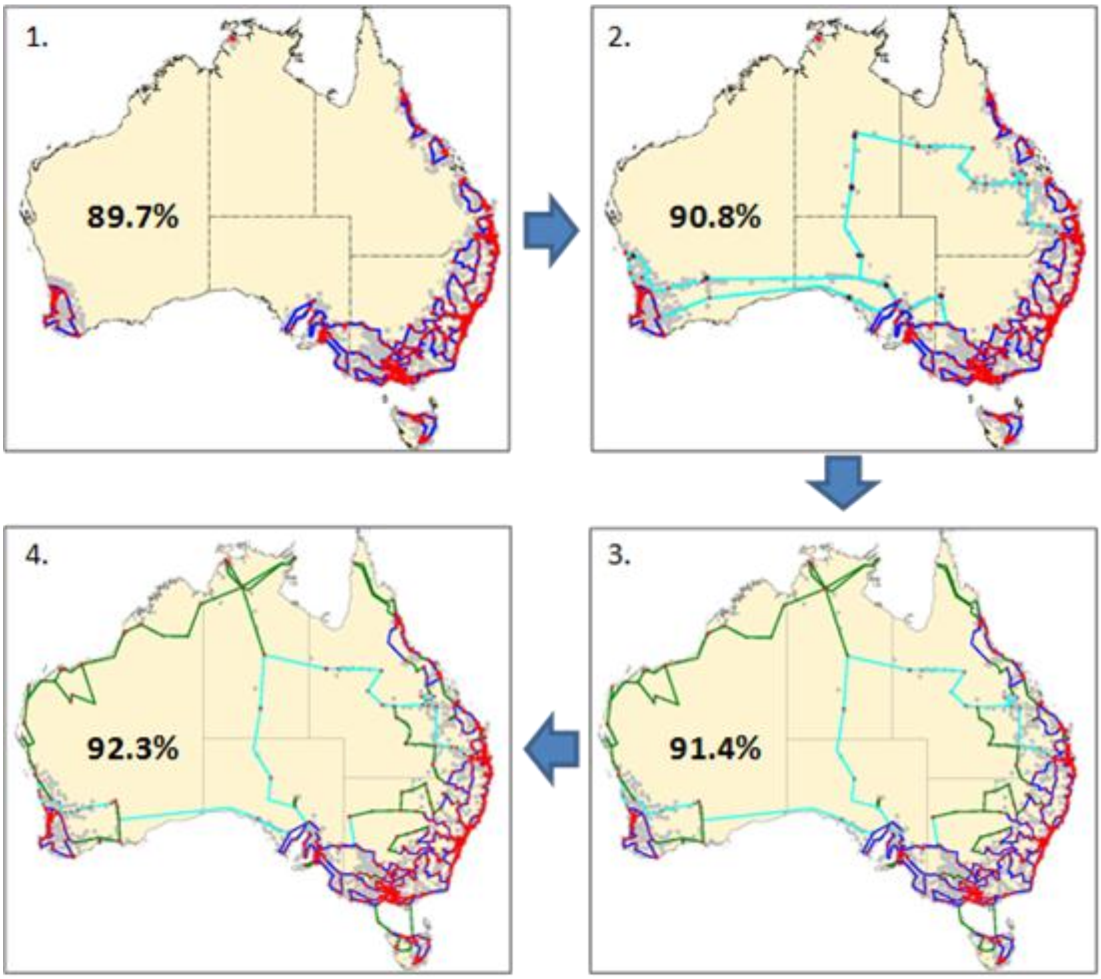
Figure 5.14: Incremental marginal cost for FTTP infrastructure footprint [Source: NBN Co, 2011]



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 5.15.

55 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 5.15: 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 5.4.2, 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.

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 5.16 illustrates a single-sided deployment, where each PCP (or multiport device) connects up to four premises.

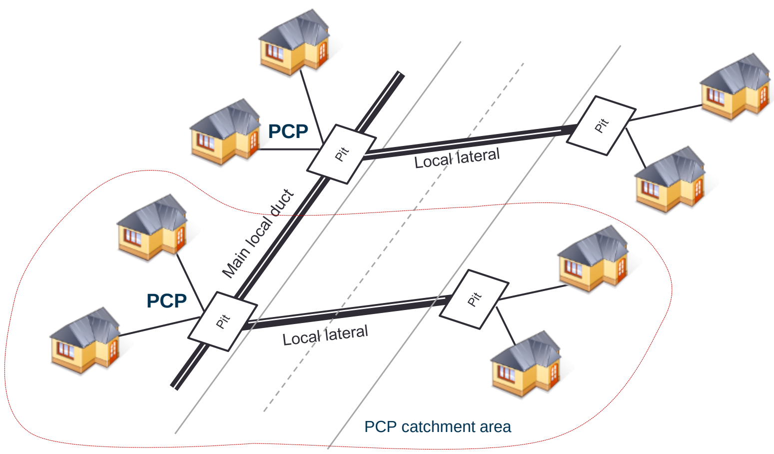


Figure 5.16: Single-sided deployment [Source: NBN Co, 2011]

Figure 5.17 illustrates a double-sided deployment.

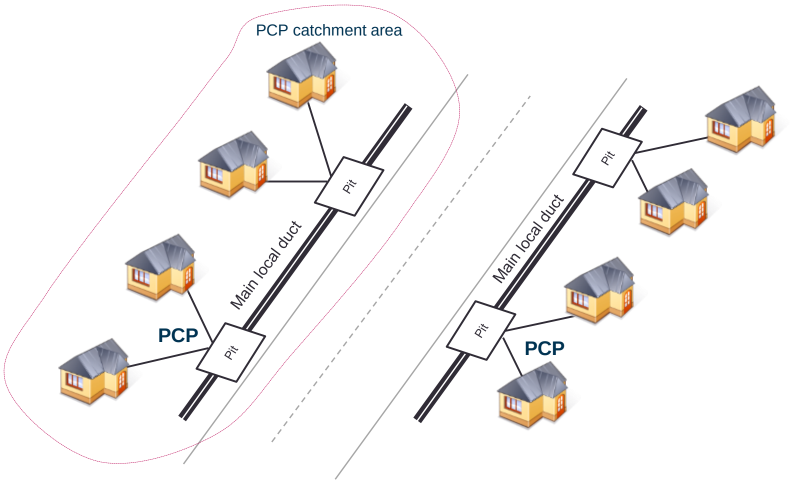
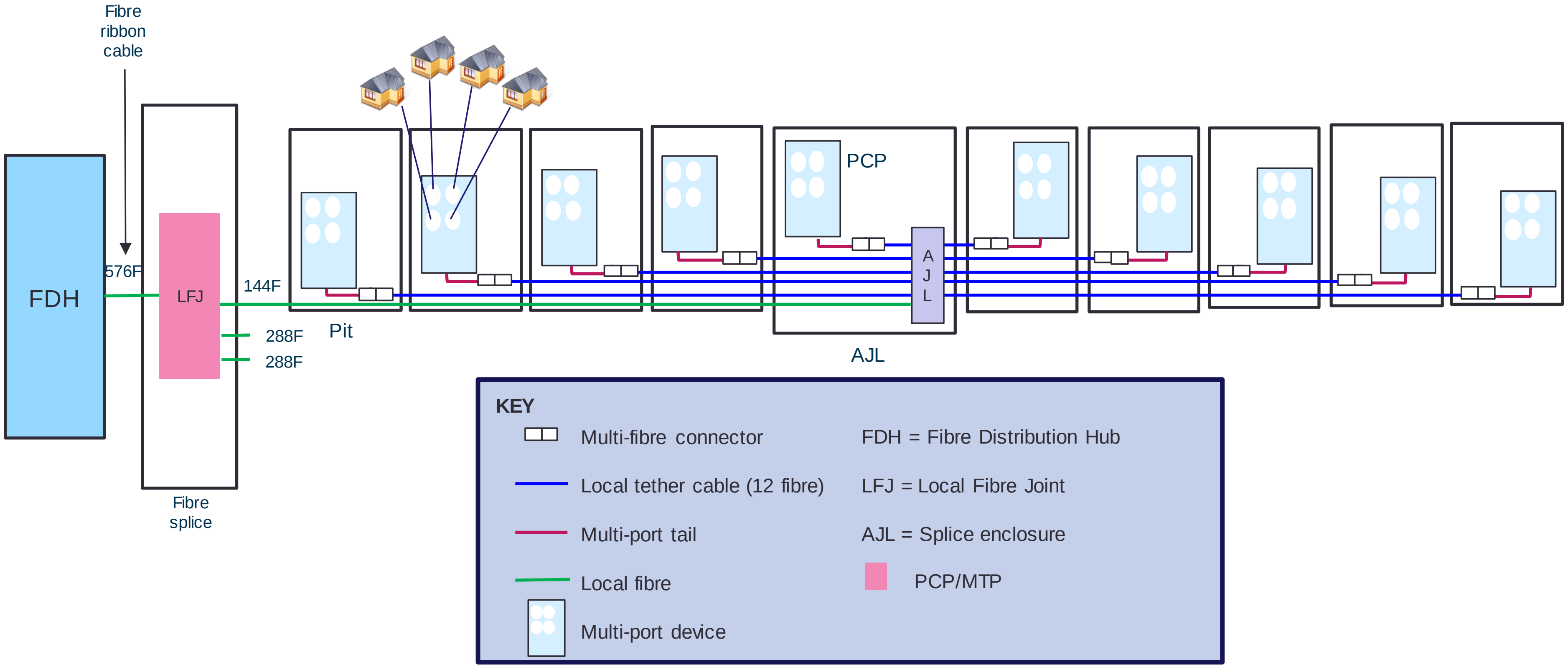


Figure 5.17: Double-sided deployment [Source: NBN Co 2011]

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

Figure 5.18: Generic local fibre architecture design [Source: NBN Co, 2011]



As shown in Figure 5.18, 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 5.19.

Figure 5.19: 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 Telstra (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), they are currently assuming a build drop in their deployment plans (subject to appropriate consents being obtained, etc.). 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. In September 2011, the fixed broadband penetration rate stood at 63.3%[56] 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%.

However, NBN Co is still considering how to implement the PCP (multiport device or fusion splicing), and at the time of writing this report, no final decision has been taken regarding this matter.

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 prudency 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.

56 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% 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.

NBN Co is still considering internally how it will implement the PCP (multiport device or fusion splicing) for the mass fibre roll-out, and at the time of writing this report, no final decision has been taken regarding this matter. Given the expected rapid take-up, we would expect that the adoption of fusion splicing would probably be the most efficient and prudent approach to minimise opex and increase user quality of experience, but this would need to be balanced against NBN Co's need for connection flexibility going forward.

5.4.5 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):

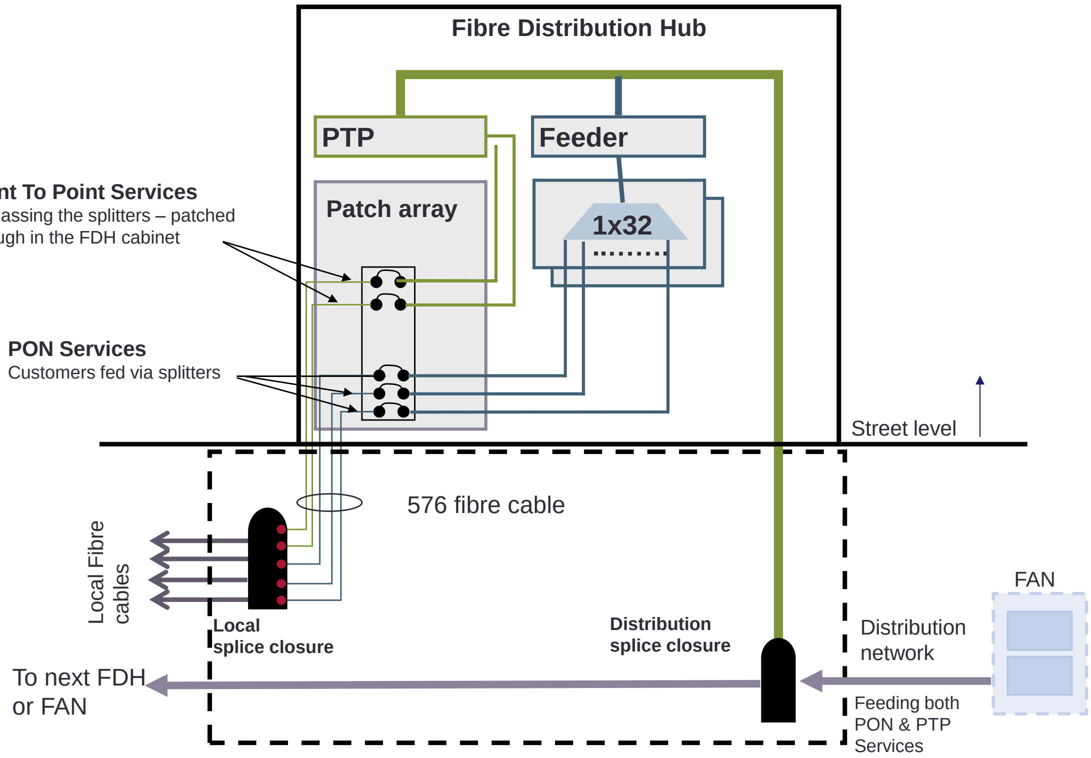
- **Underground splitter enclosure** – A standard design for an underground splitter enclosure involves an underground unit with a swinging arm in a suitable hand-hole which is sealed from the environment. Figure 3.5 (in Section 3) illustrates this type of underground splitter enclosure. In general, 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 5.20 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 5.20: 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.

5.4.6 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*

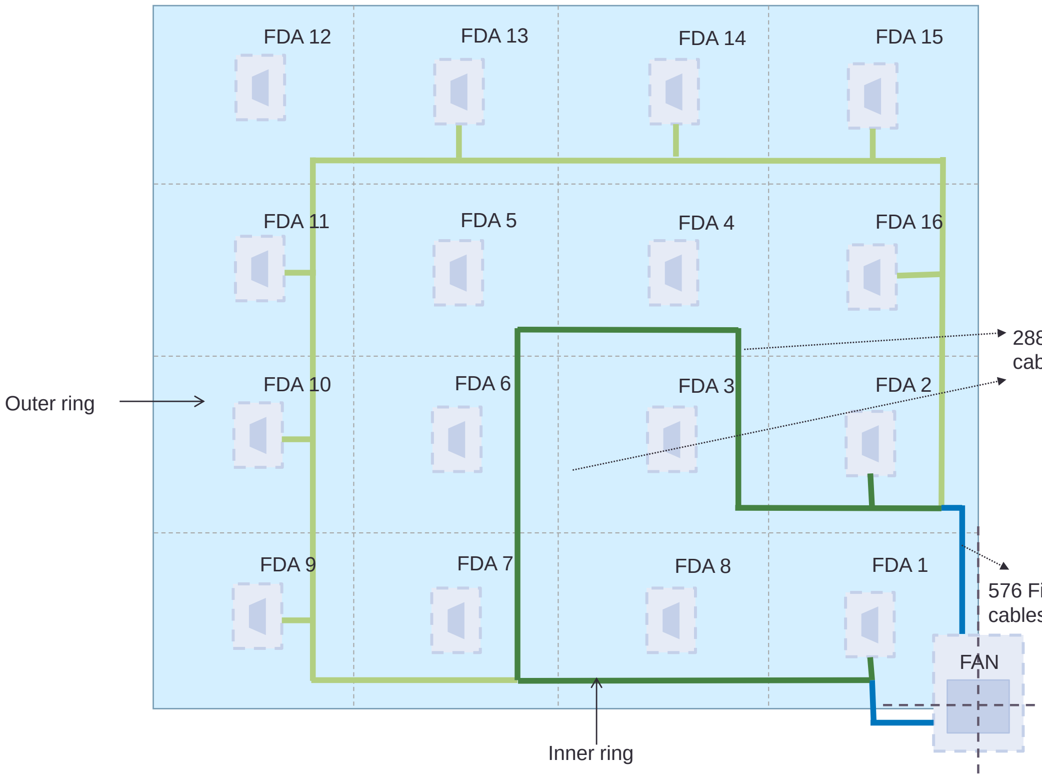
NBN Co is planning to implement a regular topology in its distribution network, consisting of up to 16 FDAs per FSAM. In an FSAM, NBN Co is planning to deploy two independent rings (i.e. an inner ring and an outer ring), each connecting 8 FDHs.[57] A typical FSAM is illustrated in

[57] Each FDH serves a single FDA.

Figure 5.21. 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 5.3 earlier.

Figure 5.21: 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 5.22 shows the number of fibres for different sizes of FSAM.

Figure 5.22: 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% × 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 5.21 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 5.21. 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 5.21 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.

5.4.7 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 20km[58] 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.

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

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 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 5.23.

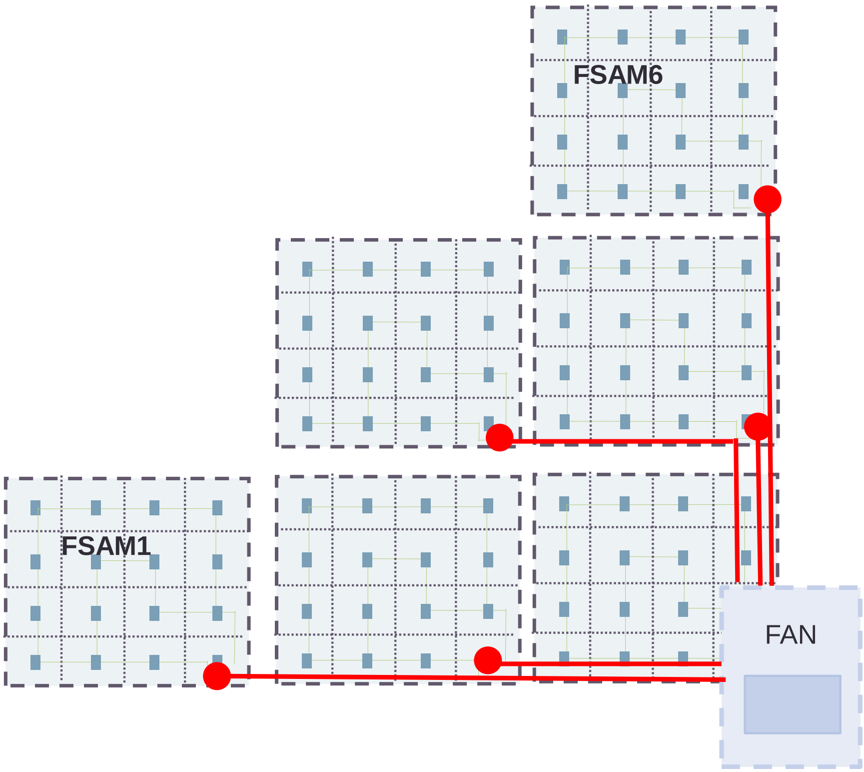


Figure 5.23: Example of an FSA with six FSAMs [Source: NBN Co]

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,[59] as it allows for different levels of protection to be implemented in the FTTP network.

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

5.4.8 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.

5.4.9 Transit network

Critical decision and related issues

► *Architecture and technology*

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/s[60] 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 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.[61]

► *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.

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[60] 1 000 000Mbps.

[61] http://stakeholders.ofcom.org.uk/binaries/research/technology-research/fibre.pdf.

NBN Co's position

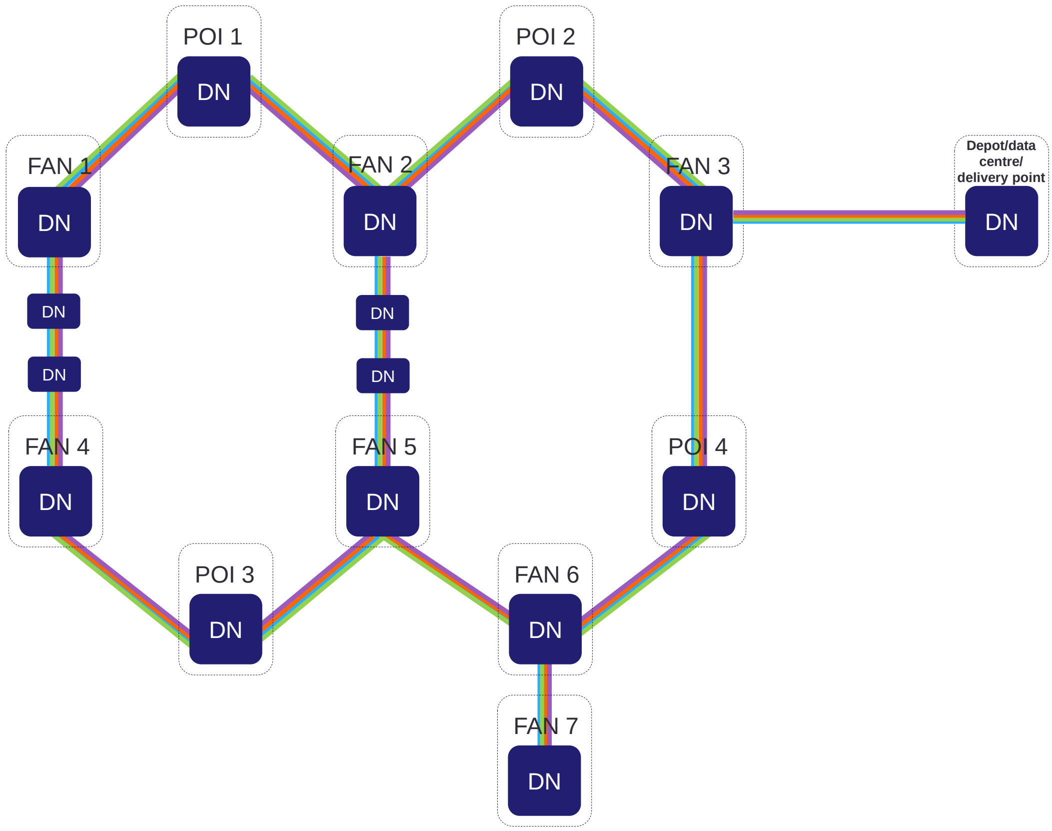
► *Architecture and technology*

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 5.24. 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 5.24 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.

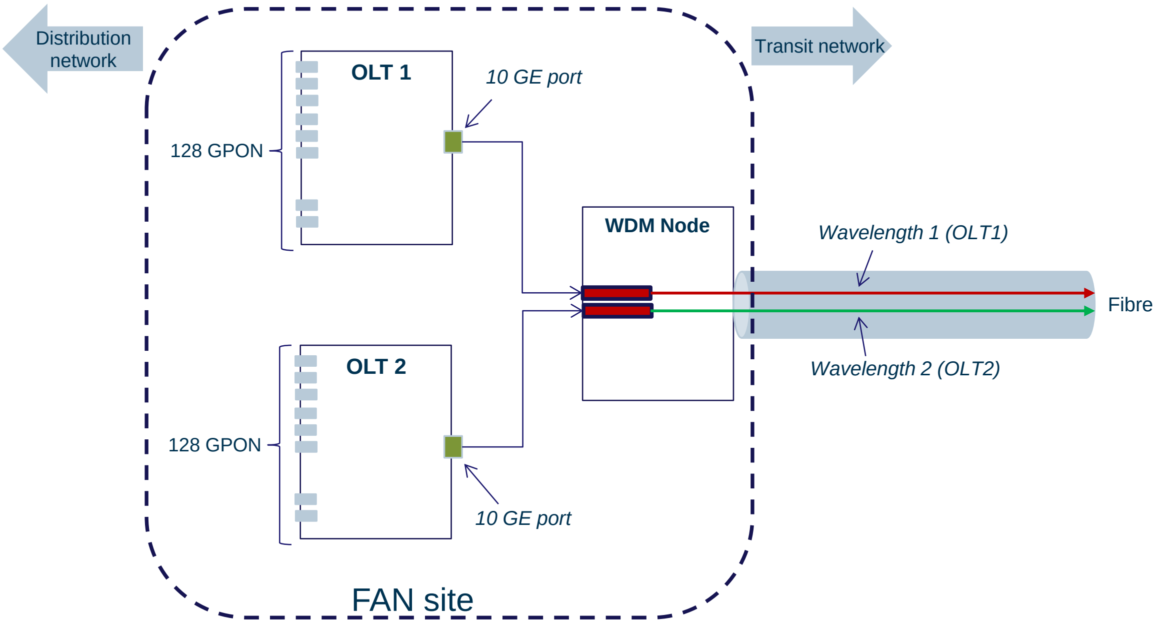
Figure 5.24: Basic DWDM physical connectivity scenarios [Source: NBN Co, 2011]



At the FAN, the 10 Gigabit Ethernet ports, which aggregate the traffic of all GPON in a single OLT,[62] are mapped directly out of the OLT onto wavelengths in the DN. This is illustrated in Figure 5.25.

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

Figure 5.25: Mapping of OLT Gigabit ports into wavelengths[63] [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.

[63] 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),[64] 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 5.25). 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.

[64] 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%.[65] 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.

5.4.10 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',[66] 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 POl s will be a matter for NBN Co".*[67]

65 16 cards per OLT × 8 GPON port per card × 32 end-user per GPON × 150kbps × 50% take-up= 300Mbps.

66 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.

67 *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',[68] as well as a list of 120 initial POIs based on the ACCC's 'competition criteria' and the Planning Rules.[69]

- 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.[70]

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.

68 http://www.accc.gov.au/content/item.phtml?itemId=963440&nodeId=64dbfce5537a9f435f389288eaa9e80b&fn=POI%20planning%20rules.pdf.

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

70 See http://www.accc.gov.au/content/index.phtml?itemId=952292.

5.5 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 prudency 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. 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.[71] 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.

71 See http://stakeholders.ofcom.org.uk/binaries/research/technology-research/fibre.pdf.

6 Review of the efficiency and prudency of NBN Co's wireless network design

6.1 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 prudency 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 prudency of the design of fixed wireless networks:

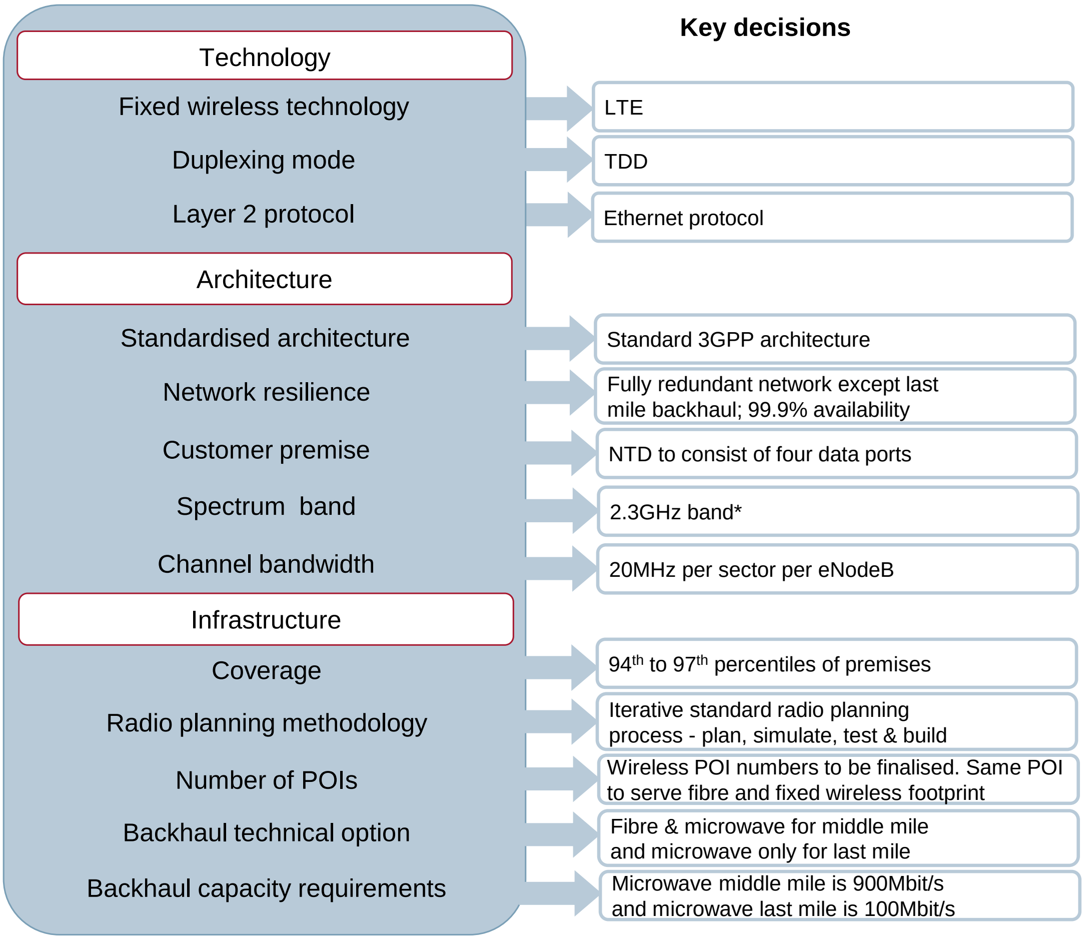
- technology:
  - LTE or WiMAX fixed wireless technology
  - FDD or TDD duplexing mode of the fixed wireless technology
  - Layer 2 protocol
- architecture:
  - standardised 3GPP or IEEE802.16 architecture
  - approach to network resilience (i.e. end-to-end service availability)
  - customer premises, 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 prudency 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 prudency 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 prudency of individual design choices and decisions (and have outlined our views on each of those elements in this Section 6), 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 6.1 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 6.1: 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 prudency 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*.

6.2 Wireless technology assessment

6.2.1 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.[72]

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.

► *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 2012[73]. 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 year[74]. 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.

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

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

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

► *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. 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 6.4 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.

6.2.2 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.

6.3 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.

6.3.1 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.

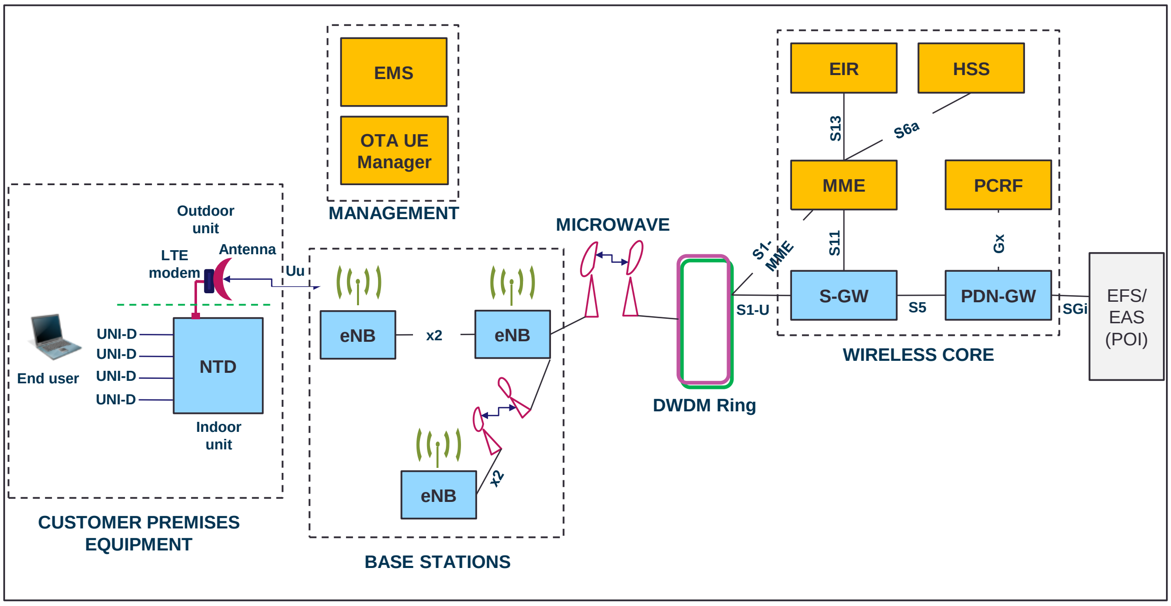
However, it has now become a viable option to deploy high-speed broadband using 4G wireless technologies, because of its bandwidth and latency capabilities and the increasing availability of large allocations of spectrum in certain bands, as evidenced by recent and forthcoming 'digital dividend' auctions. 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 6.2):

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

Figure 6.2: 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*.[75] 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 five base stations to a microwave hub, with microwave hops then used to transmit the signal to the nearest FAN site.

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
- **serving 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).

75 "*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.

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.

6.3.2 Network resilience

Critical decision and related issues

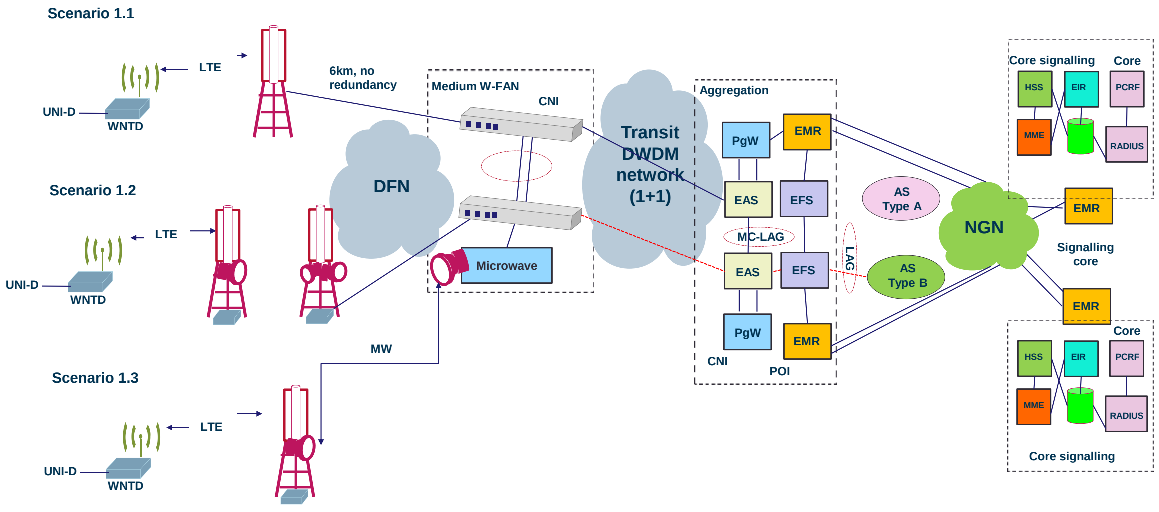
End-to-end service availability is a key factor when designing a network. It is therefore important for NBN Co to define a realistic availability target and to design its network to ensure that it will meet this target.

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 6.3.

Figure 6.3: 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%.

6.3.3 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.[76] 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 spectrum[77] 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

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

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

(Cth),[78] 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.[79] 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.

78 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.

79 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.

6.4 Wireless network infrastructure assessment

6.4.1 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.

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 6.4.

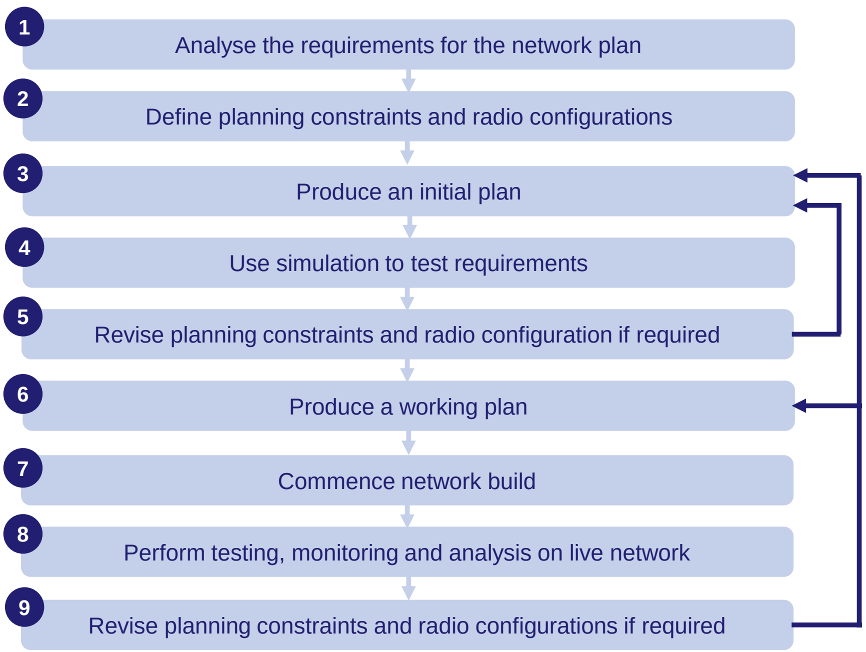


Figure 6.4: Radio planning activities [Source: Analysys Mason, 2011]

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 6.4, 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 6.4.

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) will take up the service from a service provider.[80] 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.

80 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%[81] 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.

81 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 ranges[82].
- 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)

82 The link budget developed by Analysys Mason is shown in Annex B

scheme is used for the antennae in a 20MHz channel.

- 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.

6.4.2 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 POI[83]. 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).

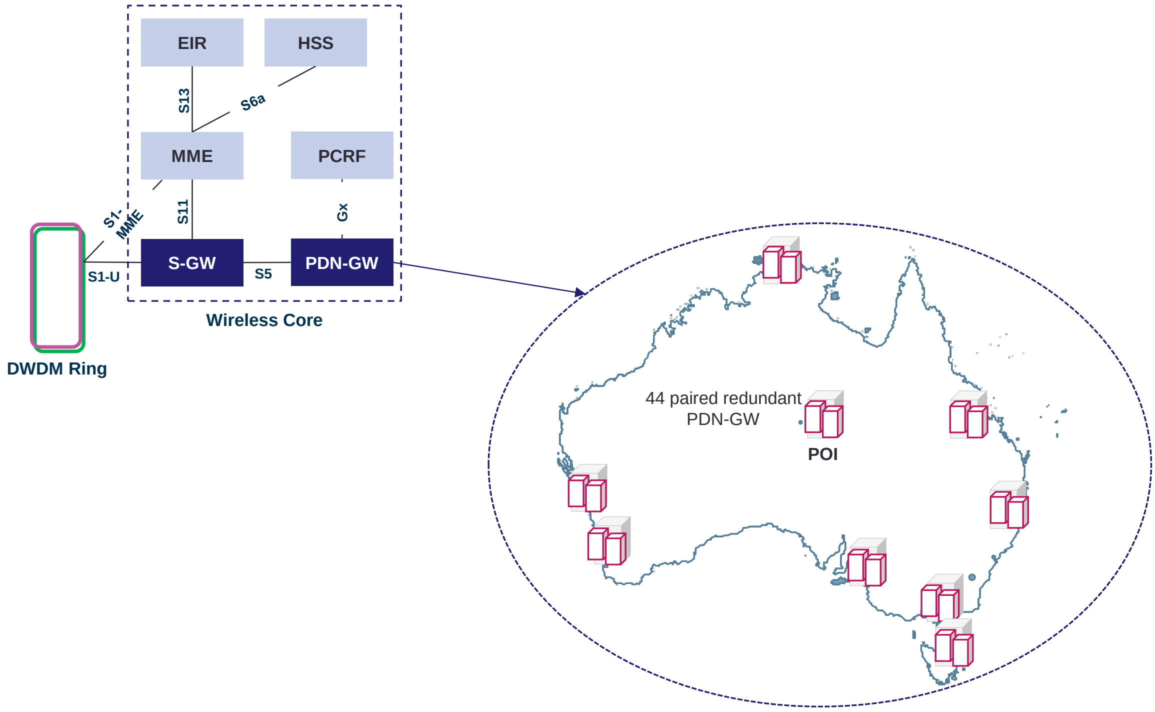
NBN Co's position

► *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 6.5. (These elements were described in detail in Section 6.3.)

83 Some rural areas will also be served by Outer metro POIs, but no rural area will be served by Metro POIs.

Figure 6.5: 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 6.3.2.

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,[84] 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.

84 Assuming all operators adopt a standardised approach.

6.4.3 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.

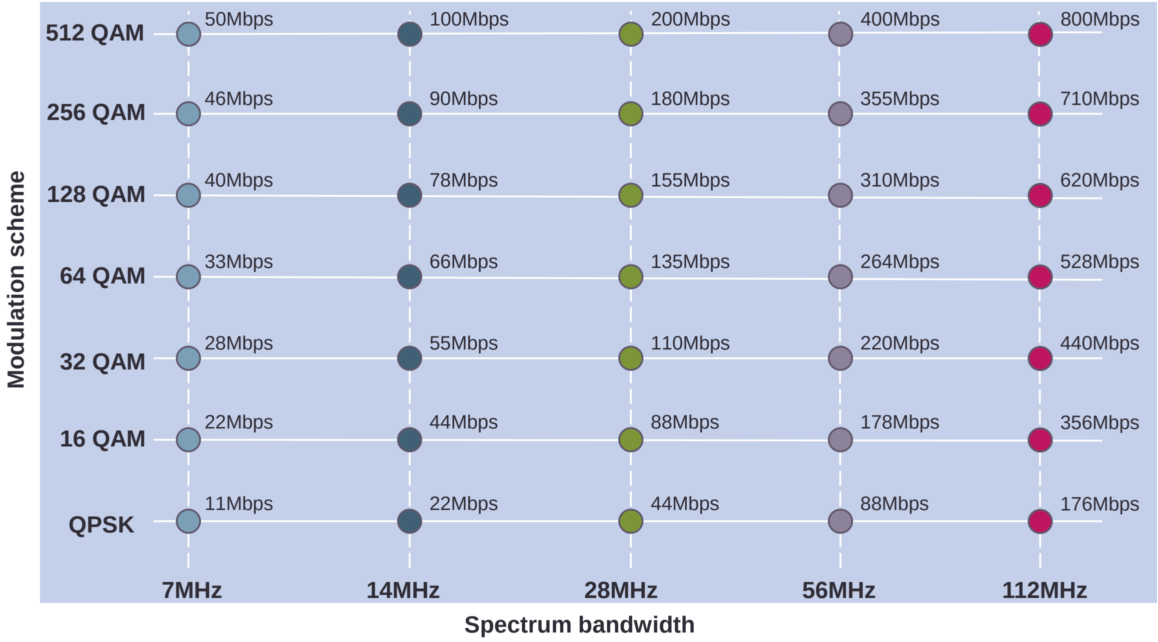
In general, fibre backhaul technology provides higher bandwidth scalability than microwave backhaul, but fibre-based solutions are more expensive than microwave. This is because installation of fibre requires extensive civil works, especially if no infrastructure (ducts or poles) exists between the base 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 6.6 provides an illustrative example of the expected throughput of current microwave systems, as a function of the modulation scheme and spectrum bandwidth available.

Figure 6.6: Microwave capacity [Source: Analysys Mason, 2011]



From Figure 6.6, 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 6.7, which also shows the impact of the weather on availability.

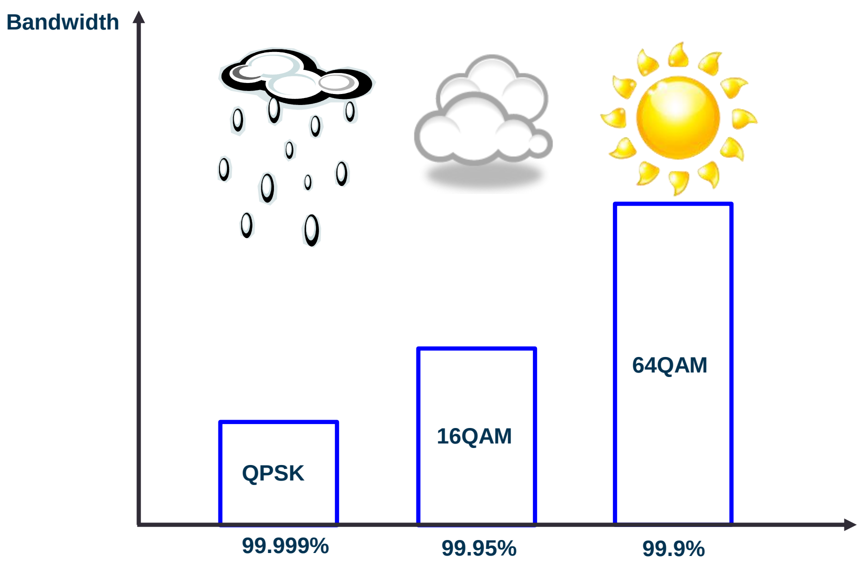


Figure 6.7: Illustration of variation in link availability under different modulation schemes [Source: Analysys Mason, 2011]

As shown in Figure 6.7, QPSK modulation provides the highest availability, even in poor weather conditions. However, as shown in Figure 6.6 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.

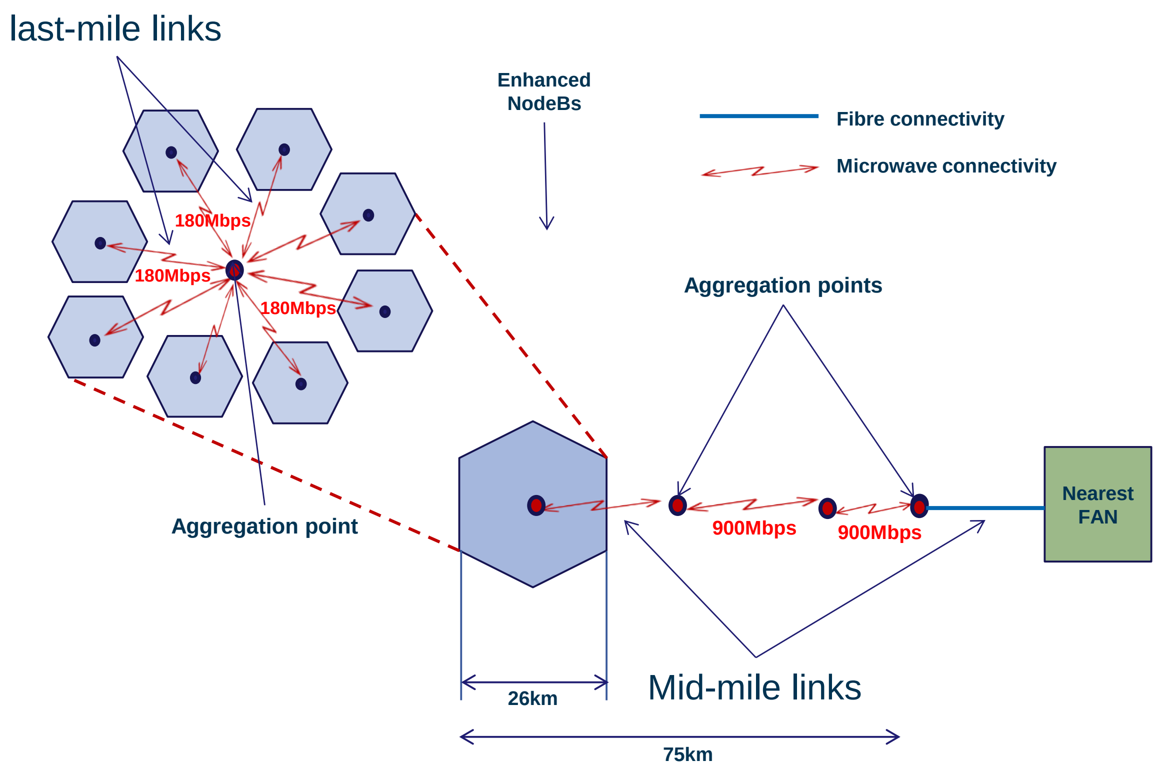
Fibre backhauling

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 6.8.

Figure 6.8: 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 6.8.

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 premises × 0.5Mbps × 115% = 103.5Mbps.

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 2×2 MIMO scheme) is 83.5Mbps at the physical layer[85], 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 = 60Mbps × 3 sectors = 180Mbps.

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:

Configuration 2 link capacity (for 3 eNodeB) = 3 × Minimum Configuration 1 link capacity

= 3 × 103.5Mbps

= 310.5Mbps

NBN Co assumes that a single mid-mile link (configuration 2) may backhaul the capacity for up to eight eNodeBs as illustrated in Figure 6.8. Using the above dimensioning rule, 8 eNodeBs will require a backhaul capacity of 828Mbps (8×103.5Mbps). For such a link, NBN Co plans to provide 900Mbps of capacity, which represents a 10% contingency with regards to the above dimensioning rule.

85 See www.motorola.com/web/Business/Solutions/Industry%20Solutions/Service%20Providers/Network%20Operators/_Documents/_static%20files/TD-LTE%20White%20Paper%20-%20FINAL.pdf.

It should be noted that, in the worst case[86], a Configuration 2 link will carry the traffic for approximately 1440 premises (assuming service take-up of 30%) during busy hours. It will 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. Transparent[87] 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.

86 Backhaul of 8 eNodeB.

87 With no multiplexing.

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:

- 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[89]
- 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 375MHz[88] (for a modulation of 256 QAM) of spectrum. This spectrum requirement may significantly increase depending on the distance to cover[89]. 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.

88 375MHz = 3×125MHz.

89 The longer the distance, the lower the modulation scheme and therefore the lower the bandwidth.

6.5 Conclusion

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

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.

Annex A FTTP network benchmarking

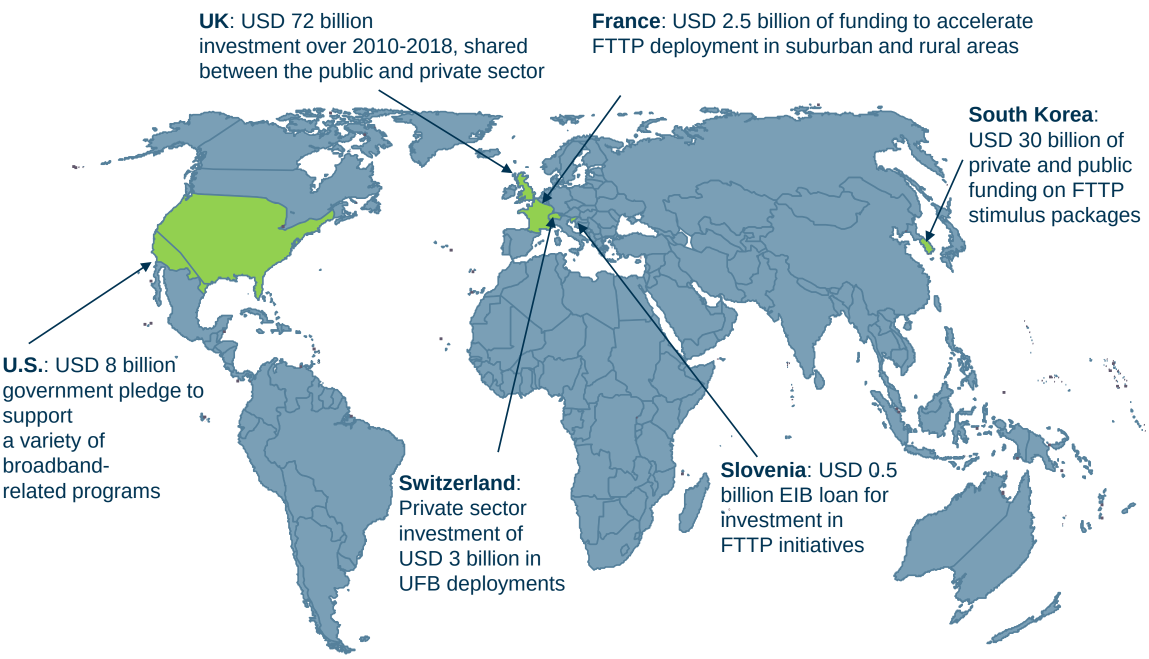
In this annex, we present six cases studies of FTTP deployments around the world to assist us in benchmarking NBN Co's technical solution against other national broadband solutions. The design of each solution reflects the unique situations and objectives of individual countries and network operators.

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

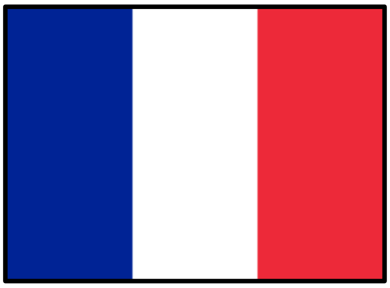
Public investment in FTTP varies significantly across markets, but it is increasingly included as part of larger, national economic stimulus packages. Here we describe a selection of national stimulus packages. These are typically joint public–private projects involving government investment in partnering, 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



UFB architecture:
FTTH (GPON and P2P)
Planned bandwidth (assured):
100Mbps download, 100Mbps upload

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.[i]

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.

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 operator[ii]. 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 2025[iii]. 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 FTTH[iv].

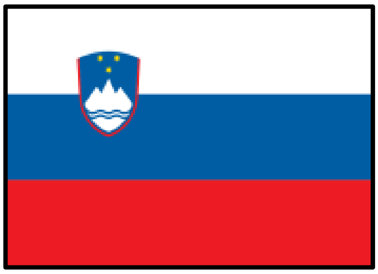
Leading altnet Iliad (Free) is rolling out FTTH using Ethernet over a P2P fibre architecture. It has plans to connect 4 million homes by 2012, and had passed 450 000 by June 2011[v].

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."[vi] By June 2011, fibre was available to 550 000 homes[vii]. 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 passed[viii]. To achieve its 10 million household coverage by 2015, FT plans to invest around USD2.68 billion[ix,x]. This budget is expected to be enhanced by partnerships to an actual total investment budget of EUR4 billion (USD5.35 billion)[xi]. 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



UFB architecture:
FTTH (P2P)
Planned bandwidth (assured):
100Mbps download, 100Mbps upload

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 FTTx[xii]. In 2010, Slovenia had 55% and 51% household coverage of FTTH and FTTC respectively, and had the third-highest percentage of homes passes 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 adopted[xiii].

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 TS[xiv].

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 QoS[xiii], 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 levels[xv].

TS has chosen Iskratel to supply equipment for the FTTH roll-out[xvi]. T-2 has chosen Extreme Networks to provide core and edge switching for the P2P network[xv].

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 households[xvii]. 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 2009[xviii]. Since 2007, FTTB has been the dominant broadband technology[xix]. FTTx services had been taken up by approximately 58% of the broadband population by June 2011[xx].

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 rate[xxi].

UFB architecture:
FTTH (EPON/GPON and P2P)
Planned bandwidth (assured):
100Mbps download, 100Mbps upload

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 3300m^2, 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 2012[xxii].

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.

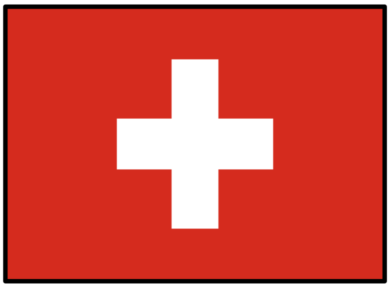
Architecture, configuration, equipment and costs

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 USD53[xxiii]. 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.[xxiv]

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)[xxv].

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'[xxvi].

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.

Ewt launched its fibre-based network (Zurinet) in Zurich in June 2008. The network was initially rolled out to St. Gallen, Fribourg, Winterthur and Berne[xxvii]. 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 connected[xxviii].

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 areas[xxix] in March 2011. There are six[xxx] 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 subsidy 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 access[xxxi].

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 products[xxxii].

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 underspend[xxxiii]. 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 Sport[xxxiv]. 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 2012[xxxv].

Current and planned FTTx deployments

BT operates a GPON FTTH pilot at Ebbsfleet, with plans to connect a total of 10 000 homes[xxxvi]. 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 2011[xxxvii]. 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 homes[xxxviii]. 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 Belfast[xxxix]), and Velocity1 (P2P Active Ethernet, 4200 homes in Wembley[xl,xli]).

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)[xlii]. BT is using Huawei as technology vendor for both its FTTC plans[xliii] and the FTTH deployment at Ebbsfleet[xliv].

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 investment[xlv]. A more recent estimate of GPON deployment cost is GBP867 per household (USD1351)[xlvi].

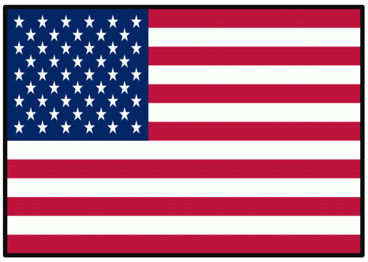
IFNL is using Alcatel Lucent for its GPON system with a 64-way split at Corby[xlvii] but notes that increasing the split requires higher laser power and therefore increases the cost[xlvii]. IFNL has adopted an agnostic approach to technology, choosing P2P or GPON, depending on the scale of the deployment and the available space at the ODF[xlviii]. It will be offering access to the infrastructure via an ALA-type active interconnect interface[xlix].

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 2011[l]. 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%)[li].



UFB architecture:
FTTC / FTTH (GPON)
Planned bandwidth (assured):
150Mbps download, 35Mbps upload

Fibre penetration was reported to be 18% of households in April 2011[lii]. 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.

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 2007[liii]. Verizon originally named Alcatel Lucent, Motorola and Tellabs as GPON vendors, although Tellabs decided to cease its GPON activity for Verizon in April 2008[liv]. Verizon reported that its cost per home passed fell from USD1220 in January 2006 to USD880 in December 2006[lv]. 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			
BS EIRP	*62.7*	*dBm*	*UE EIRP*	*36.0*	*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*
UE antenna gain	13	dBi	BS antenna gain	15.6	dBi
UE loss	0	dB	BS loss	0	dB
No. of resource blocks allocated	100		No. of resource blocks allocated	95	
Modulation scheme	64QAM3/4		Modulation scheme	QPSK 1/2	
SINR	17.5	dB	SINR	2.0	dB
Implementation loss	4	dB	Implementation loss	2.5	dB
UE noise figure	7	dB	BS noise figure	5	dB
Thermal noise per resource block	-121.5	dBm	Thermal noise per resource block	-121.5	dBm
UE reference sensitivity	*-76.0*	*dBm*	*BS reference sensitivity*	*-95.2*	*dBm*
Rx level at UE antenna	*-77.2*	*dBm*	*Rx level at BS antenna*	*-99.0*	*dBm*
Downlink path loss	*138.6*	*dB*	*Uplink path loss*	*131.2*	*dB*
Downlink path loss	138.6	dB			
Uplink path loss	131.2	dB			
Maximum path loss	*131.2*	*dB*			
BS antenna height	40	m			
UE antenna height	5	m			
Operating frequency	2,300	MHz			

Clutter class	suburban	rural	Propagation model
Cell range (km)	3.2	12.4	Extended Hata model

Annex C Principal authors

AMRISH KACKER **Position:** Senior Partner, Head of Asia–Pacific Operations, Analysys Mason **Project role**: Project Director **Qualifications**: MBA, B.Eng.	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. Amrish has successfully delivered a number of projects involving NGA/government interventions in the Asia–Pacific region. Projects of note include the following: • 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.

	Amrish has also successfully delivered a number of NGA/government interventions in Europe. Projects of note include: • 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. 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).
DR. FRANCK CHEVALIER **Position:** Manager, Analysys Mason **Project role**: Project Manager and fibre network review lead **Qualifications**: Ph.D., B.Eng. (Honours), IET Chartered Engineer	Franck was the Project Manager for the efficiency and prudency 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. 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: • 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.

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- In the past three years, Franck has been involved in over five technical reviews of national fibre networks and three technical due diligences of mobile networks, throughout the world.

Franck is regularly invited to speak and chair at international conferences on the subjects of broadband, NGA, backhaul and duct access.

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.

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.

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KHOOSHIRAM OODHORAH

Position: Consultant, Analysys Mason

Project role: Wireless network review lead

Qualifications: M.Sc., B.Sc.

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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.

Khooshiram has worked on a number of public-sector projects:

- 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.

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	Khooshiram is an accomplished user of MapInfo, Matlab, Mentum 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. Prior to joining Analysys Mason, he worked as a software engineer at Ceridian Ltd and Infosys. 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.
DR. TRICIA RAGOOBAR **Position:** Associate Consultant, Analysys Mason **Project role**: Consultant **Qualifications**: Ph.D., M.Sc., B.Sc.	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. 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 *Telecommunications Policy*. 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. 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.

Annex D Declaration

D.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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2 March 2012

D.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 and wireless network 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 worked 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 lead the previous project has now left Analysys Mason to form an independent company known as Implied Logic Ltd.[90]

[90] http://www.impliedlogic.com/Company/.

Annex E 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.

3G	Third generation
3GPP	*3G* Partnership Project
10G	10 Gigabit
ABHT	Average busy-hour throughput
ACCC	Australian Competition & Consumer Commission
ACMA	Australian Communications and Media Authority
ADSL	Asymmetric digital subscriber line
ALA	Active line access
AN	Aggregation node
APEK	Agencija za pošto in elektronske komunikacije
APON	*ATM PON*
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 *UK*
BPON	Broadband passive optical network
BPSK	Binary *PSK*
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
CoS	Class of service
CPE	Customer premise equipment
CSA	Connectivity serving area
CVC	Connectivity virtual circuit
CWDM	Coarse *WDM*
DA	Distribution area
dB	Decibel
DCN	Data communications network
DFN	Distribution fibre network
DHCP	Dynamic host configuration protocol
DL	Downlink

DNS	Domain name system
DSL	Digital subscriber line
DT	Deutsche Telecom
DTV	Digital television
DWDM	Dense wavelength division multiplexing
EDGE	Enhanced data rates for *GSM* evolution
EFMA	EFM Alliance
EIR	Equipment identity register
EMS	Element management system
eNodeB	Enhanced node B
EPON	Ethernet passive optical network
ESA	Exchange serving area
E-UTRAN	Enhanced *UTRAN*
EVC	Ethernet virtual connection
EV-DO	Evolution data-optimised
FD-LTE	*FD LTE*
FAN	Fibre access node
FCC	Federal Communication Commission
FD	Frequency division
FDA	Fibre distribution area
FDD	Frequency division duplexing
FDH	Fibre distribution hub
FDMA	Frequency division multiple access
FSA	Fibre serving area
FSAM	Fibre serving area module
FSAN	Full service access network
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
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

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
IEEE	Institute of Electrical and Electronic Engineers
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
MDU	Multi-dwelling unit
MGCP	Media gateway control protocol
MIMO	Multiple-input multiple output
MME	Mobility management entity
NBN	National broadband network
NC	Nucleus Connect
NG PON	Next generation *PON*
NGA	Next generation access
NGNBN	Next generation *NBN*
NNI	Network-network interface
NTD	Network termination device
OCR	Optical consolidation rack
ODF	Optical distribution frame
OFDF	Optical fibre distribution frame
OFDMA	Orthogonal *FDMA*
OTA UE	Over-the-air user equipment
OLT	Optical line terminal

ONT	Optical network terminal
ONU	Optical network unit
OTT	Over-the-top
P2P	Point-to-point
PDN-GW	Packet data network gateway
PCP	Primary connection point
PCRF	Policy charging rule function
PIA	Physical infrastructure access
PIR	Peak information rate
POI	Point of interconnect
PON	Passive optical network
PoP	Provide or pay
POP	Point of presence
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
RF	Radio frequency
RGW	Residential gateway
S-GW	Serving gateway
SC-FDMA	Single carrier *FDMA*
SAE	System architecture evolution
SAU	Special Access undertaking
SDU	Single-dwelling unit
SKT	SK Telecom
SME	Small/medium enterprise
SNR	Signal-to-noise ratio
SP	Service provider
TC_1	Traffic class 1
TC_2	Traffic class 2
TC_3	Traffic class 3
TC_4	Traffic class 4
TD-LTE	*TD LTE*
TD	Time division
TDD	Time division duplexing
TDM	Time division multiplexing
TDM PON	Time division multiplexing *PON*
ToP	Take or pay
TS	Telekom Slovenije
UFB	Ultra-fast broadband
UK	United Kingdom
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
USD	*US* dollar
USIM	Universal subscriber identity module
UTRAN	*UMTS* radio access network
VDSL	Very-high-bitrate digital subscriber line
VLAN	Virtual *LAN*
VoD	Video on demand
VoIP	Voice over Internet Protocol
VPN	Virtual private network
VULA	Virtual unbundled local access
WBF	Wavelength blocking filter
W-CDMA	Wideband *CDMA*
WDM	Wavelength division multiplexing
WDM PON	Wavelength division multiplexing *PON*
WiMAX	Worldwide interoperability for microwave access
XG	10^{th} generation
XG PON	10G PON
XPIC	Cross-polarisation interference cancellation