Report for nbn

Prudency and efficiency review of nbn's network selection, upgrade methodology and the design of its FTTC network

Matt Yardley, Franck Chevalier and Rod Parker

Date: 20 June 2022

Ref: 786678499-521

Contents

Annex A Principal authors of this report
Annex B Declaration
Annex C Glossary of terms

Analysys Mason Limited
North West Wing, Bush House
Aldwych
London WC2B 4PJ
UK
Tel: +44 (0)20 7395 9000
london@analysysmason.com
www.analysysmason.com
Registered in England and Wales No. 5177472

1 Executive summary

1.1 Introduction

NBN Co Limited (nbn) was established in April 2009 to design, build and operate a national broadband network to deliver high-bandwidth broadband and telephony services across Australia. nbn 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 Communications, Urban Infrastructure, Cities and the Arts, and the Minister for Finance.

Initially, nbn’s remit was to design, build and operate a wholesale-only, super-fast broadband network to provide downlink bandwidths of up to 100Mbit/s to 93% of premises in Australia using fibre to the premises (FTTP), and bandwidths of up to 12Mbit/s to the remaining 7% of Australian premises using fixed wireless access (FWA) and satellite networks.

However, following a strategic review published on 12 December 2013, the Australian Government has agreed that nbn’s roll-out should transition from a three-technology network (FTTP + FWA + satellite) to an optimised multi-technology mix (MTM) approach, with the addition of fibre-to-the-node (FTTN), fibre-to-the-building (FTTB) and hybrid-fibre-coaxial (HFC) networks.

nbn is currently developing a revised variation to the SAU (referred to as the 2021/22 SAU variation) to reflect all of the MTM technologies that comprise the nbn network. The original Special Access Undertaking (SAU) agreed in 2013 continues to apply specifically to nbn’s FTTP, fixed wireless and satellite networks, and does not cover nbn’s FTTC, FTTB, FTTN and HFC networks.

Scope of our review and factors to be addressed

As part of the 2021/22 SAU variation, nbn proposes to make submissions to the ACCC about the prudency and efficiency of the costs associated with the current design of the FTTC network, which will be rolled into nbn’s cost base and which will be recoverable through the cost recovery mechanism in the SAU.

nbn also proposes to make submissions to the ACCC about the prudency and efficiency of nbn’s methodologies and processes for determining:

- the mix of network types that nbn has deployed in each geographical area; and
- upgrades in network technology on a forward-looking basis.

Accordingly, nbn has engaged Analysys Mason to undertake an independent review of the prudency and efficiency of the following matters:

- the design of nbn’s current FTTC network;
- nbn’s methodology and processes for determining which specific type of fixed-line network it will deploy in the particular geographical areas that are within nbn’s fixed network footprint; and
- nbn’s methodology and processes for determining upgrades to the fixed network technology used in each geographical area over time.

As part of its engagement, Analysys Mason has been requested to address three key questions:

1. whether, and the extent to which, nbn's current design for its FTTC network reflects a prudent and efficient network design. Analysys Mason has been requested to focus on nbn's design choices in respect of the FTTC network and was not asked to consider how nbn determines the extent or size of the FTTC network (e.g. how many 'modules' of the FTTC network are to be deployed and why).

2. the prudency and efficiency of nbn's methodology and processes for determining which fixed network type (FTTP, FTTB, FTTC, FTTN or HFC) is to be deployed in particular geographical areas. The previous Analysys Mason report (accompanying the 2016 proposed SAU variation), answered this question with respect to the MTM networks that nbn was rolling out at that time (i.e. the FTTB, FTTN and HFC networks). Analysys Mason has been asked to focus particularly on the deployment of the FTTC network and how this affects the prudency and efficiency of nbn's methodology and processes for determining which fixed network type is to be deployed in particular geographical areas. In undertaking the analysis, Analysys Mason has been requested to take account of the requirements of the 2016 SOE, in particular the Australian Government's intention that nbn will roll out its network in a cost-effective way, using the technology best matched to each area of Australia. In this part of this present report, Analysys Mason has been requested to focus on network selection at the geo-type level and was not asked to consider network choices on a more granular level (e.g. at the street level, or post code level).

3. the prudency and efficiency of nbn's current methodology and processes for determining upgrades from FTTC and FTTN to FTTP under nbn's IAP, as summarised in Section 2.1 below. In undertaking the analysis, Analysys Mason has been requested to consider whether such upgrade methodologies and processes provide a sufficient upgrade path to meet anticipated demand for bandwidth, functionality, flexibility, reliability up to 30 June 2040.

In undertaking its assessment of the issues above, Analysys Mason has not assessed policy decisions (or the merits of such decisions) made by the Australian Government that impact upon the design of the nbn network (i.e. as set out in the 2016 SOE or the 2021 SOE). Instead, Analysys Mason has focussed its review on the key choices or decisions that have been made by nbn within the overall parameters that have been established by the Australian Government at a policy level through its 2016 SOE and 2021 SOE.

Our approach to determining the prudency and efficiency of nbn's network selection methodology

During the network roll-out, through its SoEs, the Australian Government has mandated nbn to design and deploy an optimised MTM network and provided for nbn to determine which network types were utilised on an area-by-area basis, so as to minimise peak funding, optimise economic returns and enhance the company's viability. As at the date of this report, the updated SoE also stated that nbn is expected to continue improving consumer experience when connecting to (and using) the network, and continue to support future demand, reinforce data speed capability and utilise (as appropriate) emerging and future technologies where this can improve service in an effective or cost-efficient manner.

In addition, an earlier SoE required nbn to ensure that the business rules it establishes to determine which technology is used in each locality were transparent to the community, and periodically updated to reflect technological and commercial developments.[1]

As nbn has the responsibility for determining which network type it is to deploy in particular geographical areas, it is necessary to consider whether nbn's methodology and processes for determining which network type is to be deployed in a particular geographical area are prudent and efficient.

Analysys Mason has had regard to the above stated requirements in the SoEs as the basis for our prudency and efficiency analysis of nbn's network selection methodology and processes. In doing so, we have focused our review of prudency and efficiency on network selection at the geo-type level.

In particular, we have considered whether the decisions made by nbn as a consequence of the application of its network selection methodology and processes would result in (or be likely to result in) outcomes that are consistent with the outcomes that we would expect from a prudent and efficient telecoms operator subject to the same requirements and constraints as those applicable to nbn under the SoE.

Our approach to determining the prudency and efficiency of nbn's FTTC network design

Analysys Mason considers that the key decisions that influence the efficiency and prudency of the FTTC network design include:

- technology choices, which mainly relate to the access network 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 as well as maximising the re-use of existing infrastructure.

It is on these specific areas of nbn's design of its FTTC network that we have focused our analysis, bearing in mind that some design decisions of existing networks that are to be integrated into the nbn network have already been made by third parties, namely Telstra.

In performing this analysis, we have considered whether nbn's design decisions are consistent with current international best practice for the deployment of FTTC networks in other developed markets.

---

[1] http://www.nbnco.com.au/content/dam/nbnco2/documents/nbn-multi-technology-deployment-principles.pdf

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

- In reviewing the 'prudency' of network design decisions made by nbn, we have considered 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 network design decisions made by nbn, we have considered whether those decisions are likely to achieve the best result with minimum wasted effort or expense taking into account local 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 always necessary or, indeed, practically possible to evaluate all design decisions simultaneously from both a prudency and efficiency perspective. In practice, this has meant that the 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 this 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.

Our approach to determining the prudency and efficiency of nbn's FTTP upgrade

As part of our prudency analysis, we have sought to analyse whether, and the extent to which, nbn's design decisions to upgrade FTTN and FTTC to FTTP can meet anticipated demand requirements of access seekers for bandwidth, functionality, flexibility and reliability until 30 June 2040.

In undertaking our assessment of the efficiency and prudency of nbn's design of its MTM network, we considered multiple sources of information that were provided by Webb Henderson on behalf of nbn. This included the SoE, ACCC documents and nbn documents which capture or explain the key decisions that have been made to date in respect of the design of nbn's MTM network.

In making our assessment, we have supplemented this information with our sources including Analysys Mason Research, FTTH Council, OECD and national regulatory authorities.

1.2 Review of nbn's methodology and processes for MTM network selection

Analysys Mason's assessment of nbn's network selection methodology

We believe that the methodology and processes used by nbn for determining which type of MTM network was deployed in a particular geographical area is prudent and efficient. The two-step process (i.e. the strategic modelling and the strategic overlay processes) used by nbn lead to a prudent and efficient methodology to determine which type of MTM network should be deployed in each geographical area.

We are satisfied with the methodology used for the strategic modelling process to determine the optimum type of MTM network to deploy. nbn’s methodology is based on a series of parameters that have been developed in line with successive SoE principles.

The strategic overlay process considers practical and operational issues in the deployment of the relevant network type for every individual area. It is based on a series of business rules that consider a wide range of relevant factors, including the minimisation of peak funding, optimising economic returns and enhancing nbn’s viability. In addition, the methodology also incorporates a long-term NPV consideration. We believe this process to also be prudent and efficient as it is critical to consider the different constraints in the different areas to ensure an efficient deployment of the network. For example, when the difference in peak funding is marginal between FTTP and FTTN for a business park, there may be a business case for nbn to deploy the solution which will be able to accommodate higher-capacity services (i.e. FTTP) and consequently create the opportunity to obtain greater service revenues, even though that network type may attract a higher peak-funding requirement compared to other network types.

Analysys Mason’s assessment of FTTC network deployment strategy

We believe that nbn’s rationale for deploying FTTC technology is prudent and efficient:

- Deployment of FTTC on long FTTN copper loops is prudent and efficient as it effectively shortens the copper loops and therefore increases the throughput provided to end-users while still reusing the copper final drop.

- Deployment of FTTC in areas where there is a small number of premises is also prudent and efficient as it prevents the deployment of an expensive FTTN street cabinet for a small number of premises which would lead to high fixed costs for a small number of premises.

- Deployment of FTTC in areas with a concentration of small MDUs is also prudent and efficient as it avoids the deployment of costly FTTP/HFC lead-ins and multiple visits where owners’ corporation access is required as the copper loops already exist.

- Deployment of FTTC in areas where no copper lead-in is required to be built and where there would be a high lead-in costs if FTTP was to be deployed which is also prudent and efficient.

Analysys Mason’s assessment of using a single HFC network strategy

We believe nbn’s choice to re-use the Telstra HFC network to be both prudent and efficient; it considered the future investment associated with the Optus HFC network and concluded that re-using the Optus network would increase capex and opex, given the state of the Optus HFC network at the time. This is because the Optus network included more cascaded RF amplifiers resulting in a higher level of ‘noise’ and therefore a lower potential capacity compared to the Telstra HFC network. In addition, while the Optus HFC network is overhead, the majority of the Telstra network is underground which provides benefits from a service availability perspective.

The choice of using a single HFC network (i.e. Telstra network) leads to a reduction in complexity for the design, construction and operational maintenance, compared to a dual-network environment. Finally, using a single network also means a reduction in operation and maintenance opex (i.e. it is more cost effective to operate and maintain a single network than two distinct networks).

1.3 Review of the efficiency and prudency of nbn's FTTC network design

Analysys Mason's assessment of services supported by the FTTC network

The downlink and uplink bandwidth delivered over the FTTC network will depend upon the characteristics of the copper loop, particularly the length of the sub-loop and whether vectoring can be used or not. Based on our experience of FTTC networks, we believe that nbn should be able to provide a maximum downlink bandwidth within the 50–100Mbit/s range and a maximum upload speed in the 20–40Mbit/s range, in line with nbn service portfolio for FTTC networks.

We therefore believe that the selection of products proposed by nbn in areas served by its FTTC network is prudent and reasonably accounts (through proposing a range of throughput) for uncertainties regarding the actual physical characteristics of the existing CAN (i.e. quality and copper loop length).

Analysys Mason's assessment of nbn access technology selection for FTTC networks

Analysys Mason believes that the use of VDSL2 (profile 17a) technology by nbn is prudent. VDSL2 is a mature technology which has been successfully deployed by many incumbents around the world, such as Openreach and AT&T, and is also a cost-efficient technology as it allows the re-use of the existing CAN infrastructure, avoiding costly civil engineering or the deployment of an overlay network.

nbn's approach to vectoring (i.e. not activating the technology) is prudent and minimises potential problems associated with other operators' use of the same copper cable. nbn decision not to use G.fast is also prudent as G.fast was considered as an interim step to moving to FTTP. To meet potential demand for 1G services, nbn decided to bypass the interim G.fast step and opted for the FTTP upgrade. nbn's strategy to upgrade FTTC end-users to FTTP if they require a higher speed tier is reasonable and ensures the upgraded connection is future-proof in terms of bandwidth.

Analysys Mason's assessment of FTTC architecture

The FTTC network architecture designed by nbn, which uses a PON to backhaul the traffic between the DPU and the FAN, is prudent and efficient as it allows the FTTC network to be upgraded to future-proof FTTP with minimum architectural change.

Analysys Mason's assessment of nbn traffic dimensioning

We believe the dimensioning for the backhaul of the four-port DPU based on a 1:8 PON split ratio to be appropriate for nbn to offer the range of download and upload speeds mentioned for the FTTC service. We therefore believe the backhaul dimensioning between the DPU and FAN to be prudent and efficient.

Regarding the dimensioning of the transit network, there is no standard way to dimension network links. nbn has developed and refined a detailed dimensioning methodology since the launch of its operations since 2010 and can now use actual data from that network to benchmark its dimensioning calculations. For the dimensioning of TC-4 traffic, which is defined in terms of PIR, we believe that nbn's methodology is sound as the theoretical calculation is now backed up by actual data measured on the network.

Also, nbn applies service qualification limits when provisioning TC-1 and TC-2 services into the network, which is designed to ensure that there will always be sufficient service bandwidth for TC-1 and TC-2 services, albeit with some potential impact on TC-4 traffic in cases of higher link utilisation. This seeks to ensure that TC-1 and TC-2 services will never experience congestion as there will always be enough link bandwidth to satisfy traffic that is fully utilising the amount of allocated TC-1 or TC-2 capacity. Other processes are also in place to ensure that TC-4 traffic is not unduly affected, which consist of measuring the utilisation of shared network resources, and if it determines (based on multiple utilisation measurements) that a shared network is becoming congested, it takes action to remedy the situation, for example through capacity augmentation. We believe this approach to be prudent and efficient.

1.4 Review of methodology and processes for determining upgrades to the fixed network technology

Analysys Mason's assessment of the methodology and processes for the upgrade from FTTN to FTTP

For the upgrade from FTTN to FTTP, the key activity is deploying fibre from the FTTN node to the DP in the LFN close to the end customer ready for the fibre lead-in to be installed on demand. The areas selected for the upgrade under the IAP are those with the most attractive return on investment determined by the comprehensive selection process known as RIPE. The FTTN to FTTP IAP programme is currently progressing to plan and on track to be completed by December 2023. We consider the methodology and processes being followed for determining FTTN to FTTP upgrades under nbn's IAP to be prudent and efficient.

Analysys Mason's assessment of the methodology and processes for the upgrade from FTTC to FTTP

As the FTTC network already makes use of the GPON network for backhaul from the DPU containing the FTTC VDSL2 DSLAM, with fibre already deployed in the LFN, the process for upgrading from FTTC to FTTP is more straightforward than for FTTN to FTTP. This will allow nbn to enable FTTP to be ordered for the majority of FTTC premises (approximately 900 000) by the end of 2022. The remainder of FTTC premises will be eligible for an FTTP upgrade in 2023 once additional solution elements have been designed, built and launched. We consider the approach to the original FTTC roll-out, in particular the use of GPON backhaul, plus the approach to the process for upgrading from FTTC to FTTP as prudent and efficient.

Analysys Mason's assessment of whether FTTC/FTTP upgrades meet anticipated bandwidth demand till June 2040

The deployment of an FTTP network provides much greater scope for enabling higher-bandwidth services to be offered. Once the FTTP network is in place it is possible to meet the expected demand for increased bandwidth by simply upgrading the active equipment technology layer rather than needing to implement more costly passive network upgrades. We examined two scenarios, one based on an Analysys Mason forecast rate of traffic growth of 21% and one based on nbn's more conservative rate of 15%. We found in both cases that technology available today (or currently being developed by standards bodies, and able to be deployed by nbn when needed) is capable of meeting the projected bandwidth demands till June 2040. Making FTTP available across the network would represent a prudent and efficient approach to ensuring that nbn is able to meet anticipated bandwidth demand at least up to 2040.

Analysys Mason's assessment of whether FTTC/FTTP upgrades meet the functionality and flexibility required till June 2040

It is a requirement for nbn to support the functionality needed to support typical and expected future applications which typically include SIP-based voice services, interactive data services, and best-efforts internet access. Such applications are supported by the existing FTTN and FTTC technologies albeit with some limitations in headline speed to support the most bandwidth-intensive applications. The upgrade to FTTP will allow these applications to be supported with the added benefit that existing and new applications that require higher-speed connections will be more easily accommodated by the FTTP technology. There is evidence that nbn is following the same path as other developed countries to support higher headline speeds over FTTP networks meaning that it should be able to provide the functionality required till June 2040.

It is a requirement of nbn's SoE to ensure it maintains flexibility to adapt to and adopt future advancements and innovations. The upgrade to FTTP supports higher-speed connections while maintaining the underlying IP-based network that we expect to continue to be the basis of internet connectivity. We expect this combination will provide nbn with the flexibility it needs to support future advancements and innovations till June 2040 in a prudent and efficient way.

Analysys Mason’s assessment of whether FTTC/FTTP upgrades meet reliability requirements till June 2040

The move from FTTN and FTTC technology should see an increase in the end-to-end service availability that will lead to a more reliable network, meeting reliability needs up to 2040. Indeed, our experience is that FTTP networks have materially lower fault rates than the copper networks that precede them, which we expect will ensure that the FTTP upgrades will enable reliability expectations to be met till June 2040 in a prudent and efficient way.

2 Introduction

2.1 Background

nbn Limited (nbn) was established in April 2009 to design, build and operate a national broadband network to deliver high-bandwidth broadband and telephony services across Australia. nbn 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 Communications, Urban Infrastructure, Cities and the Arts, and the Minister for Finance.

Initially, nbn's remit was to design, build and operate a wholesale-only, super-fast broadband network to provide downlink bandwidths of up to 100Mbit/s to 93% of premises in Australia using fibre to the premises (FTTP), and bandwidths of up to 12Mbit/s to the remaining 7% of Australian premises using fixed wireless access (FWA) and satellite networks.

However, following a strategic review published on 12 December 2013, the Australian Government has agreed that nbn's roll-out should transition from a three-technology network (FTTP + FWA + satellite) to an optimised multi-technology mix (MTM) approach, with the addition of fibre-to-the-node (FTTN), fibre-to-the-building (FTTB) and hybrid-fibre-coaxial (HFC) networks.

The assets required to support nbn's MTM strategy were acquired from two well-established fixed operators, Telstra and Optus. These assets include elements of the following networks:

- Telstra's copper access network
- Telstra's HFC network
- Optus's HFC network.

Consistent with the Government's policy in relation to the national broadband network, nbn intends to lodge a variation to its current Special Access Undertaking (SAU) for assessment by the ACCC.

This is the latest of a series of amendments to the SAU, which have developed as follows:

- **2013 SAU:** The SAU accepted by the ACCC on 13 December 2013 was based on an FTTP, FWA and satellite access strategy and the variation includes updates to account for the shift to the MTM strategy.

- **2016 SAU variation:** In May 2016, nbn lodged an SAU variation with the ACCC, which sought to expand the scope of the SAU to cover FTTB, FTTN and HFC technologies. As part of that process, Analysys Mason provided an independent expert report for Webb Henderson in relation to the prudency and efficiency of nbn's network selection and the design of the FTTB, FTTN and HFC networks.

- **2017 SAU variation:** nbn withdrew the 2016 SAU variation in June 2017, simultaneously lodging a revised SAU variation (which it withdrew in November 2018).

- **2019 SAU variation:** In May 2019, nbn lodged an SAU variation with the ACCC, which sought to extend the expiration date of certain non-price provisions that were set to expire on 30 June 2019, such that those provisions would continue until 30 June 2023. These non-price provisions related to customer endorsement for certain network design changes, dispute resolution arrangements, and product development processes. On 9 April 2021, following consultation, the ACCC accepted this proposed variation.

- **2021/22 SAU variation:** nbn is currently developing a revised variation to the SAU to reflect all of the MTM technologies that comprise the nbn network. (The original SAU continues to apply specifically to nbn's FTTP, fixed wireless and satellite networks, and does not cover nbn's FTTB, FTTN and HFC networks.)

  - Since the 2016 SAU variation, nbn has deployed FTTC technology as part of its implementation of the MTM model. The deployment of FTTC was carried out to push fibre closer to end-user premises than would be the case with FTTN (thereby delivering bandwidth and performance improvements).

  - FTTC as an additional nbn network technology joins FTTN, FTTB and HFC as one of the technologies that forms part of the MTM model (alongside the original technologies that are already within the scope of the SAU).

  - The MTM model formed part of the Government's Statement of Expectations to nbn dated 8 April 2014, as well as the Government's Statement of Expectations to nbn dated 24 August 2016 (2016 SOE).

As with FTTB, FTTN and HFC, FTTC has been rolled out in particular geographical areas as part of the MTM model. In addition, in September 2020, nbn launched its Investment Acceleration Program (IAP), under which nbn plans to invest AUD4.5 billion to upgrade nbn's networks. The IAP seeks to ensure that, by 2023, 75% of premises within nbn's fixed-line network footprint will have access to peak wholesale speed tiers of 500Mbit/s to close to 1Gbit/s. Under nbn's current upgrade plans, this objective will primarily be achieved by upgrading certain premises within the FTTN and FTTC network footprints to FTTP technology in an 'on-demand' manner (i.e. focusing the upgrades on those premises where there is actual, proven demand for higher-bandwidth services).

The IAP was announced by nbn's Shareholder Ministers on 23 September 2020[2], and is reflected in the requirements of the most recent Statement of Expectations issued by nbn's Shareholder Ministers on 31 August 2021 (2021 SOE)[3]. In particular, the 2021 SOE specifies that, "[w]ithin its capital constraints, nbn will continue to upgrade the network technologies to support retailers to meet demand from end users which exceeds [specified] minimum requirements, including implementing current plans to expand access to peak download speeds of up to 1 gigabit per second". More

---

[2] Ministers for Finance and Communications, Joint Media Release, 23 September 2020, https://www.financeminister.gov.au/media-release/2020/09/23/45-billion-nbn-investment-bringultra-fast-broadband-millions-families-and-businesses-and-create-25000-jobs

[3] NBN Co Ltd Statement of Expectations, 31 August 2021, https://www.communications.gov.au/publications/nbnstatementofexpectations

broadly, the 2021 SOE states that "nbn should continue to support future demand, reinforce data speed capability where needed, and act pro-competitively in providing network build activities in accordance with legal and policy parameters".

SAU variation process

nbn is currently developing a variation to the SAU to reflect the full range of MTM technologies that comprise nbn's network infrastructure. Importantly, nbn's proposed variation to the SAU will incorporate nbn's FTTB, FTTC, FTTN and HFC networks within the ambit of the SAU (as compared to the 2016 variation, which only incorporated the FTTB, FTTN and HFC networks). Part XIC of the CCA permits nbn to seek to vary an accepted SAU and provides criteria for the ACCC's assessment of this variation. The assessment criteria are identical to those which applied to the ACCC's assessment of the original SAU accepted by the ACCC in December 2013.

nbn will be seeking a variety of amendments to the SAU to cater for the inclusion of the MTM technologies (e.g. changes to the service descriptions to incorporate services provided over the new technologies, and recognising that not all services will have a network boundary point in the premises). nbn also expects to seek changes to its long-term pricing construct in the SAU. However:

- nbn will remain a wholesale-only access network, available on equivalent terms to all access seekers; and
- nbn will continue to operate at the lowest practical levels in the network stack (i.e. generally Layer 2).

2.2 Scope of our review and factors to be addressed

As part of the variation of the SAU, nbn proposes to make submissions to the ACCC about the prudency and efficiency of the costs associated with the current design of the FTTC network, which will be rolled into nbn's cost base and which will be recoverable through the cost recovery mechanism in the SAU.

nbn also proposes to make submissions to the ACCC about the prudency and efficiency of nbn's methodologies and processes for determining:

- the mix of network types that nbn has deployed in each geographical area; and
- upgrades in network technology on a forward-looking basis.

Accordingly, nbn has engaged Analysys Mason to undertake an independent review of the prudency and efficiency of the following matters:

- the design of nbn's current FTTC network;
- nbn's methodology and processes for determining which specific type of fixed-line network it will deploy in the particular geographical areas that are within nbn's fixed network footprint; and
- nbn's methodology and processes for determining upgrades to the fixed network technology used in each geographical area over time.

2.2.1 Questions to be addressed in this report by Analysys Mason

As part of its engagement, Analysys Mason has been requested to address three key questions:

1. whether, and the extent to which, nbn's current design for its FTTC network reflects a prudent and efficient network design. Analysys Mason has been requested to focus on nbn's design choices in respect of the FTTC network and was not asked to consider how nbn determines the extent or size of the FTTC network (e.g. how many 'modules' of the FTTC network are to be deployed and why).

2. the prudency and efficiency of nbn's methodology and processes for determining which fixed network type (FTTP, FTTB, FTTC, FTTN or HFC) is to be deployed in particular geographical areas. The previous Analysys Mason report (accompanying the 2016 proposed SAU variation), answered this question with respect to the MTM networks that nbn was rolling out at that time (i.e. the FTTB, FTTN and HFC networks). Analysys Mason has been asked to focus particularly on the deployment of the FTTC network and how this affects the prudency and efficiency of nbn's methodology and processes for determining which fixed network type is to be deployed in particular geographical areas. In undertaking the analysis, Analysys Mason has been requested to take account of the requirements of the 2016 SOE, in particular the Australian Government's intention that nbn will roll out its network in a cost-effective way, using the technology best matched to each area of Australia. In this part of this present report, Analysys Mason has been requested to focus on network selection at the geo-type level and was not asked to consider network choices on a more granular level (e.g. at the street level, or post code level).

3. the prudency and efficiency of nbn's current methodology and processes for determining upgrades from FTTC and FTTN to FTTP under nbn's IAP, as summarised in Section 2.1 above. In undertaking the analysis, Analysys Mason has been requested to consider whether such upgrade methodologies and processes provide a sufficient upgrade path to meet anticipated demand for bandwidth, functionality, flexibility, reliability up to 30 June 2040.

2.2.2 Factors and constraints to be considered in this review

In preparing this report, Analysys Mason has adhered to the following approach, as requested in the brief to advise:

In undertaking its assessment of the issues above, Analysys Mason has not assessed policy decisions (or the merits of such decisions) made by the Australian Government that impact upon the design of the nbn network (i.e. as set out in the 2016 SOE or the 2021 SOE). Instead, Analysys Mason has focussed its review on the key choices or decisions that have been made by nbn within the overall parameters that have been established by the Australian Government at a policy level through its 2016 SOE and 2021 SOE.

In relation to question 3 above, Analysys Mason was asked not to focus on the prudency or efficiency of nbn upgrading its network to expand access to peak download speeds of up to 1Gbit/s, but instead to focus on the prudency and efficiency of the specific methodology and processes that nbn has chosen to achieve this upgrade objective (i.e. the upgrades from FTTC and FTTN to FTTP in nbn's IAP).

As the FTTC network involves the re-use and upgrading of networks that are already constructed, the report only considers design choices in a way that has regard to the fact that some elements of the overall design are pre-determined, or not capable of being readily changed (e.g. the length and quality of copper lines connecting into the end-user premises) by virtue of the nature and characteristics of the network being upgraded.

Analysys Mason's review of the prudency and efficiency of nbn's current design of its FTTC network does not:

- re-open matters that were considered in Analysys Mason's initial review of the prudency or efficiency of the original network design for FTTP, fixed wireless and satellite in 2012, given that these matters relate to a separate and now concluded statutory process and;
- re-open matters that were considered in Analysys Mason 2016 review of the prudency or efficiency of the initial network design for FTTB, FTTN and HFC technologies (except to the extent that these matters are affected by the FTTC network).

In undertaking the review, Analysys Mason has had regard to the design considerations that nbn must take into account in connection with nbn's FTTC network, including the requirement for legacy copper services to co-exist with the FTTC network during the co-existence period and the associated implications for the migration experience.

2.3 Our approach to determining the prudency and efficiency of nbn's network selection methodology

During the network roll-out, through its SoEs, the Australian Government has mandated nbn to design and deploy an optimised MTM network and provided for nbn to determine which network types should be utilised on an area-by-area basis, so as to minimise peak funding, optimise economic returns and enhance the company's viability. As at the date of this report, the updated SoE also stated that nbn is expected to continue improving consumer experience when connecting to (and using) the network, as well as continue to support future demand, reinforce data-speed capability and utilise (as appropriate) emerging and future technologies where this can improve service in an effective or cost-efficient manner.

In addition, an earlier SoE required nbn to ensure that the business rules it establishes to determine which technology is used in each locality were transparent to the community, and periodically updated to reflect technological and commercial developments.[4]

---

[4] http://www.nbnco.com.au/content/dam/nbnco2/documents/nbn-multi-technology-deployment-principles.pdf

As nbn has the responsibility for determining which network type it is to deploy in particular geographical areas, it is necessary to consider whether nbn’s methodology and processes for determining which network type is to be deployed in a particular geographical area are prudent and efficient.

Analysys Mason has had regard to the above stated requirements in the SoEs as the basis for our prudency and efficiency analysis of nbn’s network selection methodology and processes. In doing so, we have focused our review of prudency and efficiency on network selection at the geo-type level.

In particular, we have considered whether the decisions made by nbn as a consequence of the application of its network selection methodology and processes would result in (or be likely to result in) outcomes that are consistent with the outcomes that we would expect from a prudent and efficient telecoms operator subject to the same requirements and constraints as those applicable to nbn under the SoE.

2.4 Our approach to determining the prudency and efficiency of nbn’s FTTC network design

Analysys Mason considers that the key decisions that influence the efficiency and prudency of the FTTC network design include:

- technology choices, which mainly relate to the access network 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 as well as maximising the re-use of existing infrastructure.

It is on these specific areas of nbn’s design of its FTTC network that we have focused our analysis, bearing in mind that some design decisions of existing networks that are to be integrated into the nbn network have already been made by third parties, namely Telstra.

In performing this analysis, we have considered whether nbn’s design decisions are consistent with current international best practice for the deployment of FTTC networks in other developed markets.

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

- In reviewing the ‘prudency’ of network design decisions made by nbn, we have considered 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 network design decisions made by nbn, we have considered whether those decisions are likely to achieve the best result with minimum wasted effort or expense taking into account local 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 always necessary or, indeed, practically possible, to evaluate all design decisions simultaneously from both a prudency and efficiency perspective. In practice, this has meant that the 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 this 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.

2.5 Our approach to determining the prudency and efficiency of nbn's FTTP upgrade

As part of our prudency analysis, we have sought to analyse whether, and the extent to which, nbn's design decisions to upgrade FTTN and FTTC to FTTP can meet anticipated demand requirements of access seekers for bandwidth, functionality, flexibility and reliability until 30 June 2040.

In undertaking our assessment of the efficiency and prudency of nbn's design of its MTM network, we considered multiple sources of information that were provided by Webb Henderson on behalf of nbn. This included the SoE, ACCC documents and nbn documents which capture or explain the key decisions that have been made to date in respect of the design of nbn's MTM network.

In making our assessment, we have supplemented this information with our sources including Analysys Mason Research, FTTH Council, OECD and national regulatory authorities.

2.6 Structure of this report

The remainder of this report is laid out as follows:

- Section 3 presents a technical overview of FTTC networks; it is designed as a reference point for all FTTC architectures discussed in the rest of the report.
- Section 4 presents a technical overview of FTTP networks; since nbn uses its FTTP network to backhaul its FTTC network, this section is designed as a reference point for all FTTP architectures discussed in the rest of the report.
- Section 5 presents our analysis and conclusions in respect of whether, and the extent to which, the methodology and processes used by nbn to determine the optimum network type in different geographical areas result in an efficient and prudent network mix.
- Section 6 presents our analysis and conclusions in respect of whether, and the extent to which, nbn's design for its FTTC network reflects an efficient and prudent network design.
- Section 7 presents our analysis and conclusions in respect of whether, and the extent to which, nbn's FTTN and FTTC to FTTP upgrade reflects an efficient and prudent network design.

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

- **Annex A** describes the expertise and experience of the principal authors of this report.
- **Annex B** includes declarations from Analysys Mason as per the requirements of *Expert Evidence Practice Note (GPN-EXPT)* (25 October 2016) supplied by Webb Henderson.
- **Annex C** provides a list of key acronyms used in this report.

3 Technical overview of FTTx networks

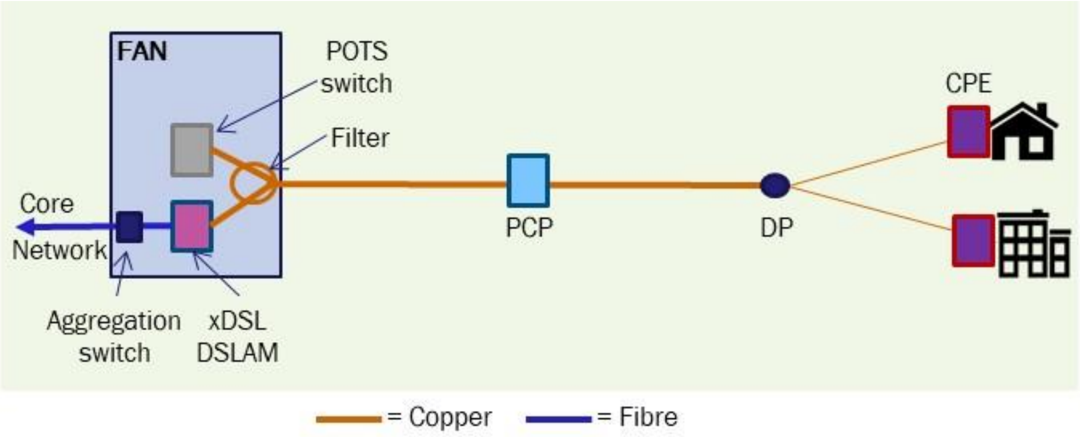
In this section we first describe the legacy copper access networks, defining all key elements of the network which serves as a reference for the rest of this report. We then provide an architecture overview of FTTN, FTTB and FTTC networks, describing the key nodes for each of these networks. We then describe the different standards for digital subscriber lines (DSL) that are used in FTTN, FTTB and FTTC architectures to provide broadband services. Finally, we provide the FTTC roadmap in terms of download speeds that can be delivered by different DSL technology to understand the maximum speed which can be provisioned on the wholesale broadband product, depending on the technology used.

3.1 Legacy copper network architecture

A typical legacy broadband network, using the legacy copper network is illustrated in Figure 3.1. In Figure 3.1, the key network nodes in a legacy broadband network architecture include the following:

- fibre access node (FAN)
- copper access network (CAN)
- primary connection point (PCP)
- distribution point (DP)
- customer premises equipment (CPE).

Figure 3.1: Legacy broadband access network architecture [Source: Analysys Mason]



We describe the (legacy) equipment contained in each of these network nodes below.

3.1.1 FAN

A FAN, which is most likely to be an existing telephone exchange building, hosts key active and passive network components including:

- **Main distribution frame (MDF):** a passive connection panel in the FAN between copper lines connecting customer premises to the FAN and core network equipment.
- **Filters** to separate PSTN telephony connections from broadband connections.
- **POTS switch:** the legacy switch used for telephony services.
- **DSL access multiplexer (DSLAM):** the equipment used to provide the broadband connection using the copper telephone lines. The first deployments of xDSL technology used variants of ADSL technology (i.e. ADSL2+) providing bandwidths up to 24Mbit/s.
- **Ethernet aggregation switch (EAS)** which aggregates all broadband connections from different DSLAMs and routes the traffic between the core and access networks.

3.1.2 CAN and PCP

The PCP provides a flexible passive copper connection point usually hosted in a cabinet or pillar physically located between the FAN enclosure and the customer premises, and serves between 50 and 500 customer premises. In Australia, a typical PCP is implemented using a pillar. Most exchanges host a number of PCPs, all connected via the legacy CAN. The copper network between the FAN and the PCP is usually referred to as the exchange side (or E-side) and the copper network between the PCP and customer premises is usually referred to as the distribution side (or D-side). The PCP connects E-side and D-side by using copper jumpers (connectors) in a connection panel (mini-MDF).

3.1.3 DP

The DP is another passive connection point in the network which connects the copper network to customer premises. It usually takes the form of a small box and can be located either on a pole (overhead infrastructure) or in a foot-hole (underground infrastructure). The DP usually connects 5–20 customer premises to the copper network. The network segment between the DP and customer premises is usually referred to as the last drop.

3.1.4 Customer premises

The last drop is usually terminated at the customer premises using a wall plate which is commonly known as the master telephone socket. A DSL filter is installed in the telephone socket at the customer premises to separate PSTN telephony (baseband) signals from broadband signals. The CPE is connected to the DSL filter. It usually takes the form of a DSL modem/router with Ethernet and/or Wi-Fi connections to connect to customers’ terminals (laptop PCs, tablets etc.) to provide access to the Internet. It should be noted that the CPE must be compatible with the DSL technology used by the DSLAM located in the FAN site.

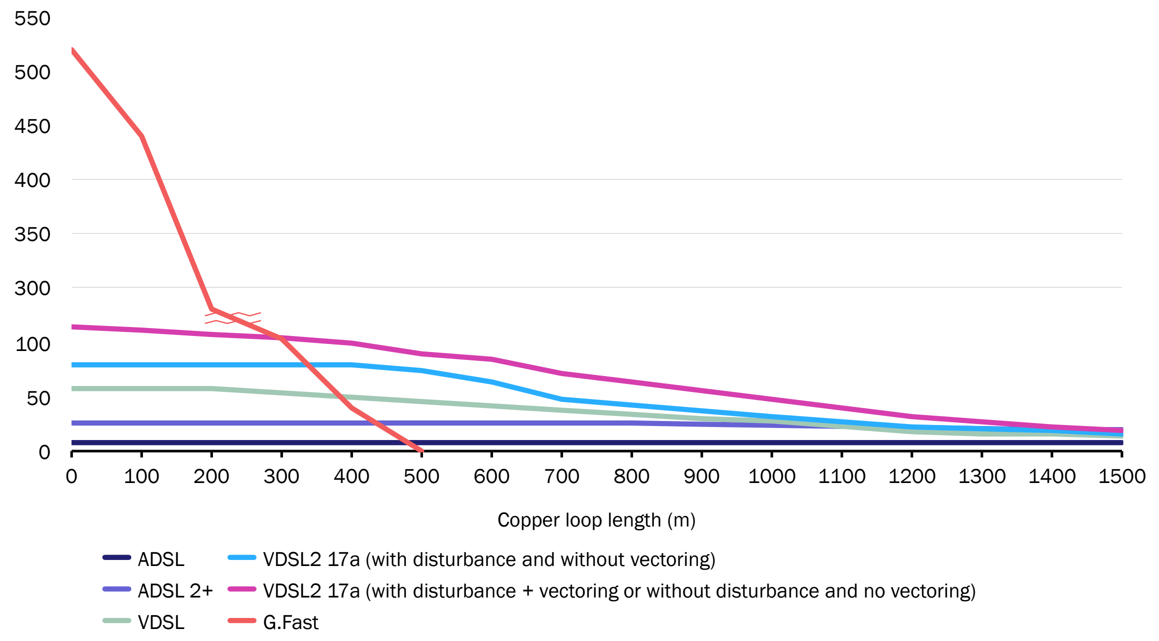
Based on observations made in this section, operators have had to decrease the length of their copper local loops to be able to take full advantage of new standards and to provide ever-increasing broadband bandwidth to their end-users. In the following sections, we describe the typical architectures which can be deployed to reduce the copper loop length, namely:

- FTTN
- FTTB
- FTTC.

3.2 FTTN architecture overview

In order to understand the rationale for FTTN/FTTB and FTTC architecture, it is first important to understand the relationship between broadband bandwidth performance and copper loop length. This is illustrated in Figure 3.2 for different xDSL technologies.

Figure 3.2: illustration of downlink broadband bandwidth as a function of the copper loop length for different xDSL technologies [Source: Analysys Mason]



A full description of each xDSL technology is provided in Section 3.5 of this report.

Figure 3.2 clearly shows that more recent xDSL standards (e.g. VDSL 2[5]) provide a significant increase in downlink and uplink bandwidth for shorter copper loops (i.e. loops up to 1.5km)

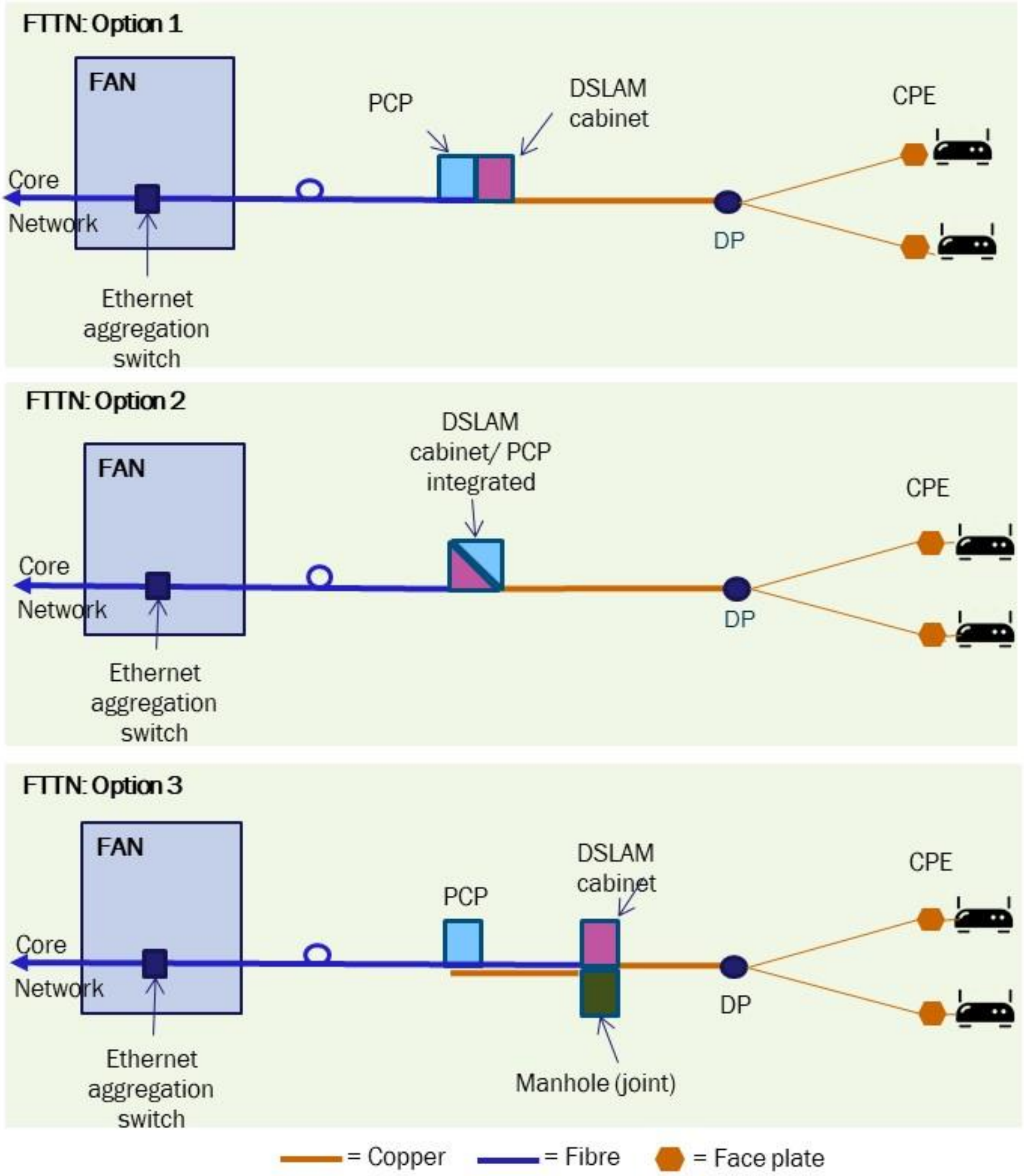
---

[5] We do not consider G.fast to be part of the xDSL technology family

compared to more mature standards (e.g. ADSL 2+). However, VDSL 2 performance gain compared with other DSL technologies significantly decreases for copper loops longer than 1.5km providing a similar absolute performance to earlier DSL technologies.

The shortening of copper loops can be achieved by the deployment of an FTTN architecture. FTTN involves rolling out fibre from the FAN to the PCP location where usually a street cabinet hosting the DSLAM will be deployed. Typically, an additional cabinet hosting the DSLAM is located close to the PCP cabinet to enable copper-line connections between the DSLAM and the PCP (see FTTN Option 1 in Figure 3.3, below). Alternatively, if there are constraints on physical space at the PCP location, or planning permission restrictions, a new integrated cabinet hosting both the PCP and the DSLAM can be deployed at the original PCP location (see FTTN Option 2 in Figure 3.3). Finally, if no new cabinets can be installed at the PCP location due to physical space or planning permission restrictions, the DSLAM cabinet could also be hosted in a totally new location between the PCP and customer premises, above an existing manhole which has suitable joints for copper interconnection (see FTTN Option 3 in Figure 3.3).

Figure 3.3: FTTN architecture options examples [Source: Analysys Mason]



Where possible to minimise civil engineering costs, fibre is deployed using the same duct infrastructure as the legacy copper cables between the exchange and the DSLAM cabinet.

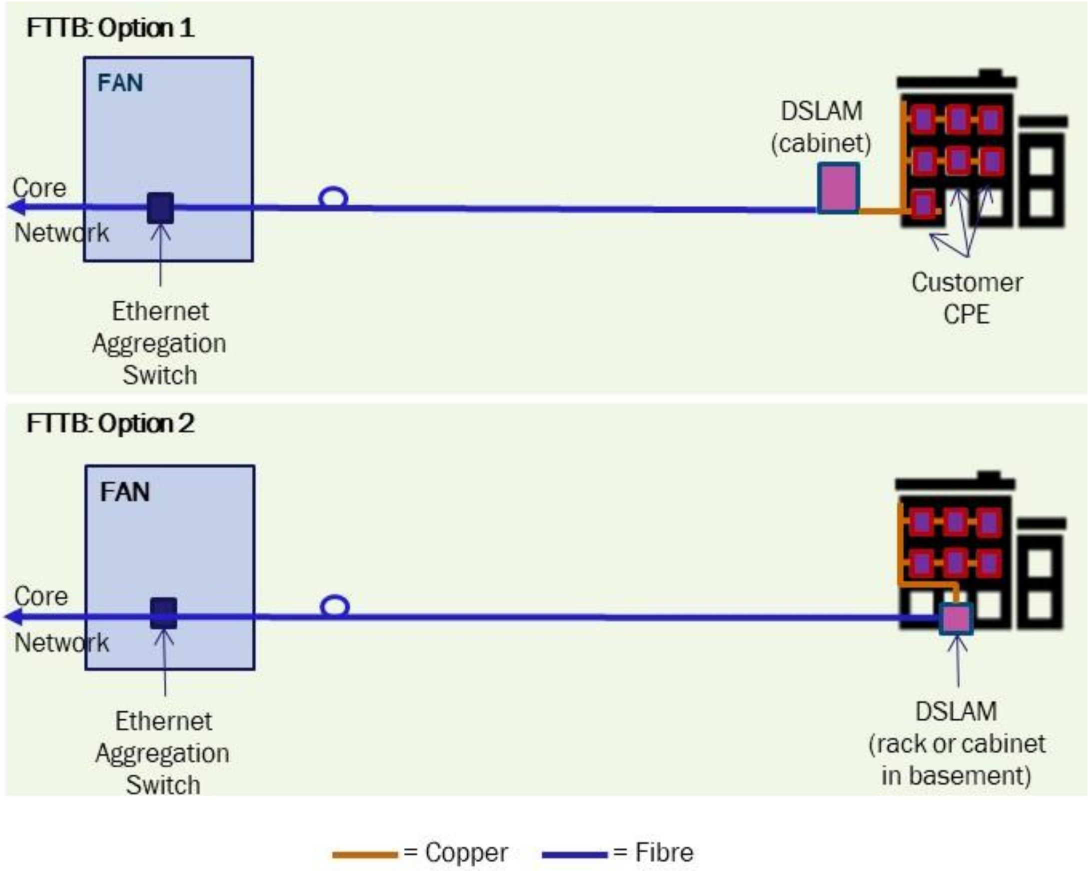
The longer the copper loop length, the lower the bandwidth that can be achieved at the customer premises, so the positioning of the DSLAM cabinet is a key design factor. This is a compromise between the broadband bandwidth that can be achieved and the number of customer premises that can be served from a single cabinet. In general, the closer to the FAN the cabinet is, the more customer premises it can serve and consequently the more cost effective, as fewer cabinets can be deployed to serve the customer premises in a defined area. However, as illustrated in Figure 3.2, the further away the cabinet is from the customer premises, the lower the broadband bandwidth due to the increasing length of the copper loop. Therefore, when designing FTTN networks, operators have to carefully consider the location of street cabinets as they need to optimise the balance between cost and performance (bandwidth) by taking account of:

- existing locations for interconnecting with the copper network
- the economies of scale associated with the number of customer premises served from a single cabinet
- the distance from the customer premises to ensure the broadband speeds advertised by the operator can be delivered.

3.3 FTTB architecture overview

An FTTB network architecture is used to provide broadband services to a building that accommodates many customer premises, often referred to as a multi-dwelling unit (MDU). Whilst a key design and performance factor of an FTTN network is the position of the DSLAM cabinet (usually close to the PCP), an FTTB network reduces the copper loop further by placing the DSLAM either in a small cabinet just outside the MDU (see Option 1 in Figure 3.4) or in the basement of the MDU (see Option 2 in Figure 3.4).

Figure 3.4: FTTB architecture options [Source: Analysys Mason]



Today, VDSL2 is the technology typically used in an FTTB architecture to deliver broadband services.

We describe FTTB Option 1 and 2 in more detail below.

FTTB Option 1

In FTTB Option 1, a small street cabinet (hosting the DSLAM) is deployed just outside the MDU to serve all premises within the building, and connected to the FAN using fibre. Assuming that the building's internal copper wiring is suitable, it can be used to connect each customer premises to the DSLAM cabinet. Re-using the building's internal wiring reduces the disruption within the building, which is beneficial to both building owners and premises tenants/owners, and network operators as it minimises costs. However, when the internal copper wiring is not suitable, new internal wiring has to be deployed. Not only is this costly and disruptive but it also requires prior agreement of the building owner(s), which in some cases can be difficult to obtain. Therefore, the suitability of a building's internal wiring represents a financial and technical risk for operators when deploying an FTTB solution. Note that in some far-sighted developed countries the governments/local authorities have changed building regulations so that all new MDUs must be built so that they can accommodate high-performance broadband connections internally to maximise broadband availability and take-up. However, there may still be issues related to delivering high-performance broadband connections within older existing MDUs.

In FTTB Option 1, the external DSLAM cabinet may provide broadband services to several MDUs, depending on the proximity of the MDUs to be served and depending on the number of premises within each MDU. For example, if four MDUs are within 250m of each other and if each MDU contains 10 premises, then the optimum solution for the operator may be to pursue FTTB Option 1 using a 48-port DSLAM compact cabinet.

FTTB Option 2

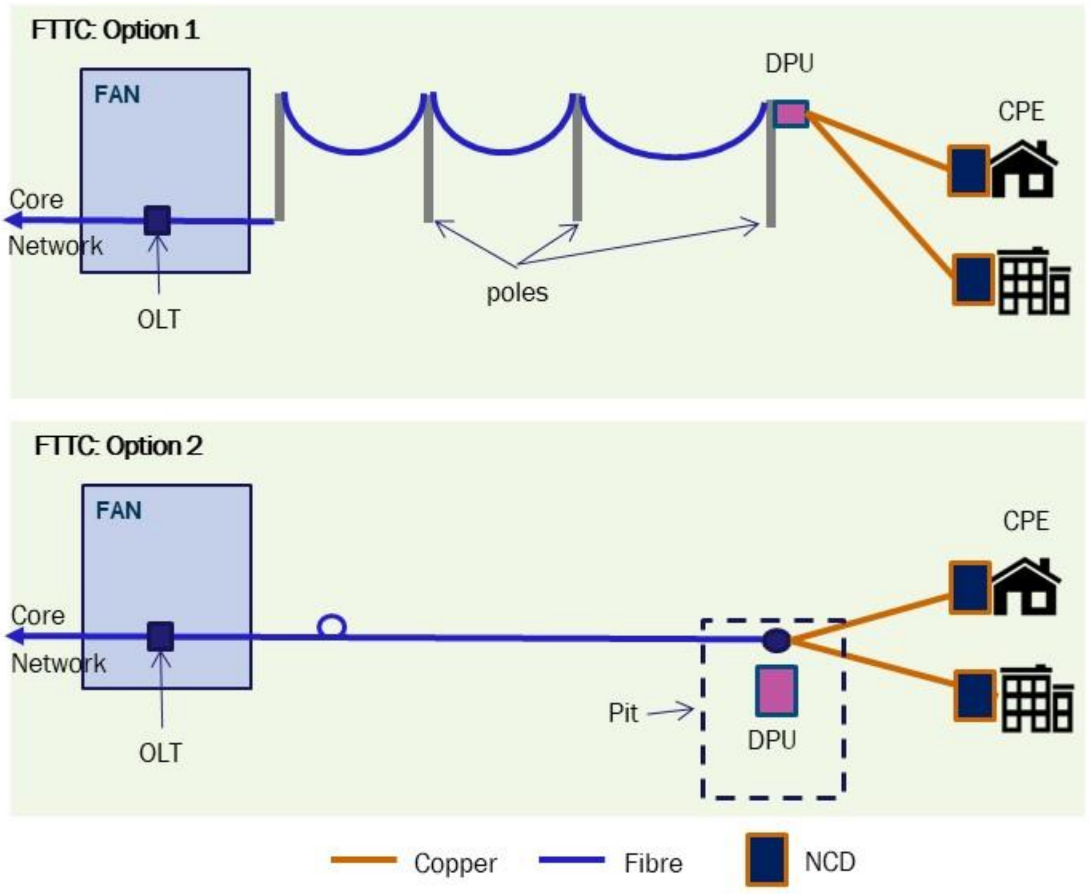
In FTTB Option 2, the DSLAM is deployed in the basement of an MDU and can take the form of a standard rack hosting DSLAM equipment or a standalone compact DSLAM unit. Deploying the DSLAM in a rack is scalable as DSLAM cards can be added to match the number of premises to be served.

FTTB Option 2 tends to be deployed in large MDUs (e.g. 40 or more customer premises) to take advantage of scale economies since the entire DSLAM can be dedicated to that building. However, it is not always possible for operators to have convenient access to the basement of an MDU as it requires prior permission from the building's owner. In cases where the operator cannot get access to the MDU's basement, it will deploy a cabinet just outside the MDU, as explained for FTTB Option 1.

3.4 FTTC architecture overview

The FTTC architecture consists of deploying fibre to a small DSLAM located at the DP known as a distribution point unit (DPU). Typically, the FTTC DPU takes the form of a small box located at the top of a pole for last drops delivered overhead (see FTTC Option 1 in Figure 3.5). Alternatively, for premises served by underground infrastructure, the DPU can be hosted in a sealed box in the last foot-hole of the network connecting the copper last drop to the customer premises (see FTTC Option 2 in Figure 3.5).

Figure 3.5: FTTC architecture options [Source: Analysys Mason]



By significantly shortening the copper loop compared to FTTN/FTTB, FTTC architecture can achieve higher bandwidth as illustrated in Figure 3.2. The DPU is backhauled to the FAN using an FTTP network. In the case of nbn, the FTTC network uses the FTTP passive optical network (PON) backhaul. Typical technology used at the DPU include VDSL2 and G.fast (see next section for a detailed description of these technologies).

3.5 xDSL technology

Incumbent operators designed and built their copper access networks to deliver legacy 'plain old telephony services' (POTS). With the increasing demand for higher-bandwidth data services, a broadband technology – DSL – was developed and used by operators over their legacy copper access infrastructure to provide end-users with downlink bandwidth of 'up to' 120Mbit/s[6]. The reason that broadband services are marketed as 'up to' a certain bandwidth is because, with DSL technologies, the actual bandwidth experienced at customer premises is dependent on the length (and quality) of

---

[6] 120Mbit/s is provided by VDSL2 technology with vectoring enabled as illustrated in Figure 3.2

the copper loop between the active equipment providing the broadband signal in the operator's network and the customer premises.

To address increasing broadband bandwidth demand, various DSL standards (referred to collectively as xDSL) have significantly evolved over time providing ever-increasing downlink and uplink bandwidth capability. xDSL standards include:

- ADSL family
  - ADSL1
  - ADSL 2
  - ADSL 2+.

- VDSL family
  - VDSL 1
  - VDSL 2.

The dependence between bandwidth performance and copper loop distance for the above xDSL technology is illustrated in Figure 3.2.

Two important observations can be made from Figure 3.2:

- the bandwidth decreases with the copper loop length for all xDSL technologies
- improvement in bandwidth provided by latest VDSL technology is for relatively short copper loops (up to about 1.5km in the above figure).

Therefore, advances in xDSL technology tend to benefit premises that are connected with shorter loop lengths.

3.5.1 VDSL standards

VDSL systems were developed to deliver higher bandwidth than ADSL systems, by using more spectrum in the copper cable. Since higher-frequency signals are more attenuated than low-frequency signals, VDSL is typically used over shorter loops than the loops used in ADSL systems. VDSL can also provide either symmetric or asymmetric bandwidths, although most services are asymmetric. Second-generation systems (VDSL2; ITU-T G.993.2) typically use frequencies of up to 17MHz to provide bandwidths exceeding 100Mbit/s downstream and 40Mbit/s upstream, or frequencies up to 30MHz to simultaneously provide bandwidths exceeding 100Mbit/s in both the uplink and downlink directions.

VDSL1

First-generation VDSL1 standards were published in 2001. They initially defined the use of the frequency band from 25kHz to 12MHz, supporting (over a single pair) downlink rates of up to 52Mbit/s and uplink rates of up to 16Mbit/s. The key factors in the standard are:

- The selection of frequency division duplexing (FDD) as the preferred duplexing method instead of time division duplexing (TDD). FDD reduces the effect of crosstalk compared to TDD systems and therefore increases bandwidth capability. Discrete multi-tone (DMT) modulation is the preferred modulation scheme for VDSL1 (as it was for ADSL systems).
- The introduction of a novel band-plan approach that used alternating uplink and downlink spectrum. Annex A of the VDSL standard defines North American requirements, whilst Annex B defines European requirements. Note that the frequency band used for VDSL1 was later extended from 12MHz to 30MHz.

Despite the apparently performance-favourable deployment conditions presented by relatively short copper loops, VDSL still needs to accommodate a number of special issues, as follows.

- Radio interference of VDSL systems with other wireless systems. The larger range of frequencies used by VDSL1 overlaps with those licensed to other uses. This is addressed by creating frequency ‘notches’ (filters) where the transmitted power level in the VDSL system across the frequencies that third-party systems use is reduced.
- In the downlink direction, cabinet-based modems can introduce excessive levels of far-end cross-talk (FEXT) into lines from exchange-based modems. This typically occurs between cabinet-based VDSL and exchange-based ADSL2/2+ systems. The cabinet-based VDSL modems interfere with signals on the longer ADSL exchange loop at a point where the signal in that loop is already relatively weak. Therefore, in cabinet-based VDSL systems, the power spectral density (PSD) is reduced across the ADSL frequency band.
- In the uplink direction, transmitters on short cabinet loops operating at full power can introduce excessive levels of FEXT into long cabinet loops. This is referred to as the ‘near-far’ problem and typically occurs between VDSL systems. The short loops interfere with signals on longer loops at a point where the signal in that loop is already relatively weak. Since cabinet loops are much shorter than exchange loops (as used in ADSL2/2+ systems) and because FEXT is not fully attenuated in loops up to around 1.5km, the level of uplink FEXT at the receiver (located in the cabinet) can be high. This problem is addressed by reducing the transmit powers on short cabinet loops, referred to as ‘uplink power back-off’ (UPBO).[7]
- Elevated levels of FEXT interference because of the high frequencies used. This can be overcome very effectively using a process called vectoring (which is explained in Section 3.5.3).

---

[7] Downstream power back-off is not generally required, as the transmitters are co-located (either in the exchange or cabinet), such that the FEXT that couples into the long line has to travel further than in the uplink case, and is therefore attenuated; any problems in the downlink direction can be managed using PSD shaping.

VDSL2

The VDSL2 standard (G.993.2), published in 2006, was developed to meet the requirements of many diverse deployment scenarios. For example, the short-reach, potentially high-bandwidth, conditions presented by MDUs (in an FTTB architecture) are very different from those presented by cabinets that feed residential households via longer cabinet loops (in FTTN architecture), where in addition to bandwidth, reach is also an important consideration.

Such reach-rate trade-off requirements were met not by specifying a single compromise solution, but by introducing a set of so-called ‘profiles’ that match specific deployment conditions. The profiles are defined in terms of the following parameters:

- sub-carrier spacing
- transmit power in uplink and downlink directions
- minimum bidirectional net bandwidth capability
- index of the highest data-bearing sub-carrier supported in uplink and downlink direction
- inter-leave and de-inter-leave delay
- whether support for ADSL uplink band US0 is required or not.

Eight profiles (labelled 8a, 8b, 8c, 8d, 12a, 12b, 17a and 30a) were consequently specified. For example, Profile 30a is designed for situations where distances are very short, making it practical to use spectrum up to 30MHz. The vast majority of VDSL2 deployments internationally use the 17a profile and this is also the case for most, if not all, current deployments in Australia. The PSDs defined in VDSL2 are similar to those defined in VDSL1. However, there is one main difference, concerning the way PSDs are amended to reduce interference between cabinet- and exchange-based xDSL systems. In VDSL1, separate PSDs were defined for cabinet- and exchange-based systems, whilst in VDSL2 the PSD can be changed via a set of parameters, whereas the transmit powers vary with frequency range employed by the system, as shown in Figure 3.6.

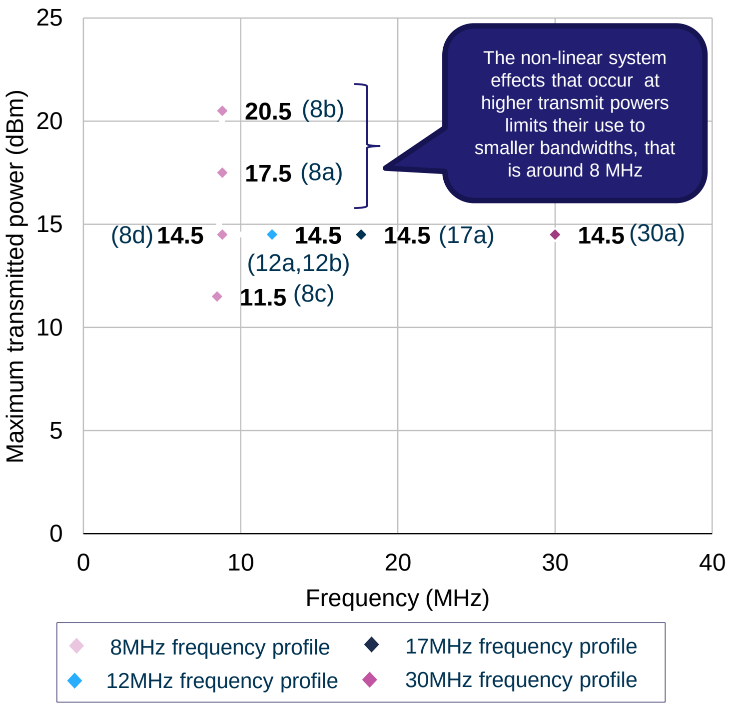
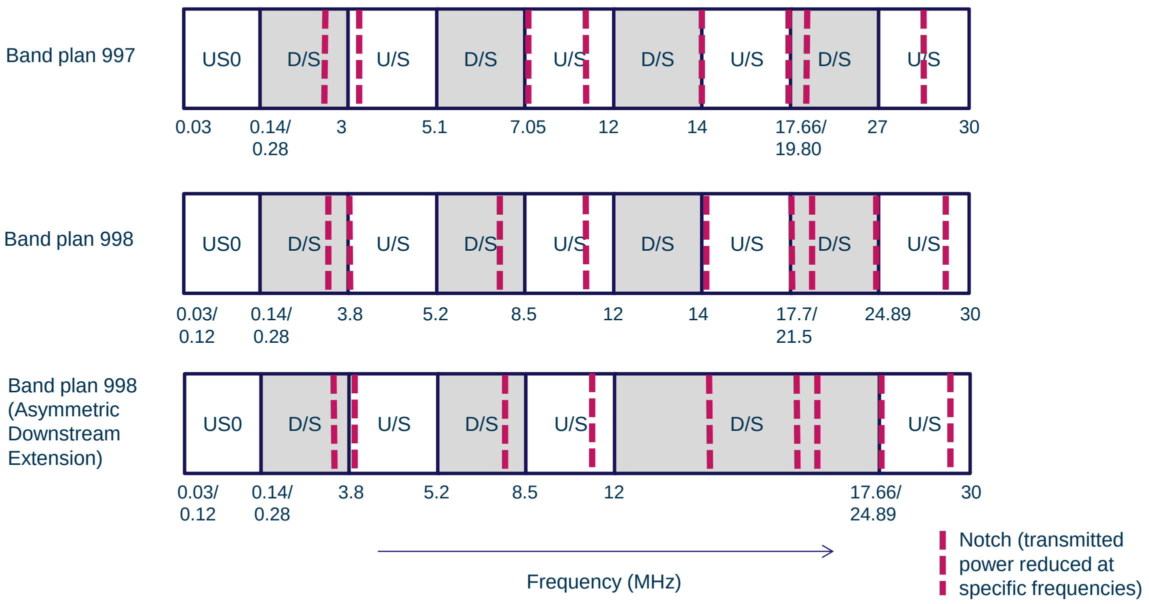


Figure 3.6: VDSL2 transmit power versus frequency [Source: Adapted from ITU Recommendation G.993.2]

For 8MHz frequency ranges (shown as pink scatter points on Figure 3.6), there are a range of transmit powers specified. For other frequency ranges, the transmit power is specified at 14.5dBm. Note that VDSL2 can use as a first uplink band the same frequencies as used by ADSL2/2+ (denoted US0 in the VDSL standard). This low-frequency band extends the reach of VDSL2 compared with VDSL1. However, for copper loop lengths (reach) in excess of 1.5km, ADSL2 remains the most appropriate xDSL solution.

The frequency plans for VDSL2 Annex B (which details Europe-specific requirements) are shown in Figure 3.7.

Figure 3.7: Frequency plans for VDSL2 Annex B (European requirements) [Source: Adapted from ITU Recommendation G.993.2]



Note the use of 'notches' to mitigate interference of the VDSL2 system with external radio systems, such as ham radio.

3.5.2 G.fast standards

The G.fast[8] standards (G.9700 and G.9701) were published in 2014, and were developed to provide a very high broadband bandwidth over a very short copper loop length (typically less than 250m). Therefore, G.fast technology is typically associated with FTTC architecture (see Section 3.4) or FTTB architectures, where the copper loops are relatively short.

It should be noted that while nbn has trialled G.fast technology, it has not decided to adopt the technology in its network at this time. Accordingly, this report does not consider the use of G.fast as a technology option within the MTM, nor prudency or efficiency of any network design that implements the G.fast standard.

The G.fast standard was designed to be optionally compatible with VDSL standards by operating at higher frequencies than VDSL2: the starting frequency for G.fast can be 2.2, 8.5, 17.6 or 30MHz. Initially, G.fast was designed to operate over a 106MHz spectrum band. However, the next iteration of the standard doubles the operating frequency band to 212MHz.

To cancel FEXT, vectoring is mandatory when using G.fast. This means that it is challenging to use G.fast when multiple operators use copper pairs within the same cable binder to provide services to their end-users (see more detail on vectoring in the next section). There are currently no standards enabling multiple G.fast operators to share the same cables.

---

[8] 'fast' is a recursive acronym for 'fast access to subscriber terminals'.

G.fast uses TDD technology, which means that the full spectrum can be used by the uplink or by the downlink at different moments in time. Therefore, G.fast bandwidth is usually specified as an aggregate between the uplink and downlink bandwidth. As illustrated on Figure 3.2, G.fast technology can achieve download throughput in excess of 400Mbit/s for copper loop length shorter than 100m.

3.5.3 Vectoring technology

The activation of vectoring virtually eliminates FEXT, providing significant gain in terms of bandwidth to all lines. A report[9] commissioned by the Body of European Regulators for Electronic Communication (BEREC) states that the bandwidth gain associated with vectoring can be up to 100%. As shown in Figure 3.2, based on data provided by nbn and our personal experience, we have assumed that on average, the activation of vectoring for a line in a disturbed environment[10] can improve VDSL2 download speed by 50% (i.e. from 80Mbit/s download speed without vectoring to 120Mbit/s with VDSL2).

The latest VDSL2 DSLAMs have in-built vectoring capabilities which can be turned on or off, depending on the requirement and feasibility of vectoring implementation. Also, it should be noted that all end-user premises must be equipped with vectoring-enabled CPE, which usually involves all end-user CPEs to be replaced.

Activation of vectoring is considered to be a cost-effective upgrade by operators as it does not involve any changes in infrastructure; that is vectoring can be deployed using the existing FTTN infrastructure and in particular does not require any fibre extension.

However, if the vectoring system does not compensate for the interference of all VDSL2 lines in a cable (binder), the vectoring gain can be reduced significantly. This situation can occur if multiple operators want to use copper pairs within the same cable binder with their own separate DSLAMs for providing VDSL2-based broadband services to their respective end-users. To avoid this issue, the vectoring system has to control all VDSL2 lines of a cable. This means it is not usually possible that more than one operator can use vectoring on VDSL2 lines in the same cable, which represents a significant limitation, especially in the case of nbn where other operators (e.g. TPG) may use the same cable binder as nbn to serve customers in a given MDU for example.

3.6 FTTC roadmap

Based on Figure 3.2, it is possible to predict the maximum possible speed for VDSL and G.fast for a maximum copper loop length. This is provided in Figure 3.8.

---

[9] *Case Studies on Regulatory Decisions regarding Vectoring in the European Union*, BEREC, September 2014.

[10] *A disturbed environment refers to the case where a line is subject to interference from neighbouring lines in the same copper cable*

Figure 3.8: Maximum bandwidth provided by VDSL2 and G.fast technologies [Source: Analysys Mason]

Technology	Maximum possible headline downlink speed (Mbit/s)[11]	Copper loop assumption (m)
VDSL2 17a (without disturbance or with disturbance and with vectoring)	100	<400
G.fast (vectoring used as default)	400	<100

Given that all FTTC are installed within 200m of the end-user premises (due to reverse power constraints), the vast majority of final drops are free of disturbance – that is that there are no other copper pairs in the cable to interfere with the end-user broadband services. In a disturbance-free environment, the vectoring technology is redundant and would not provide any improved performance to end-users in terms of speed. According to nbn, 70% of active FTTC lines are free of disturbances. Also nbn states that 85% of its FTTC lines are able to achieve a downlink speed of up to 100Mbit/s. Based on the above observations, the vast majority of nbn wholesale services associated with FTTC technology can provide up to 100Mbit/s bandwidth in the downlink, which is in line with the 50–100Mbit/s downlink speed currently proposed by nbn.

If higher product speed is required by end-users and/or RSPs (e.g. 250Mbit/s download speed product), nbn would need to either use G.fast on the FTTC network or migrate end-users to a different network technology (e.g. FTTP). nbn has no current plans to introduce G.fast technology and therefore, FTTP represents the only option to provide a higher tier product speed.

---

[11] For a 200m last drop

4 Technical overview of FTTP networks

In this section we first give an overview of FTTP network architectures, defining all key nodes and network elements, which serves as a reference for the rest of this report. We then describe the different PON standards which are used in FTTP networks to provide broadband services. Finally, we provide the FTTP roadmap in terms of download speeds that can be delivered by different PON technologies to understand the maximum speed that can be provisioned on the wholesale broadband product, depending on the technology used.

4.1 FTTP architecture overview

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

- PON topology
- P2P topology.

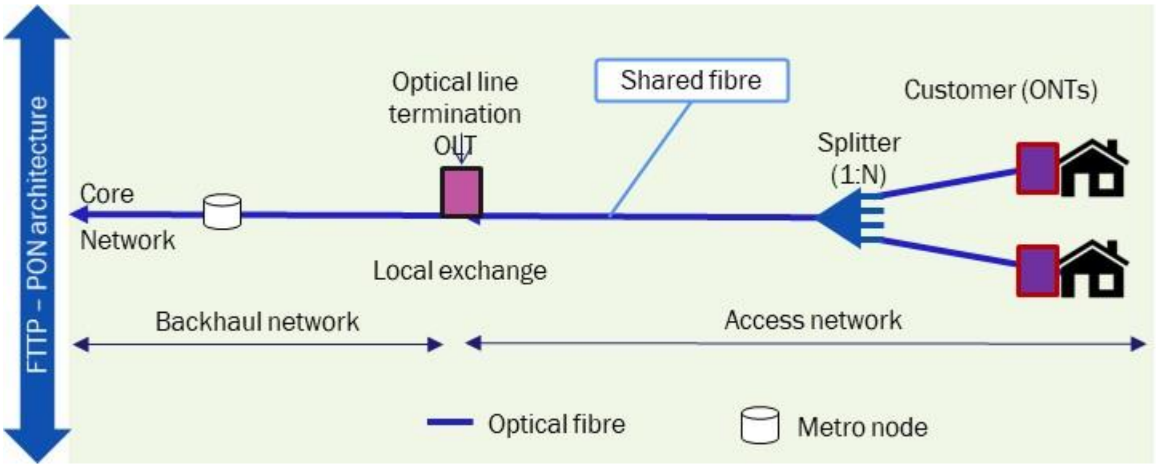
Each option is described in more detail below.

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 primarily provides GPON-based fibre services, complemented by some P2P-based services to meet the specific requirements of the enterprise and government segment.

4.1.1 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 terminals (ONTs) located at end-user premises. These components are illustrated in Figure 4.1 below.

Figure 4.1: PON architecture [Source: Analysys Mason]

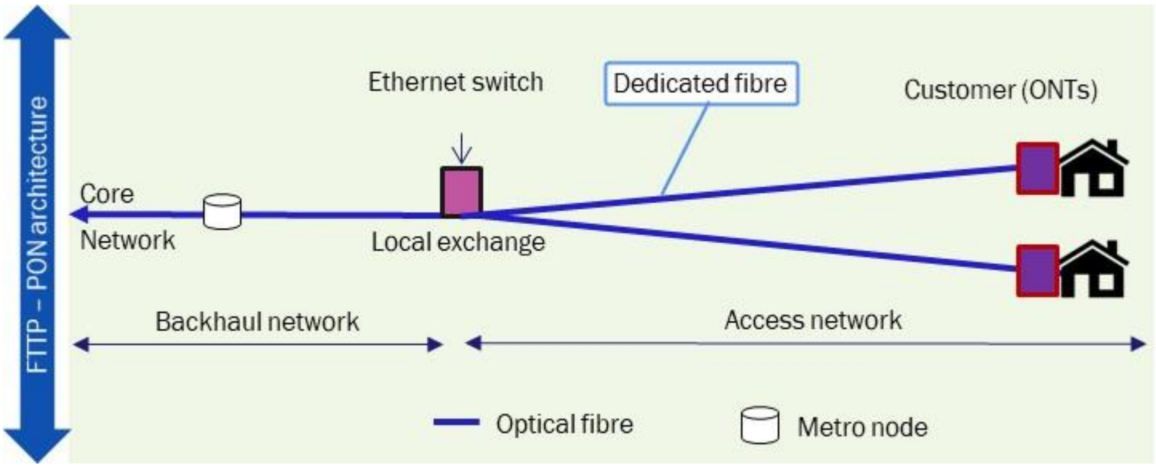


In a PON, the single fibre between the OLT and the passive splitter is shared by all customers connected to the PON, which significantly reduces the number of fibres required in the network.

4.1.2 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 4.2.

Figure 4.2: P2P architecture [Source: Analysys Mason]



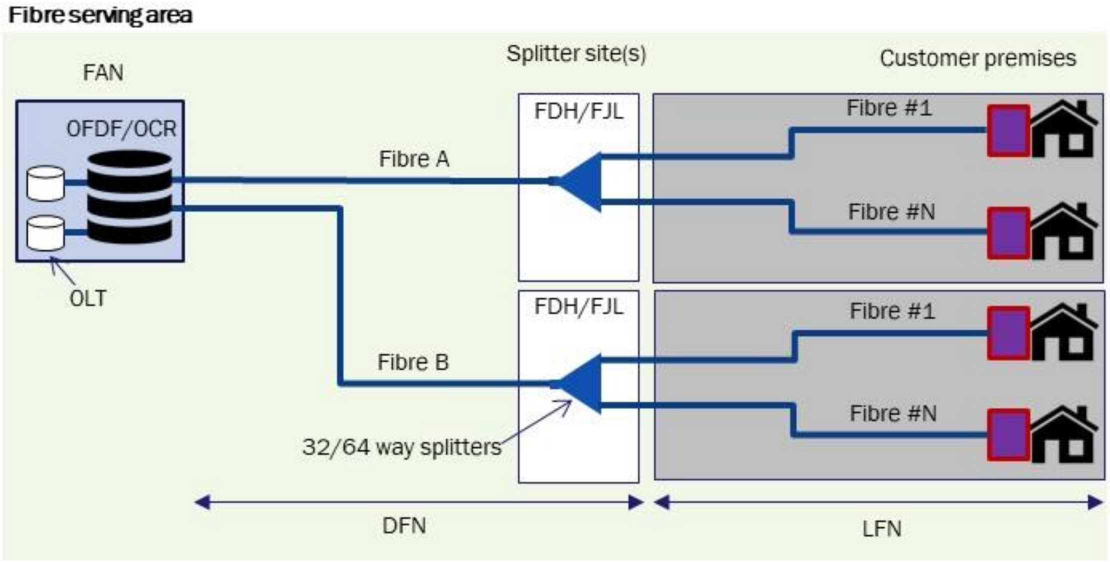
4.2 PON architecture options

4.2.1 GPON architecture and deployment options

Reference model and definition of terms

Figure 4.3 below shows a reference GPON architecture in the context of the nbn network.

Figure 4.3: Reference GPON architecture [Source: Analysys Mason]



For the purposes of this report, we define the following terms in relation to Figure 4.3:

- **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 eight or sixteen line-card ports. Each line-card port drives a single PON, which leaves the FAN as a single distribution fibre. There are two types of fibre management equipment: an optical fibre distribution frame (OFDF), 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:** passive elements that split the incoming optical signal *n* ways. In Figure 4.3, 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):** 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.
- **Flexible joint location (FJL):** Logically equivalent to an FDH except that the splitters are located in an enclosure underground instead of a cabinet[12].
- **Fibre distribution area (FDA):** defined as the geographical area served by an FDH (i.e. all customers attached to a particular FDH).
- **Distribution fibre network (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.

---

[12] FJL architecture is currently preferred by nbn for deploying its FTTC/FTTP networks

- **Local fibre network (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 4.3, 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, two main splitter architectures are currently used in the industry:

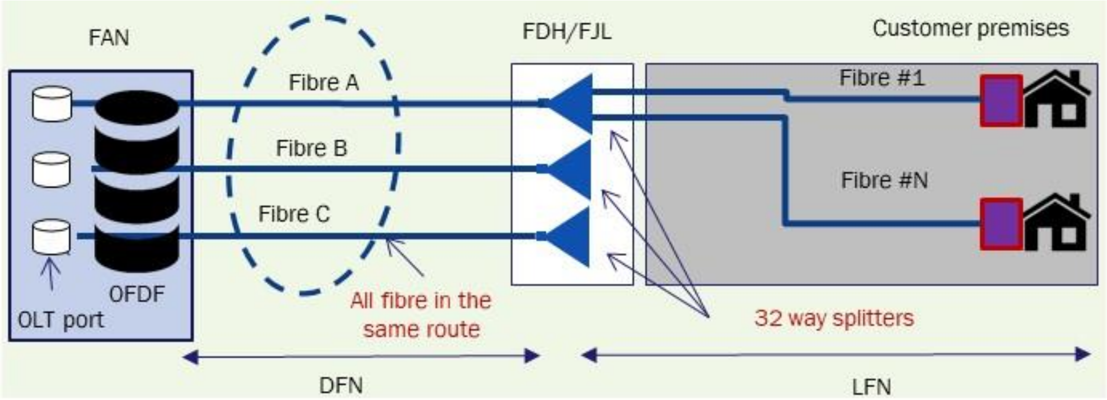
- centralised architecture
- cascaded architecture.

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

► *Centralised architecture*

Figure 4.4 shows the centralised splitter architecture.[13]

Figure 4.4: 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 4.4 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 4.5 below.

---

[13] 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.

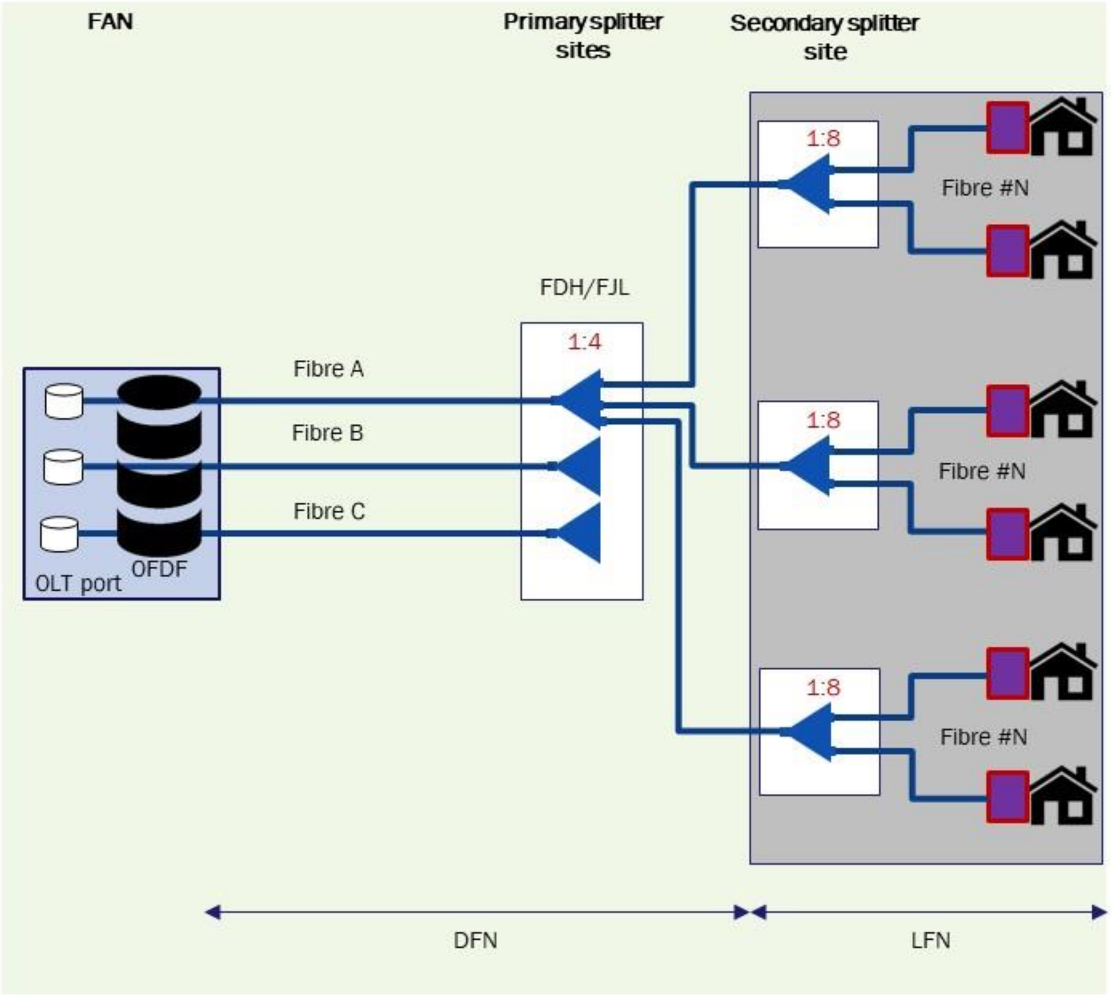
Figure 4.5: Underground enclosure (left) and street cabinet (right) for splitters [Source: Analysys Mason]

The use of a centralised architecture has the advantage of providing an aggregation point for splitters, which in a low-penetration scenario can save OLT cards. Also, the fact that splitters are aggregated in a 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. Also, having a centralised architecture provides more flexibility as heavy users can be distributed more evenly across different PONs, by connecting heavy users to different splitters and hence to different PON networks from the central splitter location.

- *Cascaded architecture*

Figure 4.6 shows the cascaded splitter architecture.

Figure 4.6: Cascaded splitter architecture [Source: Analysys Mason]



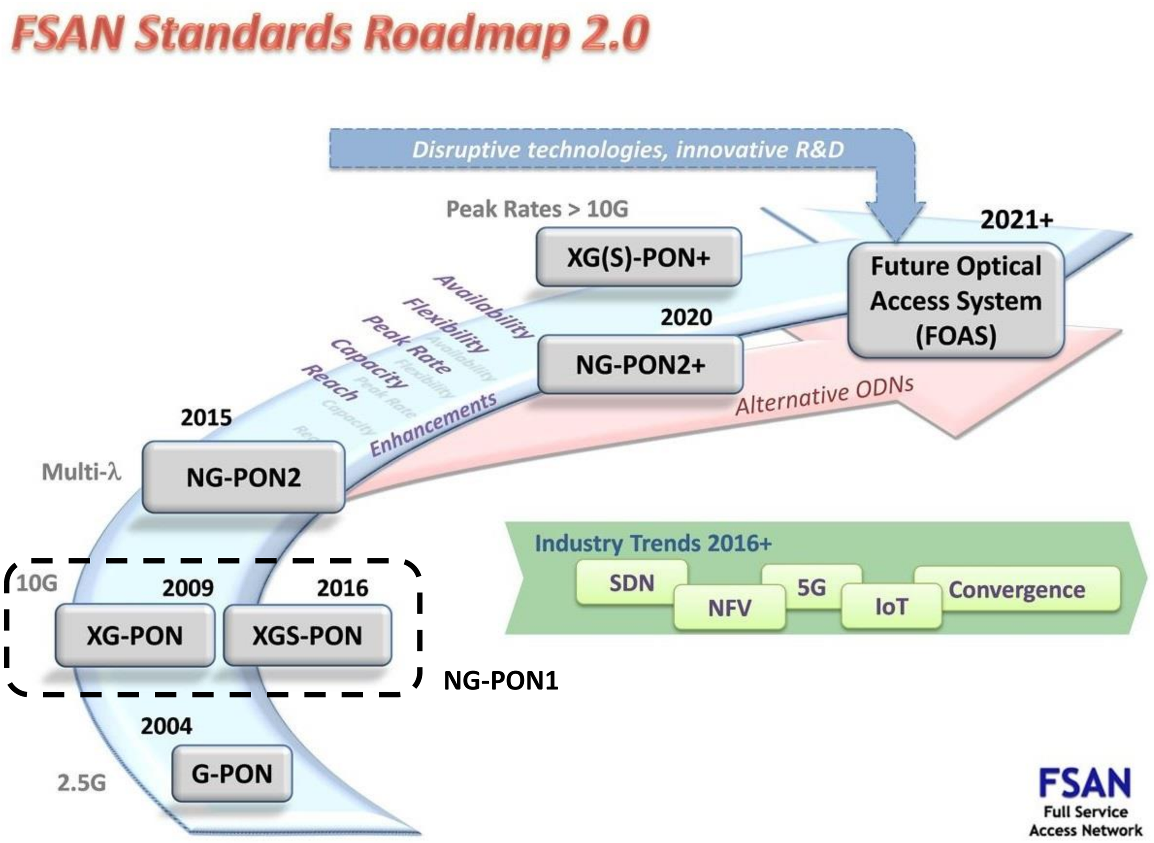
In contrast to the centralised and distributed architectures, a cascaded architecture uses multiple levels of split (commonly two) as illustrated in Figure 4.6, which shows a 1×4 splitter followed by a 1×8 splitter to achieve a total 32-way split. In this example, all splitters are located in the external 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 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.

4.3 xPON technology

In order to guide the development of existing and future PON technology standards, the FSAN Group[14] set out a PON technology roadmap in December 2016. This roadmap is illustrated in Figure 4.7.

Figure 4.7: FSAN Standards Roadmap 2.0 [Source: FSAN]



In the above figure, there are five main GPON/NGPON technology families:

- GPON
- next-generation PON 1 (NG-PON1)
- next-generation PON 2 (NG-PON2)
- XG(S)-PON+ and NG-PON2+
- Future optical access system (FOAS).

We describe the main characteristics of each of these technologies below.

---

[14] FSAN is not a standards development organisation (SDO) in itself but bring a technical contribution to the standards

4.3.1 GPON

GPON technology is by far the most common technology deployed in PON networks outside of China, Japan and South Korea. GPON was standardised in 2004 by the ITU-T (G.984 standards) and can provide 2.5Gbit/s of bandwidth in the downstream direction and 1.25Gbit/s of bandwidth in the upstream direction. As a PON-based technology, the downstream and upstream bandwidths are both shared between all users connected to the PON.

4.3.2 NG-PON 1

NG-PON1 standards essentially include two different NG-PON technologies:

Ten Gigabit PON (XG-PON)	XG-PON was standardised (ITU G.987) in 2009 and can provide an asymmetrical bandwidth of 10Gbit/s downstream and 2.5Gbit/s upstream. XG-PON is essentially a higher-bandwidth version of GPON. It has the same capabilities as GPON and can co-exist on the same fibre with GPON. XG-PON has been trialled and commercially deployed by a small number of operators prior to 2017 (e.g. KDDI, Singtel and Etisalat) but is no longer deployed as it has been superseded by Ten Gigabit Symmetrical PON (XGS-PON).
Ten Gigabit Symmetrical PON (XGS-PON)	Recognising the limitations of the asymmetrical profile of XG-PON, XGS-PON was standardised under ITU G.9807.1 in 2016. XGS-PON provides 10Gbit/s of bandwidth for both the upstream and the downstream. XGS-PON can also co-exist with GPON on the same PON but cannot co-exist with XG-PON[15]. XGS-PON has been commercially deployed by a number of operators (e.g. NBI in Ireland; Ooredoo Qatar; China Telecom; Salt in Switzerland; AT&T; Telefonica Spain) and has gathered some momentum amongst operators.

4.3.3 NG PON2

NG-PON2 standards essentially include two different NG-PON technologies:

Time-wavelength division multiplexing (TWDM) PON	TWDM-PON[16] which was standardised as part of the NG-PON2 standards under ITU G.989 in 2015.

---

[15] XG-PON and XGS-PON share the same downstream spectrum as illustrated in Figure 4.8.

[16] TWDM PON is part of the NG-PON 2 family.

Characterised by flexible bit-rate wavelengths[17], TWDM-PON can provide the equivalent of up to four[18] XG-PON or four XGS-PON[19] overlay systems within a single PON network. This is illustrated for a four XG-PON overlay system in Figure 4.9, where the four 10Gbit/s downstream overlay signals are transmitted on wavelengths λ_1 to λ_4 and the four 2.5Gbit/s upstream overlay signals are transmitted on wavelengths λ_5 to λ_8. To get the full benefits of wavelength mobility[20], tuneable lasers are required in TWDM-PON systems.

As discussed in Section 4.3.6, TWDM-PON can co-exist with GPON, and XG-PON or XGS-PON.

Among major operators, only Verizon (USA) and Altice (USA with operations in Portugal and France) have deployed TWDM-PON in any volume, and it remains too costly to be widely adopted for the residential mass market in the short to medium term.

Wavelength division multiplexing (WDM) PON

WDM-PON, which was also standardised as part of the NG PON2 standards in 2015. WDM-PON functions by allocating a dedicated wavelength to every end-user on the PON, effectively providing them with a logical point-to-point connection. WDM-PON currently typically provides a dedicated 1Gbit/s of symmetrical bandwidth to each connect end-user. However, WDM-PON requires tuneable lasers, making it expensive to deploy in mass residential markets, hence its low adoption to date as a technology for the residential market.

4.3.4 NG-PON2+

FTTP operators worldwide are increasingly upgrading their networks from GPON to XGS-PON. However, the desire to extract as much capacity as possible from fibre networks means that there is significant interest in PON technologies that offer capacity beyond 10Gbit/s XGS-PON such as 25GS PON and 50G PON collectively known as NG-PON2+.

25GS-PON

Since NG-PON2 is proving too costly to deploy for the residential market (due mainly to the requirement for tuneable 10Gbit/s lasers), the interim 25GS-PON – which provides 25Gbit/s of

---

[17] TWDM PON wavelength can either be 2.5Gbit/s or 10Gbit/s

[18] G.989.2 fully standardises TWDM PON for 4 wavelengths but the full standardisation of 8 wavelength systems is for further work. However, G.989.2 already allocates up to 8 wavelengths in each direction for TWDM-PON.

[19] or a mix of XG-PON and XGS-PON

[20] Wavelength mobility refers to the ability of dynamically turning on or off particular wavelengths, switch across wavelengths, or logically bonding wavelengths together.

symmetrical bandwidth – is being actively pursued by the 25GS-PON MSA industry-standard group. The group is led by Nokia on the vendor side, and key operator members of this group include nbn, AT&T, Chunghwa, Chorus, INEA and Proximus. The stated goal of this group was "to promote and accelerate the development of 25 Gigabit Symmetric Passive Optical Network technology[21]" because the ITU had not reached a consensus to standardise any 25Gbit/s PON, and decided to focus instead on 50G-PON (discussed below). Nokia's 25Gbit/s technology is powered by its own Quillion chipsets, which are now deployed in new GPON and XGS-PON 'combo-boards', thereby making all recent Nokia deployments 25GS-PON-ready.

Proximus deployed the world's first live 25G-PON network in Antwerp, Belgium in May 2021 and expects 25GS-PON technology to be commercially deployed by the end of 2022[22].

50G PON

There is considerable interest in 50G PON deployments among the global operator community. For example, the Lianyungang branch of China Mobile recently completed a successful test of the technology on its live network[23]. This is significant because the scale of the FTTP roll-out means that 50G PON deployment in a country as large as China can generate very substantial economies of scale, which may help to reduce costs for operators in other parts of the world. But operator interest in 50G PON is not confined to China; major European operators such as Swisscom and Telefónica are investigating its potential. Telefónica has recently stated that it envisages deploying 50G PON in the medium term following the initial step of deploying XGS-PON. Telefónica's interest in the technology is particularly important due to the operator's strong presence across Latin America and its extensive ultra-broadband footprint (154.7 million premises at the end of 1H 2021).

Operators' support of 50G PON worldwide also reflects the standardisation of the technology; this process started in 2018. The ITU officially published the first version of the 50G PON standard in September 2021 (Standard ITU G.9804) for single-wavelength systems[24].

The complexity of 50G PON systems is a little greater than that of earlier PON generations, but the significant deployment volumes for new PON technologies lead to substantial cost reductions. This is demonstrated by how the costs for XGS-PON have fallen over time. Such a scenario is also likely for 50G PON. 50G PON systems can also make use of digital signal processing (DSP), which means that they will be able to use lower-cost 25G optical components. The cost of DSP can be amortised across growing deployment volumes and will be reduced over time as described in Moore's law. Based on the above observations, we envisage that the first 50G PON roll-outs will occur in the next two to three years.

---

[21] 25GS-PON Group, 25 Gigabit Symmetric Passive Optical Network Specifications, October, 2020

[22] 25G will be just one element in a new toolkit for fibre operators, Analysys Mason, July 2021

[23] 50G PON offers a solution for operators that are looking to move beyond XGS-PON, Analysys Mason, December 2021

[24] Multiple-wavelength systems remain under study

We understand that 50G PON is supported by vendor ADTRAN which competes with Nokia to provide GPON equipment.

Since nbn is part of the 25GS-PON MSA industry-standard group, and has invested in Nokia technology, 25GS PON is a more likely choice for nbn than 50G PON in the medium term.

4.3.5 Future optical access systems

In common with other telecoms network elements, it is expected that PON networks will eventually be virtualised and deployed using cloud-native technologies. This will reduce the amount of hardware required, thus significantly reducing hardware, power, cooling, and maintenance costs. Also, the use of cloud-native technology will enable the use of containerised microservices that are not dependent on purpose-built hardware, but run in software containers deployed on off-the-shelf servers (which may or may not actually be located in the cloud). They are easy to test, deploy and upgrade individually, without having to disrupt the whole system.

The first step into virtualisation is to disaggregate control functions from the physical layer. Then, a central control function can be implemented to ensure all PON areas are configured in a consistent manner, and that the most appropriate action can be taken when a network failure occurs, for example ensuring service restoration in the fastest possible way.

The combination of centralisation of PON functions and the extended reach of the optical interfaces in the next generations of PON network will enable to cover a larger area from a single exchange leading to the optimisation of the number exchanges[25]. However, this benefit can only be realised if:

- the control layer and physical layer are disaggregated
- there is sufficient funding to enable additional fibre connecting decommissioned exchanges to active exchanges to be deployed
- there is sufficient funding to enable the decommissioning of existing exchanges.

nbn has decided to initially focus on the disaggregation of the control and physical layers and will have the option to decommission exchanges if it is beneficial to do so.

---

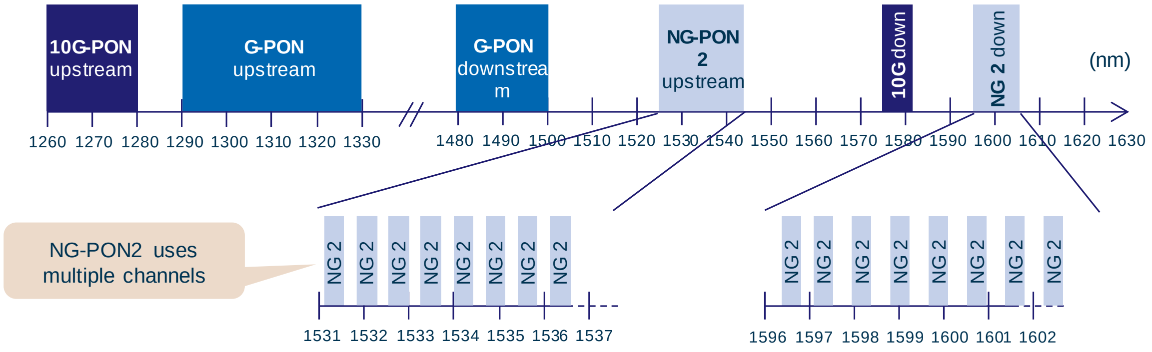
[25] Equivalent to a FAN in the case of nbn

4.3.6 Co-existence of different PON technologies and upgrade path

Standardised GPON spectrum

The all-encompassing full-service network vision of the FSAN group consists in creating a utility network (i.e. the PON network) which can provide a full range of services over the same physical infrastructure. The (N)G-PON standards largely reflect this position as they are defined to co-exist on the same physical PON network. This is achieved by allocating different frequency bands to different NG-PON technologies so that they can be multiplexed together into the same fibre without interfering with each other. The standardised spectrum[26] used by each (N)G-PON technology is illustrated in Figure 4.8 below:

Figure 4.8: Spectrum used by NG-PON technologies [Source: adapted from ITU-T[26]]



Although not shown in Figure 4.8, 25GS-PON and 50GS-PON use different fixed wavelengths to both GPON and XGS-PON, so can co-exist with them with minimal upgrade disruption.

NG-PON2 standards allocates enough spectrum for TWDM-PON to accommodate up to eight different wavelengths for both upstream and downstream, enabling up to 8x10Gbit/s upstream and downstream capacity to be shared between end-users connected to a PON. To multiplex/demultiplex all wavelengths associated with TWDM-PON, a WDM multiplexer/demultiplexer is integrated as part of the TWDM-PON system.

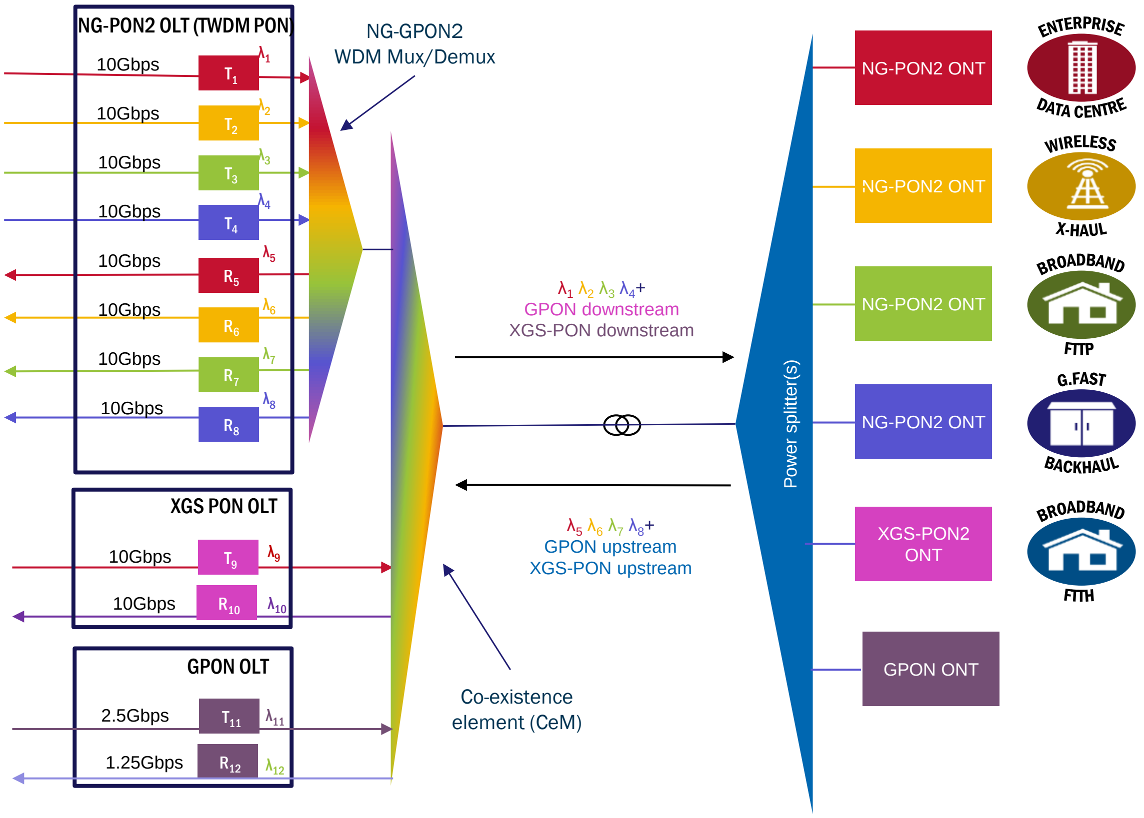
Co-existence of GPON technology

For different generations of PON technologies to co-exist on the same PON network, a co-existence element is required to multiplex the different wavelengths into the same fibre. The co-existence is implemented as a WDM multiplexer. Figure 4.9 illustrates a PON network with different (N)G-PON overlay, clearly identifying the role of the co-existence element.

---

[26] See ITU-T G.989.2 40-Gigabit-capable passive optical networks 2 (NG-PON2): Physical media dependent (PMD) layer specification, Appendix 1

Figure 4.9: Example of aggregation of different PON technologies on the same PON network [Source: Analysys Mason]



It should be noted that, in future generations of GPON (e.g. XGS-PON+ / NG-PON2+), the co-existence element will be integrated as part of the line card, and therefore it will not be a separate element in the PON system which needs to be installed on Day One.

The ability of the different PON technologies to co-exist means that operator does not have to perform any forced migrations of end-users from the 'legacy' PON technology (e.g. GPON) to next-generation PON technology (e.g. XGS-PON). Instead, the migration can be planned over several years, allowing different end-users to be connected to different (N)G-PON overlays. This also means that, when operators introduce a new NG-PON overlay, the operator does not have to replace all the ONTs simultaneously as 'legacy end-users' can continue using the 'legacy' systems with their existing ONT. We discuss the upgrade path options in the next section.

4.4 FTTP roadmap

We define:

- **the aggregate throughput** as the total capacity that has to be shared between all end-users attached to a particular PON network
- **the headline speed** as the service speed advertised by the operator which may not be achieved 100% of the time, especially during the busy hour.

Figure 4.10 summarises the aggregate throughput and end-user headline speed for different xPON technologies.

Figure 4.10: aggregate and end-user headline speed for different xPON technologies [Source: Analysys Mason]

Technology	Status	Aggregate downlink/uplink throughput (Gbit/s)	Top tier end-user headline downlink/uplink speed (Gbit/s)
GPON	Standard G.984	2.5 / 1.25	1 / 0.5
XGS-PON	Standard G.9807	10 / 10	5 / 5
25GS-PON	Being specified	25 / 25	10 / 10
50G-PON	Standard G.9804	50 /50	20 / 20

From the above table, and based on our experience of PON networks, operators offer top-tier headline-speed services that are between 40% and 50% of the aggregate throughout associated with a particular xPON technology.

This is made possible by statistical multiplexing which dictates that, while some end-users will peak at a particular time, others will not use any bandwidth at that same time. Therefore it is theoretically possible for many end-users to achieve the top-tier speed as long as end users peak at different times.

However, there is a limit as to how many end-users in a particular PON can subscribe to the top-tier speed, as ultimately, the aggregate bandwidth has to be shared between all these end users.

5 Review of nbn’s methodology and processes for MTM network selection

The Australian Government’s 2014 SoE gave nbn a mandate to design and deploy an MTM national broadband network. The Government’s direction provided nbn with flexibility regarding technical, operational and network design decisions to implement the network, but nbn was expected to:

- Deliver the network within the constraint of a public equity capital limit of AUD29.5 billion specified in its funding agreement with the Australian Government and the Australian Government’s broadband policy objectives.
- Determine which technologies are utilised on an area-by-area basis so as to minimise peak funding, optimise economic returns, and enhance the company’s viability.
- Be guided by the Australian Government’s policy objectives of providing download data rates (and proportionate upload rates) of at least 25Mbit/s to all premises and at least 50Mbit/s to 90% of fixed-line premises as soon as possible.

In making these decisions, nbn also had to have regard to a broader range of considerations, such as long-term business-case considerations and its strategy associated with exercising its rights (under the revised agreements with Telstra) to acquire some of the copper network assets from Telstra, as well as some of the HFC network assets from Telstra and Optus.

In this section, we first analyse the methodology and processes used by nbn to select the network type to deploy in each area and assess the prudency and efficiency of the methodology and processes.

We then consider nbn’s strategy regarding the use of a single HFC network for each area, assessing the relative benefits and drawbacks of operating and upgrading a single network per area.

5.1 nbn’s network selection methodology and processes

nbn adopted a two-step approach for determining which type of MTM network it would deploy in a particular geographical area. This approach comprises the strategic modelling process and the strategic overlay process:

- **Strategic modelling process**: the optimum network type for each area is determined based on a linear programme model (the ‘MTM Optimiser’), which considers financial and non-financial business rules, as well as the SoE, to derive the optimal technology to be used for that area.
- **Strategic overlay process**: once the optimum network type has been determined by the MTM Optimiser, nbn then applies a strategic overlay to review the outcome of the MTM Optimiser to address practical issues associated with the deployment of that particular network in the relevant geographical area.

We describe each of these steps in more detail in the following sections.

5.1.1 Strategic modelling process

Description of the strategic modelling process

The strategic model is implemented using nbn's MTM Optimiser tool which is undertaken at the Access Distribution Area level – i.e. the smallest geographical aggregation of premises used in nbn's planning, typically covering approximately 180 premises. The main output of the MTM Optimiser is to calculate the peak funding requirement from the cashflow model to determine the optimum technology to use. The MTM Optimiser is based on a linear programme model that concurrently considers the various outcomes of a wide array of parameters for each geographical area. These parameters comprise the following:

- **Geospatial**: drivers of cost, revenue, quality and complexity for each area, such as area size, distances from transit fibre, number of premises, type of premises, road distances, quality and length of copper runs, ducts, pits and pipes, aerial and underground cabling.
- **Technology architecture**: unit-by-unit breakdown of technology requirements within any given architecture.
- **Costs**: cost per unit as informed by delivery and supply partner contracts.
- **Revenues**: expected revenues per premises as determined by likely customer demand.
- **Product / speed parameters**: product and technology drivers that drive expected revenue and end-user experience (speed).

The base logic of the MTM Optimiser is to create every 'alternative possibility' for every given area and assess their respective merit. As such, costs and revenues are modelled for every area, and for every technology outcome. The MTM Optimiser also considers the deployment capacity required to deliver each outcome and, concurrently, evaluates and produces the optimum output in terms of a network type for each area.

The results of optimisation outputs can be broadly summarised as a generic framework through which nbn is delivering the MTM, illustrated in Figure 5.1.

Figure 5.1: Generic outcomes of the strategic MTM Plan [Source: nbn]

Principles	Preferred technology
• FTTP built and planned • Small and densely populated areas • New development with no copper infrastructure	FTTP
• Existence of HFC network • Areas where HFC extension and lead-in commercially sensible near existing HFC footprint	HFC

Principles	Preferred technology
• Larger areas with high number of premises • Existence of adequate copper network	FTTN
• Deployment of FTTC on long FTTN copper loop to improve speed • Small MDU areas where the FTTN fixed costs were not economic • Small premises count in access deployment areas (ADAs) • Areas where FTTC does not require a lead-in to be built	FTTC
• Large or high-value MDU buildings	FTTB
• Everywhere else	FWA and satellite

Rationale for deploying FTTP technology

FTTP technology has generally been deployed in areas which have either been already built or released to delivery partners as FTTP areas under commitments made previously by nbn in accordance with the requirements of the Australian Government's previous policy for nbn. (i.e. where the planning of the network was already at an advanced stage and therefore nbn believed that it was efficient to continue with these plans).

In addition, nbn deployed FTTP in new developments (i.e. greenfield areas), where no existing copper network was installed. Finally, in relatively small areas which are densely populated, nbn also deployed FTTP technology to provide its wholesale broadband services.

Rationale for deploying HFC technology

HFC technology was primarily deployed in areas where there was already an HFC network footprint (i.e. existing Telstra HFC networks). Also, nbn deployed HFC infrastructure in areas which were adjacent to areas of the existing HFC footprint. It should be noted that although both Optus and Telstra HFC networks were available, nbn decided to use predominantly the Telstra HFC network except for 20 000 premises in Queensland where the Optus HFC network is used. This decision choice is further explained in Section 5.1.3.

Rationale for deploying FTTB technology

nbn deployed FTTB technology to serve large and high-value MDUs, predominantly where the building internal copper wiring could be re-used. FTTB was either deployed using an external cabinet serving several medium-sized MDUs (Option 1) or a large MDU where the active equipment was located in the basement of the building (Option 2) as explained in Section 3.3.

Rationale for deploying FTTN technology

nbn deployed FTTN architecture in areas that were not otherwise covered by FTTP, HFC or FTTB and where population densities are not sufficiently low to revert to FWA and/satellite networks. However, in areas where long copper loops existed or where the economics made sense to deploy higher performance FTTC, nbn selected FTTC instead of FTTN technology (see below rationale for FTTC technology deployment).

Rationale for deploying FTTC technology

- **Deployment of FTTC on long FTTN copper loop to improve speed**

  Where an ADA contained long copper lines, multiple solutions including full FTTN, FTTP, FTTC were considered. If the deployment of FTTP/C resulted in a better outcome (lower cost or higher revenue or lower peak funding requirement) this technology was selected.

- **Deployment in small MDUs**

  ADAs with a concentration of small MDUs typically produced a lower-cost outcome when served with FTTC rather than FTTP or HFC as FTTC avoids the need for costly lead-ins and multiple visits for installation of new lead-ins as copper loops already exist.

- **ADAs with small premises count**

  FTTN has a relatively high fixed cost associated with the deployment of a street cabinet. FTTC is preferred to FTTN in areas where there is a small number of premises (e.g. fewer than 50 premises). In this case, deploying FTTC prevents the deployment of an expensive street cabinet.

- **Areas where FTTC does not require a lead-in to be built and where there would be a high lead-in costs if FTTP was to be deployed**

  In areas where a copper lead-in exists, and where the fibre lead-in for an FTTP network would be expensive to deploy, FTTC was selected as the preferred technology. For example, if a copper pillar in the centre of an ADA had eight long copper lines to connect premises at the boundary of the ADA, the cost to deploy FTTP was greater than the cost to deploy FTTC. Therefore, FTTC technology was also selected in these areas.

Rationale for deploying FWA and satellite technologies

In areas which are less densely populated and where the above network types were not deployed, nbn deployed a FWA and/or satellite access network. An assessment of the prudency and efficiency of these network types is provided in an Analysys Mason report published by ACCC in 2012[27] but is out of scope for this report.

---

[27] http://www.accc.gov.au/system/files/Analysys%20Mason%20-%20Review%20of%20the%20efficiency%20and%20prudency%20of%20NBN%20Co%27s%20fibre%2C%20wireless%20and%20satellite%20network%20design%20%28public%20version%29.pdf

Examples of network selection using the MTM Optimiser

To illustrate the above process, let us consider an illustrative Distribution Area (DA) with a surface area of 0.2km^2 and with 250 premises. Let us assume that this DA has no HFC infrastructure but has a number of adjacent DAs with existing HFC infrastructure.

Using these characteristics, the MTM Optimiser calculates the costs associated with the deployment of different network types, as well as the revenues that nbn would expect to generate in that DA, to determine the maximum peak funding which will be associated with each of these network types.

When carrying out its peak funding analysis, nbn considered the following input for each area under investigation:

- expected revenues to be generated in the DA under investigation
- capex required to build the network in the DA
- opex required to operate the network in the DA.

It should be noted that nbn assumed that monthly revenues per connection in FTTP areas were greater than monthly revenues per connection in FTTN/FTTB and HFC areas. This is because FTTP has a greater potential to provide higher speed tiers than other network types and that prices for higher speed tiers are higher than for lower speed tiers.

The peak funding required for deploying different network types in that DA is as follows:

- FTTN: lowest peak funding
- FTTC: second lowest peak funding
- HFC: peak funding significantly higher than FTTN but lower than FTTP
- FTTP: highest peak funding.

Therefore, with all other parameters constant, the MTM Optimiser would suggest an FTTN network as the best candidate to meet the above defined business rules, and would therefore be selected.

5.1.2 Strategic overlay process

Description of strategic overlay process

Once the optimum network type has been determined by the MTM Optimiser, nbn then applied a strategic overlay to review the outcome of the MTM Optimiser to address practical issues of deploying such technology in the considered area.

To ensure the MTM Optimiser continued to meet successive SoE overall objectives in a realistic and deliverable plan, nbn used a series of business rules (which were updated with the different SOEs requirements) as part of the strategic overlay process, which included the following:

- **nbn's Statutory Infrastructure Provider targets**:
  - minimum target of 25Mbit/s download speed and minimum of 5Mbit/s upload speed for 92% of fixed-line premises
  - minimum of 50Mbit/s download speed and minimum of 10Mbit/s upload speed for 90% of fixed-line premises.

This speed criterion supersedes peak funding and/or payback considerations.

- **Underserved constraint**: all underserved premises were prioritised and had to be delivered by the end of December 2018 (as per SoE requirement to prioritise underserved areas). This is a scheduling constraint.
- **Long-term revenue potential**: for high-revenue areas, long-term NPV should be considered to choose the appropriate network type. A pure peak funding and/or payback period analysis will not fully reflect this potential.
- **Transit network availability**: the construction of a fibre serving area cannot be completed before respective FAN and/or transit network infrastructure is in place.
- **Activations capacity**: forecast activations cannot exceed 'truck roll' capacity limits.
- **Construction capacity**: area-by-area construction forecasts cannot exceed delivery partner[28] capacity limits (i.e. industry capacity to roll-out a particular technology per year).
- **Service requirements of end-users** (e.g. selection of FTTP in business areas to meet the higher bandwidth requirements of enterprise and business customers).
- **Specific considerations for the construction of the network** in particular geographical areas (e.g. MDU-specific business rules).
- **Contiguous technology plans**: the ideal end state is for contiguous build profiles (e.g. no FTTx islands in contiguous HFC areas).
- **Other strategic issues** (e.g. variation between initially assumed costs and costs occurred in actual deployment situation).

Examples of network selection using strategic overlay

In this example, let us assume an illustrative DA of 280 premises spread over an area of 0.3km^2 and containing 65% business premises (essentially a business park). It is also assumed that there is no HFC infrastructure in adjacent DAs.

---

[28] Delivery partners are contractors engaged by nbn to design and roll-out the network such as Telstra

Using these characteristics, the MTM Optimiser calculates costs associated with the deployment of different technologies as well as the revenues that nbn would expect to generate in that DA to determine the maximum peak funding associated with each of these networks. The peak funding required for deploying different network types in that DA is as follows:

- FTTN: lowest peak funding
- FTTP: peak funding marginally higher than FTTN but significantly lower than HFC
- FTTC: comparable to FTTP
- HFC: highest peak funding.

Based on the results provided by the MTM Optimiser alone, an FTTN network would be selected as the optimum network type to deploy as it leads to the least peak funding requirement. However:

- The DA considered in this example is within a business park where high speed tiers are more likely to be required than in residential areas.

- The difference in peak funding between the FTTN and FTTP architecture is only marginal.

- For the considered DA, the deployment of FTTP leads to a significantly higher long-term NPV than FTTN, mainly due to higher revenues generated from services provided by the FTTP architecture (which can provide higher speed tiers).

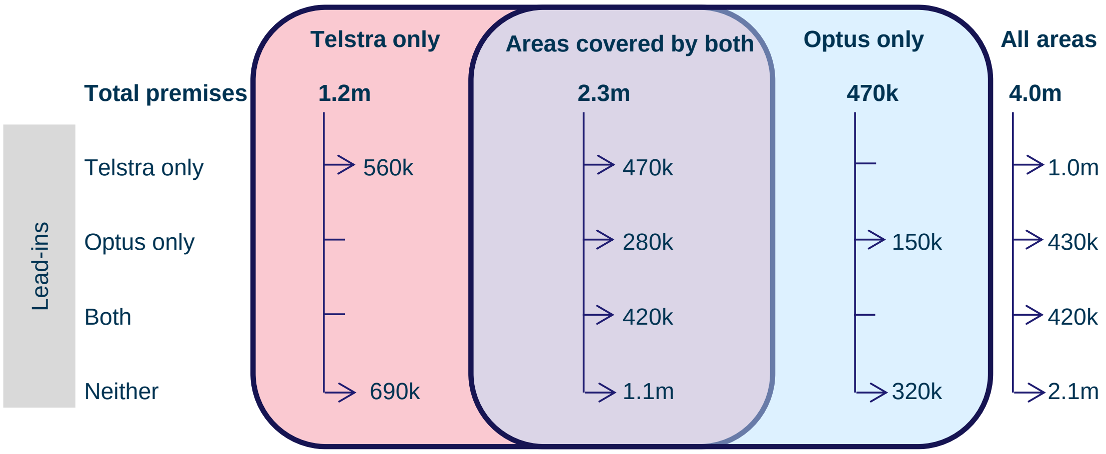
Based on the above observations, the strategic overlay process means that FTTP may be selected for deployment, despite FTTP having a marginally higher peak funding requirement than FTTN.

5.1.3 HFC network strategy

HFC network coverage overview

As part of its national network roll-out, nbn has acquired certain assets that form part of the Telstra and Optus HFC networks. The acquisition of the assets included Telstra and Optus networks in Melbourne, Sydney and Brisbane together with the Telstra-only roll-out in Perth, Adelaide and the Gold Coast. Together, the networks cover 4 million premises of which 2.3 million premises were covered by both networks, 1.2 million premises were covered by Telstra only and 470 000 premises are covered by Optus only. An illustration of the coverage areas and availability of lead-ins is provided in Figure 5.2.

Figure 5.2: HFC coverage and lead-in overview [Source: nbn data]



Lead-ins		Telstra only	Areas covered by both	Optus only	All areas
	Total premises	**1.2m**	**2.3m**	**470k**	**4.0m**
	Telstra only	560k	470k		1.0m
	Optus only		280k	150k	430k
	Both		420k		420k
	Neither	690k	1.1m	320k	2.1m

Lead-ins are already provided to nearly half of the premises in the proposed HFC footprint areas. Lead-ins have been provided to premises that either currently take services from the HFC operators or have done so in the past. One million of the lead-ins are provided to Telstra premises only, whereas 430 000 of the lead-ins are provided by Optus only. In 420 000 premises, lead-ins have been provided by both Telstra and Optus indicating that the premises have taken services from each operator at some point.

nbn decided to only use the Telstra network, except in Queensland where nbn used the Optus HFC network which covers 20 000 premises.

The choice of predominantly re-using the Telstra network and not re-using the Optus HFC network was justified by the following:

- On average, the Telstra network has fewer RF amplifiers than the Optus network (i.e. N+3 as opposed to the N+5 RF amplifier configuration of the Optus network). This makes the Telstra network better suited to providing higher bandwidths through the use of higher modulation schemes in the future. Equally, this meant that the Optus network could deliver significantly less capacity than the Telstra network (due to the high number of cascaded RF amplifiers resulting in higher noise levels compared to the Telstra HFC network).

- The Optus HFC network includes 30 exchange sites which aggregate the traffic of optical nodes These exchanges are hosted in small containers. Since the Optus network would need significant capacity upgrade (for the reasons mentioned above), additional space would be required in exchanges to accommodate the equipment required for the capacity upgrade. However, based on a survey performed by nbn, the exchanges were already 90% utilised in terms of space. Therefore, container extensions or additional containers would have been required to upgrade the network which would have been very expensive. Also, exchanges would have required significant power upgrades, which again, would have been very costly.

- 70% of the Telstra coaxial network is deployed underground, compared to none of the Optus network, which makes the Telstra network more attractive from a resilience and availability perspective as underground infrastructure is less prone to faults than aerial infrastructure.
- Using a single HFC network (i.e. Telstra HFC network) in overlapping areas significantly reduces complexity in the design, construction and operational maintenance:
  - **Reduced design complexity**: a single network to design means a simpler design process as there is only one network plant to be considered.
  - **Reduced construction complexity**: delivery partners can follow a single set of design rules, work off a single coax line at the time, simpler utility and pole make-ready process etc.
  - **Reduced operational maintenance complexity**: simpler data integrity checks, delivery partners only need training/skills in one network per exchange serving area.
- Using the Telstra HFC network in overlapping areas means a larger volume of infrastructure provides economies of scale to make the design and construction more efficient and therefore potentially shortening deployment timeframes and potentially providing capex savings.
- Using the Telstra HFC network in overlapping areas also means that a single network will have to be maintained, providing substantial opex savings.

5.1.4 Distribution of premises per network type

The total number of premises served by the different network types is shown in Figure 5.3.

Figure 5.3: Multi-technology mix of premises [Source: nbn]

Network type	# premises at end of roll-out (millions)	% of premises at end of roll-out (rounded)
FTTN	4.2	34.3%
HFC	2.5	20.6%
FTTP	2.3	18.7%
FTTC	1.5	12.3%
FTTB	0.7	5.4%
FWA	0.6	5.2%
Satellite	0.4	3.4%
Total	**12.3**	**100%**

As shown in the Figure 5.3, nbn serves nearly 40% of premises (i.e. ~4.9 million premises) using either FTTN or FTTB, more than 20% of premises (2.5 million premises) using HFC, and nearly 19% of premises (2.3 million) using FTTP. It also serves in excess of 1.5 million premises using FTTC. The remaining premises, located in more remote areas, are served by FWA and/or satellite.

Understanding the distribution of network types is crucial for estimating the total end-to-end service availability across the network as the characteristics of each network vary leading to different availability figures for each technology type. The combination of each network type to provide an overall end-to-end service availability is described in Section 7.4.

5.2 Analysys Mason assessment of nbn's decisions

Analysys Mason's assessment of nbn's network selection methodology

We believe that the methodology and processes used by nbn for determining which type of MTM network was deployed in a particular geographical area is prudent and efficient. The two-step process (i.e. the strategic modelling and the strategic overlay processes) used by nbn leads to a prudent and efficient methodology to determine which type of MTM network should be deployed in each geographical area.

We are satisfied with the methodology used for the strategic modelling process to determine the optimum type of MTM network to deploy. nbn's methodology is based on a series of parameters that have been developed in line with successive SoE principles.

The strategic overlay process considers practical and operational issues in the deployment of the relevant network type for every individual area. It is based on a series of business rules that consider a wide range of relevant factors, including the minimisation of peak funding, optimising economic returns and enhancing nbn's viability. In addition, the methodology also incorporates a long-term NPV consideration. We believe this process to also be prudent and efficient as it is critical to consider the different constraints in the different areas to ensure an efficient deployment of the network. For example, when the difference in peak funding is marginal between FTTP and FTTN for a business park, there may be a business case for nbn to deploy the solution which will be able to accommodate higher-capacity services (i.e. FTTP) and consequently create the opportunity to obtain higher service revenues, even though that network type may attract a higher peak-funding requirement compared to other network types.

Analysys Mason's assessment of FTTC network deployment strategy

We believe that nbn's rationale for deploying FTTC technology is prudent and efficient:

– Deployment of FTTC on long FTTN copper loops is prudent and efficient as it effectively shortens the copper loops and therefore increases the throughput provided to end-users while still reusing the copper final drop.

– Deployment of FTTC in areas where there is a small number of premises is also prudent and efficient as it prevents the deployment of an expensive FTTN street cabinet for a small number of premises which would lead to high fixed costs for a small number of premises.

– Deployment of FTTC in areas with a concentration of small MDUs is also prudent and efficient as it avoids the deployment of costly FTTP/HFC lead-ins and multiple visits where owners' corporation access is required as the copper loops already exist.

– Deployment of FTTC in areas where no copper lead-in is required to be built and where there would be a high lead-in costs if FTTP was to be deployed which is also prudent and efficient.

Analysys Mason's assessment of using a single HFC network strategy

We believe nbn's choice to re-use the Telstra HFC network to be both prudent and efficient; it considered the future investment associated with the Optus HFC network and concluded that re-using the Optus network would increase capex and opex, given the state of the Optus HFC network at the time. This is because the Optus network included more cascaded RF amplifiers resulting in a higher level of noise and therefore a lower potential capacity compared to the Telstra HFC network. In addition, while the Optus HFC network is overhead, the majority of the Telstra network is underground which provides benefits from a service availability perspective.

The choice of using a single HFC network (i.e. Telstra network) leads to a reduction in complexity for the design, construction and operational maintenance, compared to a dual-network environment. Finally, using a single network also means a reduction in operation and maintenance opex (i.e. it is more cost effective to operate and maintain a single network than two distinct networks).

6 Review of the efficiency and prudency of nbn's FTTC network design

In this section, Analysys Mason sets out its assessment of the extent to which nbn's design for its FTTC network is efficient and prudent, based on the strategy of deploying a PON network up to the DPU and re-using Telstra copper loop from the DPU to the end-user.

In this section, we consider the following decisions, which we believe will have the most impact:

- FTTC services and technology selected by nbn to support its wholesale service portfolio (assessed in Section 6.1).
- FTTC network architecture, including end-to-end architecture between customer premises and the PoI and network dimensioning to meet the service requirements (assessed in Section 6.2).

It is the *combination* of these individual design choices and decisions that together determine whether the FTTC network design as a whole is efficient and prudent. Therefore, we have assessed the efficiency and prudency of individual design choices and decisions, and have then – based on this assessment – provided our overall conclusion on the extent to which nbn's design of its FTTC network is efficient and prudent as a whole.

It should also be noted that some of the key design choices have been specified or influenced by the Australian Government in the respective SoEs and by the Statutory Infrastructure Provider targets highlighted in sections 360P and 360S of the Telecommunications Act. In accordance with our instructions, this report does *not* examine the merits of any specifications given by the Australian Government, but only those specific choices that have been made by nbn within the overall parameters established by the Australian Government at a policy level through its SoEs or its Statutory Infrastructure Provider targets.

6.1 Assessment of FTTC services and technology

6.1.1 Services supported by the FTTC network

To meet the various requirements of different end-users, the nbn network supports three different traffic classes for its FTTC wholesale access product, defined by nbn as Traffic Class 1 (TC-1), Traffic Class 2 (TC-2) and Traffic Class 4 (TC-4). The characteristics of these are summarised in Figure 6.1 below. TC-1 is intended to support real-time voice applications, while TC-2 is aimed at businesses that require services with a guaranteed bandwidth at any time when the service is available. TC-1 and TC-2 are specified by nbn in terms of a committed information rate (CIR), meaning that the end-user can expect to receive at least these minimum speeds at all times.

TC-4 is intended to support high-speed internet services, and is specified by nbn in terms of peak information rate (PIR), meaning that the end-user can expect to receive these maximum speeds but not at all times on the FTTC network.

Figure 6.1: Summary of traffic classes defined by nbn for areas served by FTTC technology [Source: nbn]

	TC-1	TC-2	TC-4
Bandwidth profile	• 150kbit/s • 300kbit/s • 500kbit/s • 1Mbit/s • 2Mbit/s • 5Mbit/s	• 5Mbit/s • 10Mbit/s • 20Mbit/s	• 12Mbit/s (downlink) and 1Mbit/s (uplink) • 25/5Mbit/s • 25/10Mbit/s • 50/20Mbit/s • 50-100/20Mbit/s[29] (Home Fast) • 50–100/20–40Mbit/s

RSPs typically procure wholesale access services from nbn with various traffic classes, and these are used to provide retail services to end-users, depending on the end-user's requirements. For example, businesses are most likely to be the only type of end-users taking retail services based on TC-2, which may be used to provide virtual private network connectivity between multiple sites. In comparison, some residential users will take a TC-1-based retail service for fixed voice services, if required. TC-4-based services will typically be used to provide residential internet access services that do not require the same stringent quality and/or availability parameters as those aimed at businesses.

The finite bandwidth available within each section of the nbn network will be shared between the different services being provided to end-users. As illustrated in Figure 6.2, this bandwidth will be dynamically allocated between the different services being used, to help meet the performance targets for the corresponding traffic classes. This means, for example, that end-users will only be able to obtain the instantaneous peak speed specified for TC-4-based services if they do not use other traffic classes at the same time. However, the minimum bandwidth, the CIR, specified for the TC-1 and TC-2 traffic classes will be guaranteed.

---

[29] When the bandwidth profile is expressed as a range, the upper number shows the maximum PIR which can be achieved and the actual PIR can fall anywhere in that range

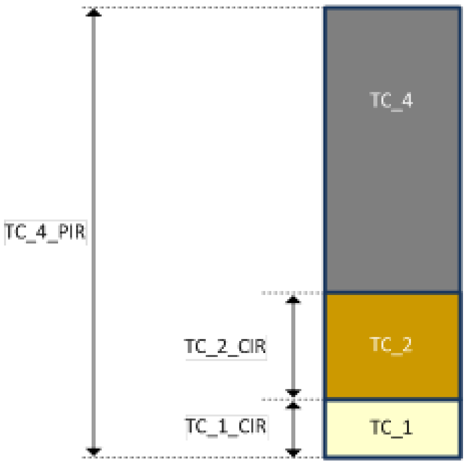


Figure 6.2: Access service bandwidth specification [Source: nbn, 2021]

As demonstrated in Section 3.5 of this report, the bandwidth that can be provided on an FTTC network is dependent upon the length of the copper loop, the active technology used (i.e. VDSL vs VDSL2 vs G.fast) and the activation of vectoring. Since nbn uses VDSL2 for its FTTC network, the maximum downlink bandwidth associated with the TC-4 class of service is 50–100Mbit/s which is in line with the performance that can be observed in Figure 3.2 of Section 3.2 for VDSL2 (without vectoring activation) based on an FTTC network. It should be noted that nbn can offer higher speed tiers, but only in ADAs served by either FTTP or HFC networks.

6.1.2 Access technology

A number of incumbent PSTN operators around the world use VDSL2 technology (with a 17a frequency profile) to provide broadband services to their end-users using the legacy PSTN CAN. Examples include Openreach, Belgacom, Telekom, TIM and AT&T. The majority of these operators (notably Belgacom, Telekom and AT&T) use vectoring technology to increase the bandwidth they can provide. However, other operators offering wholesale services have decided not to use vectoring. For example, after conducting some trials, Openreach decided not to use vectoring due to its obligation to provide copper unbundling. Similarly, TIM has experienced some difficulties in deploying vectoring technology, mainly due to the presence of third-party RSPs using unbundled sub-loops to deliver their broadband services. Sub-loop unbundling presents a major barrier to vectoring technology as it means that more than one operator uses the copper cable, and vectoring systems will function only if a single operator controls all the copper pairs as explained in Section 3.5.3.

nbn uses VDSL2 technology with profile 17a for its FTTC network. nbn has not activated vectoring due to the following considerations:

- DPUs only serve four premises and copper lengths are expected to be under 200m as noted in Section 3.6
- the copper lengths and shared paths are expected to be minimal (nbn estimates that 70% of FTTC lines are disturbance free)
- the benefits of vectoring would also be minimal for the reasons described above
- the cost of including vectoring capability in the DPUs is high relative to the minimal expected benefits.

Also, nbn has decided not to use G.fast technology at this time as it was considered as an interim step to moving to FTTP. Introducing G.fast would involve some risks around the speed benefits depending on lead-in length and quality of copper lines (the speed associated with G.fast technology is highly correlated with both copper length and quality). To meet potential demand for 1G services where required by an RSP or end-user, it was decided to bypass the interim step and move straight to FTTP.

6.2 Assessment of the FTTC network architecture and dimensioning

This subsection provides our assessment of the issues relating to the selection of the proposed FTTC network architecture, including:

- end-to-end architecture
- network dimensioning.

6.2.1 End-to-end architecture

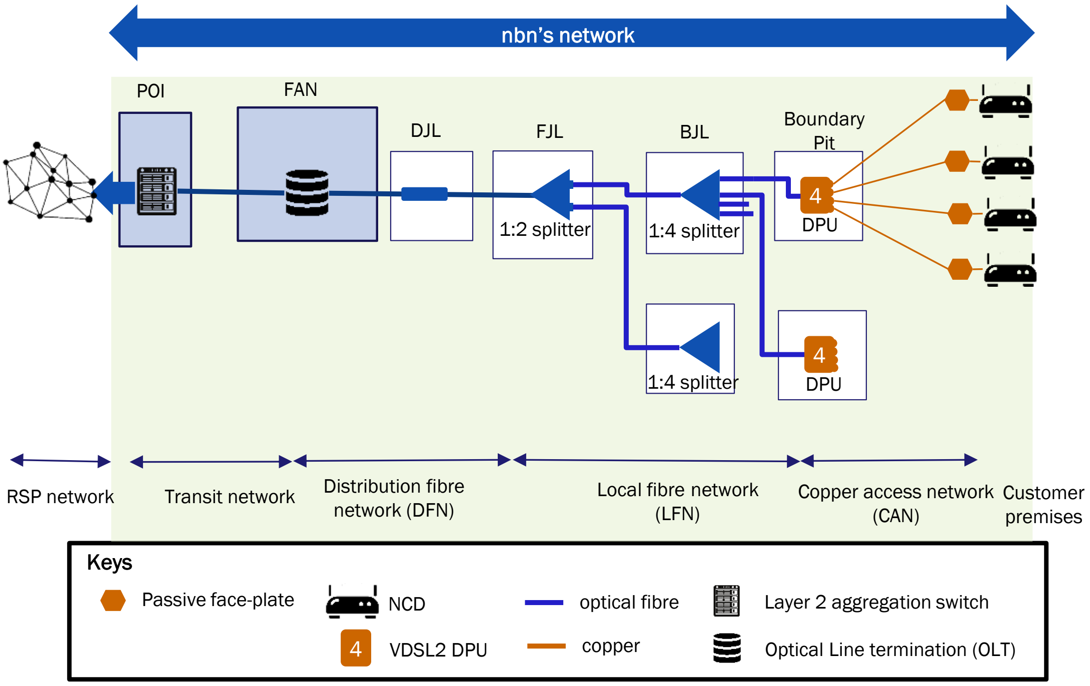
nbn has to design its FTTC network to provide a set of wholesale broadband services with the characteristics described in Section 6.1.1. Since the bandwidth capable of being provided to customer premises connected to an FTTC network is a function of the copper loop length, the location of the DPU serving those premises has to be carefully considered to ensure that the copper loops are short enough to provide the required bandwidth.

In addition, all links in the network have to be dimensioned appropriately so that there is no capacity bottleneck and each end-user receives a broadband service that meets the performance targets for uplink and downlink speeds.

To provide wholesale broadband services with the characteristics described in Section 6.1.1, nbn will deploy an FTTC architecture in selected areas.

The logical blocks of this architecture are illustrated in Figure 6.3 below.

Figure 6.3: Generic end-to-end architecture for nbn's FTTC network [Source: adapted from nbn]



As shown, the architecture can be understood in terms of six segments:

- end-user premises
- CAN
- LFN
- DFN
- transit network
- retail service provider (RSP) network.

We provide a brief overview of each of these segments below:

- **At the customer premises**, nbn physically terminates its wholesale service at the CPE, at the network connection device (NCD). The NCD connects to the copper and reverse-powers the DPU. On the customer side, it offers a UNI-D to which the end users connect their residential gateway.
- **The CAN** consists of the last-drop copper loop connecting the DPU and the customer premises. The DPU is the active equipment which terminates the GPON signal on the network side and generates the VDSL2 signal on the network side. The DPU is a mini DSLAM, being a combination of an ONT and a four-port DSLAM. This means that up to four end users can be connected to that device.
- **The LFN** is defined as the fibre network between the FJL and DPU. The FJL, located in a pit, connects the fibre from the DJL to the LFN fibre using a 1:2 splitter. The LFN also includes a break-out joint location (BJL), which is usually located in a manhole and which hosts a 1:4 splitter.

- **The DFN** is defined as the fibre network between the DJL and the FAN, where nbn deploys an OLT.
- **The transit network** connects the OLT to a pair of EASs hosted in an aggregation node. The transit network includes a fibre network plus active equipment to ensure reliable transmission. The transit network uses 1+1 path redundancy between the FAN and the POI to provide resilient transport. nbn uses dense wavelength division multiplexing (DWDM) to ensure that the capacity deployed in the transit network is cost-effectively scalable with growth in end-user demand (note that for simplicity, this WDM equipment is not shown in Figure 6.3 above). Also, nbn has deployed its own fibre infrastructure in the transit network; in areas where dark fibre is available, nbn also takes dark fibre from other operators if this makes commercial sense. Aggregation nodes will aggregate the traffic from several FANs: there will be 121 aggregation nodes in the whole network. To aggregate the traffic, a pair of resiliently configured EASs will be deployed in each aggregation node. The EASs will connect to a pair of switches which will provide the interfaces for RSPs to connect to, namely the PoIs.
- **The RSP network** provides authentication functionality through the broadband network gateway (BNG) and access to the internet.

As illustrated in Figure 6.3, in nbn's FTTC architecture, the CAN network is backhauled by an FTTP PON network up to the end-user boundary pit which means that the migration from FTTC to FTTP can be carried out with minimum disruption as described in Section 7.1.2.

6.2.2 Network dimensioning

In FTTC networks, the CAN does not need to be dimensioned as each copper line is dedicated to an end-user. However, nbn needs to ensure that two network sections are dimensioned correctly:

- the backhaul between the DPU and the OLT in the FAN
- the transit network from the OLT to the EAS in the POI.

Dimensioning of the backhaul network between the DPU and the OLT in the FAN

nbn backhauls the FTTC network using a GPON with a 1:8 splitting ratio (one 1:2 splitter in the FJL and one 1:4 splitter in the BJL)[30].

We believe the dimensioning for the backhaul of the four-port DPU based on 1:8 PON split ratio to be appropriate to offer these downlink and uplink speeds.

Dimensioning of the transit network

For links which aggregate traffic in the transit network (e.g. connections between OLT and the aggregation node), nbn has to implement network dimensioning rules to ensure the deployed

---

[30] When considering the additional 1:4 splitter added in the DPU pit or pole for the migration to FTTP, the overall split ration remains 1:32 (same as for historical FTTP wholesale services)

capacity will support the broadband traffic demand (in terms of both uplink and downlink bandwidth) to be able to support the performance targets of the different classes of service provisioned. It should be noted that this methodology is independent of the type of access network used by nbn to deliver its services (i.e. these dimensioning rules are not specific to traffic carried on the FTTC network).

nbn has designed its aggregation links according to specific design rules which we believe are reasonable considering the different types of traffic (i.e. TC-1, TC-2 and TC-4) and the different traffic priorities associated with each traffic type. .

Since TC-1 and TC-2 traffic are based on CIR and not PIR, the dimensioning rules are significantly different from that used for TC-4 traffic. Also, since TC-1 and TC-2 are higher-priority traffic classes than TC-4, any potential congestion on a link will affect TC-4 first.

Methodology to avoid congestion

In order to avoid congestion in its network, nbn measures the utilisation of shared network resources, and if it determines based on multiple utilisation measurements that a shared network is becoming congested, it takes action to remedy the situation, for example through capacity augmentation. The results of this methodology are reflected in public customer experience reporting on congestion[31].

6.2.3 Analysys Mason assessment of nbn decisions

Analysys Mason's assessment of services supported by the FTTC network

The downlink and uplink bandwidth delivered over the FTTC network will depend upon the characteristics of the copper loop, particularly the length of the sub-loop and whether vectoring can be used or not. Based on our experience of FTTC networks, we believe that nbn should be able to provide a maximum downlink bandwidth within the 50–100Mbit/s range and a maximum upload speed in the 20–40Mbit/s range, in line with nbn service portfolio for FTTC networks.

We therefore believe that the selection of products proposed by nbn in areas served by its FTTC network is prudent and reasonably accounts (through proposing a range of throughput) for uncertainties regarding the actual physical characteristics of the existing CAN (i.e. quality and copper loop length).

---

[31] https://www.nbnco.com.au/corporate-information/about-nbn-co/updates/dashboard-december-2021)

Analysys Mason's assessment of nbn access technology selection for FTTC networks

Analysys Mason believes that the use of VDSL2 (profile 17a) technology by nbn is prudent. VDSL2 is a mature technology which has been successfully deployed by many incumbents around the world, such as Openreach and AT&T, and is also a cost-efficient technology as it allows the re-use of the existing CAN infrastructure, avoiding costly civil engineering or the deployment of an overlay network.

nbn's approach to vectoring (i.e. not activating the technology) is prudent and minimises potential problems associated with other operators' use of the same copper cable. nbn's decision not to use G.fast is also prudent as G.fast was considered as an interim step to moving to FTTP. To meet potential demand for 1G services, nbn decided to bypass the interim G.fast step and opted for the FTTP upgrade. nbn's strategy to upgrade FTTC end-users to FTTP if they require a higher speed tier is reasonable and ensures the upgraded connection is future-proof in terms of bandwidth.

Analysys Mason's assessment of FTTC architecture

The FTTC network architecture designed by nbn, which uses a PON to backhaul the traffic between the DPU and the FAN, is prudent and efficient as it allows the FTTC network to be upgraded to future-proof FTTP with minimum architectural change.

Analysys Mason's assessment of nbn traffic dimensioning

The dimensioning of the backhaul between the DPU and the FAN is prudent and efficient. Regarding the dimensioning of the transit network, there is no standard way to dimension network links. nbn has developed and refined a detailed dimensioning methodology since the launch of its operations since 2010 and can now use actual data from that network to benchmark its dimensioning calculations. For the dimensioning of TC-4 traffic, which is defined in terms of PIR, we believe that nbn's methodology is sound as the theoretical calculation is now backed up by actual data measured on the network.

Also, nbn applies service qualification limits when provisioning TC-1 and TC-2 services into the network, which is designed to ensure that there will always be sufficient service bandwidth for TC-1 and TC-2 services, albeit with some potential impact on TC-4 traffic in cases of higher link utilisation. This seeks to ensure that TC-1 and TC-2 services will never experience congestion as there will always be enough link bandwidth to satisfy traffic that is fully utilising the amount of allocated TC-1 or TC-2 capacity. Other processes are also in place to ensure that TC-4 traffic is not unduly affected, which consist of measuring the utilisation of shared network resources, and if it determines based on multiple utilisation measurements that a shared network is becoming congested, it takes action to remedy the situation, for example through capacity augmentation. We believe this approach to be prudent and efficient.

7 Review of methodology and processes for determining upgrades to the fixed network technology

nbn has embarked on the upgrade of its FTTN and FTTC networks to FTTP in order to meet expected customer demand for bandwidth and new functionality, while providing flexibility and reliability. This section examines whether nbn’s approach meets those requirements and considers whether nbn’s current methodology and processes for determining upgrades from FTTC and FTTN to FTTP under nbn’s Investment Acceleration Program (IAP) are prudent and efficient.

nbn intends that the FTTP upgrades will allow it to offer services with ‘Home Ultrafast’ bandwidth profiles (defined by nbn as download speeds of 500Mbit/s and greater). It will also allow profiles to be offered of greater than 100Mbit/s, not currently supported in FTTN and FTTC areas, including the nbn-defined ‘Home Superfast’ (250Mbit/s and above) and provide a roadmap to offering higher-speed services in future.

It is intended that the FTTN network will be upgraded to enable c.2 million premises to be able to order a Home Ultrafast bandwidth profile by the end of 2023, and that eligible premises in the FTTC footprint will also be able to order this profile by that date. The upgrade of an end customer to FTTP will be initiated by the RSP.

As end-customer bandwidth demands increase over time (with the introduction of new, more bandwidth-intensive applications), it is important that the active equipment in the FTTP network can be upgraded to support higher-bandwidth services. There are a number of PON technology upgrade options that nbn can take advantage of as described in Section 7.3.4.

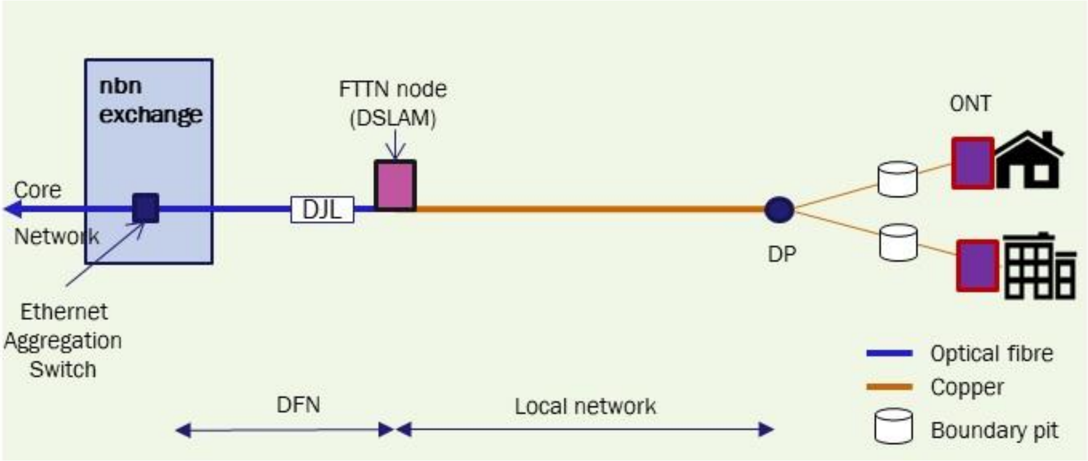
7.1 Operational considerations for technology upgrades

nbn has developed a strategy for upgrading its FTTN and FTTC deployments to FTTP. In this section we describe the main activities of each upgrade process.

7.1.1 FTTN to FTTP upgrade operational considerations

The typical architecture for an nbn FTTN deployment is shown in Figure 7.1.

Figure 7.1: nbn FTTN reference architecture (underground deployment) [Source: Analysys Mason]



When the FTTN node was installed, fibre was laid from the exchange through the DJL to the FTTN node containing the VDSL2 DSLAM. The copper network was retained to support temporary continued supply of voice services from the exchange while the VDSL2 DSLAM was used to deliver broadband when the end customer upgraded to nbn's broadband service.

The key upgrade when moving from an FTTN to an FTTP architecture is the deployment of fibre between the FTTN node and the DP which then becomes the splitter multi-port (SMP) for the FTTP network as shown in Figure 7.2.

Figure 7.2: nbn FTTP reference architecture for upgrades from FTTN upgrades [Source: Analysys Mason]

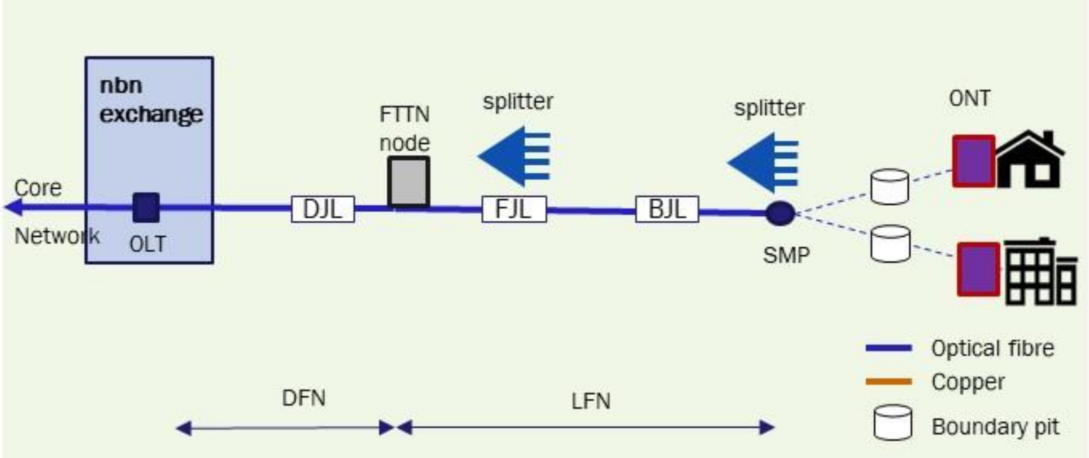


Figure 7.2 shows the fibre being run from the FTTN node location to an SMP at the distribution point close to the end customer premises. Splitters are installed in a two-stage configuration with the primary splitter located in the FJL, usually close to the FTTN node, and the secondary splitter at

the DP location which becomes the SMP. A mix of 1:4 and 1:8 splitters in different configurations provide a 1:32 ratio, the standard splitter ratio for the nbn build. The last drop is installed on demand when the end customer requests service, with no forced migration to FTTP planned in the near term. The diagram shows the fibre and splitters deployed in underground chambers, but in some areas the infrastructure is overhead. However, aerial infrastructure is estimated by nbn to account for only 5–10% of the existing build. The key operational issues highlighted by nbn during the implementation of the FTTN to FTTP upgrade are:

- resource availability (as in some areas the original nbn network roll-out was completed some time ago, and the civil infrastructure workforce may have moved on to other infrastructure programmes)
- relatively high requirement for civil works (leading to health and safety risks including the potential for field work injury)
- possibility of damaging other utility infrastructure during the upgrade process
- implementation of new operational processes relating to lead-ins relating to:
  - fibre lead-in design works
  - Telstra duct reservations
  - aerial field reports where fibre lead-ins are delivered to premises aerially

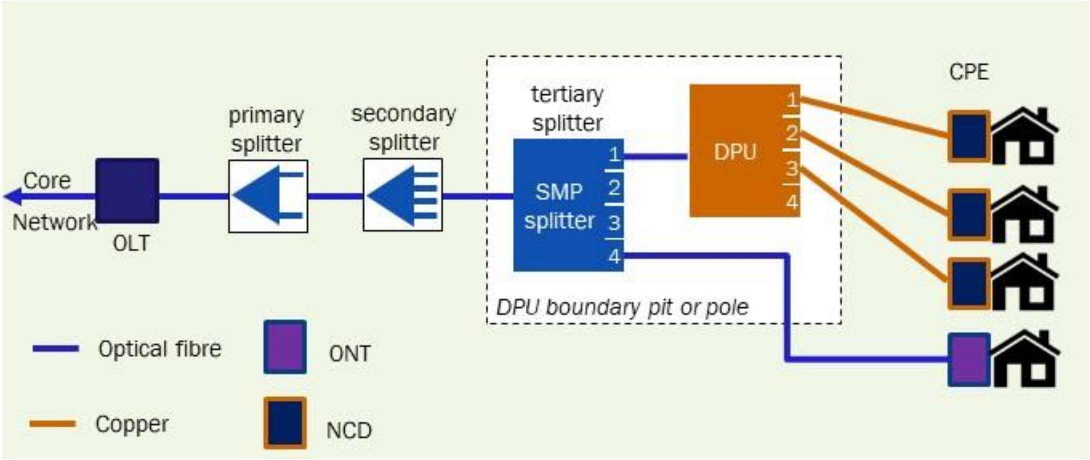
The issues described above are typical of a large upgrade project of this type and such risks have been successfully managed by nbn throughout the FTTP build to date. There are also issues relating to ensuring the accuracy of assumed costs of implementation and return on investment assessment based on expected take-up. However, this is fundamentally a commercial/financial issue and covered in Section 7.2.2.

7.1.2 FTTC to FTTP upgrade operational considerations

The upgrade from FTTC to FTTP is more straightforward that for FTTN to FTTP, as the fibre deployed to the DPU as part of the FTTC roll-out is effectively a PON network (as described in Section 6.2.1) and can be directly used for the FTTP upgrade. The FTTC reference architecture is shown previously in Figure 6.3.

The process to upgrade from FTTC to FTTP involves deploying a splitter or SMP alongside the DPU with the same number of end customer ports as the DPU. The DPU is disconnected from the OLT and reconnected via the SMP, with the other SMP ports available for providing FTTP links to end customers as shown in Figure 7.3.

Figure 7.3: FTTC to FTTP upgrade connectivity [Source: Analysys Mason]



The SMP is installed on demand when the first end customer requests a service that requires FTTP. There is an outage for all customers connected to the DPU when the SMP is installed and the DPU connected to the SMP. The other end customers are connected as they request FTTP service. When the last customer requests the FTTP service, the DPU is removed and the port previously used for connecting the SMP to the DPU is then used to connect the final FTTP end customer.

This straightforward process means that FTTC DPUs can be enabled for FTTP upgrade without any prior intervention in the field or specific design work. However, some premises need additional design elements to be designed, built and launched to help facilitate the implementation. nbn has reported the main operational challenges involved in the FTTC to FTTP upgrade as being:

- The need for new field tasks and associated commercial changes to implement the SMP as the DPU, requiring delivery partners to plan and raise a planned network outage request a number of days ahead of doing the work.
- The transition of former build functions and resources performed in bulk at the time of network construction into on-demand operational tasks.
- Implementation of new operational processes for lead-ins as for FTTN to FTTP upgrades.

The FTTC to FTTP upgrade process is logical and straightforward, utilising the existing deployed network to a high degree with the implementation driven by customer demand.

7.2 Timeline and process for upgrades from FTTN/FTTC to FTTP

7.2.1 Overall timeline for upgrades from FTTN/FTTC to FTTP

nbn's IAP programme announced in September 2020 has an overall aim to make nbn's highest wholesale speed tiers of greater than 100Mbit/s available to 75% of homes and businesses on the fixed line network as demand arises by 2023. For FTTN served areas, this involves the extension of the LFN from the node in selected areas where current or emerging high bandwidth demand has been identified that is expected to provide a commercial return on investment. For FTTC areas, it is intended that all areas will be enabled for FTTP in two phases – Phase 1 (initial c.900 000 premises) for completion in 2022 and Phase 2 remaining c.600 000 premises for completion in 2023.

The process for upgrading from FTTC to FTTP is simpler than for FTTN to FTTP as it does not require an extension of the LFN. For Phase 1 during 2022, installing a fibre SMP will enable the FTTP connection to be made. Phase 2 premises are scheduled for 2023 due to additional solution elements needing to be designed, built and launched. This includes premises with aerial network infrastructure or larger MDUs.

A full FTTP upgrade will be required over the period to 2040 to meet bandwidth demand over that timeframe.

7.2.2 Process and timeline for FTTN IAP upgrades

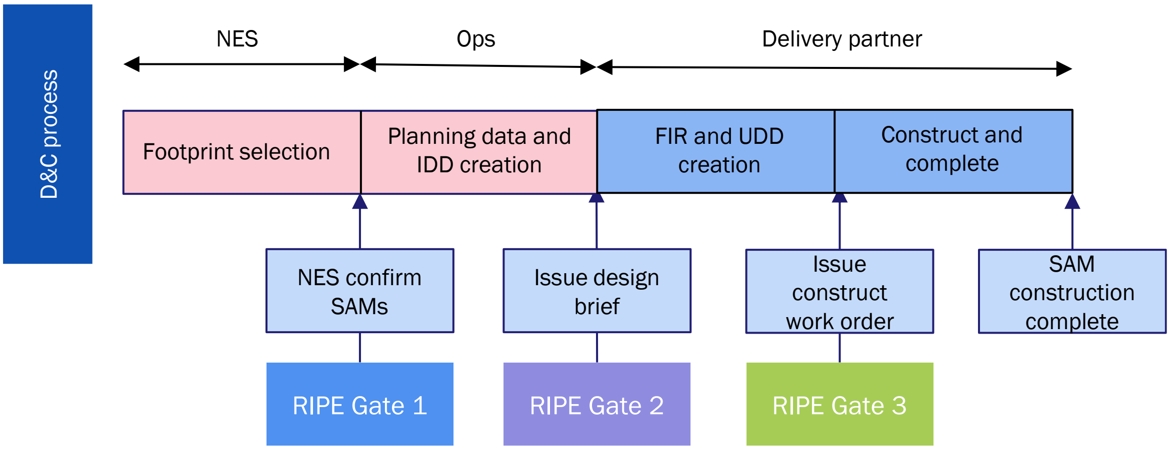
The FTTN to FTTP upgrade needs a rigorous area selection process to be implemented to ensure that the selection of areas to be upgraded meets prudency and efficiency considerations. nbn has developed the return on investment process evaluation (RIPE) to ensure that appropriate areas are selected for upgrade during the IAP.

RIPE approach

RIPE was designed to ensure that nbn spends as much of its IAP investment as possible in areas that provide the most attractive return on investment opportunities. This takes into account the cost of deployment and the likely revenue from the end customers in the selected areas and has three review points before approval to proceed is given to implement the upgrade as shown in Figure 7.4.

A key aspect of RIPE is the verification of costs against the IAP business case. The MTM model was refined to be used as an input into the IAP business case. Also it can be noted that the MTM model was used for an extended period before those refinements as a benchmark to check projected build costs provided during the RIPE process.

Figure 7.4: RIPE upgrade process [Source: nbn]



Selection of areas for inclusion in FTTN to FTTP IAP upgrade

RIPE is used to select ADAs to be included in the upgrade from FTTN to FTTP based on areas that minimise upfront build costs and maximise the demand for high-speed services. The RIPE typically considers all ADAs within a SAM and makes a decision on whether to upgrade based on various factors including, but not limited to, the cost to deploy.

Progress of IAP upgrades from FTTN to FTTP

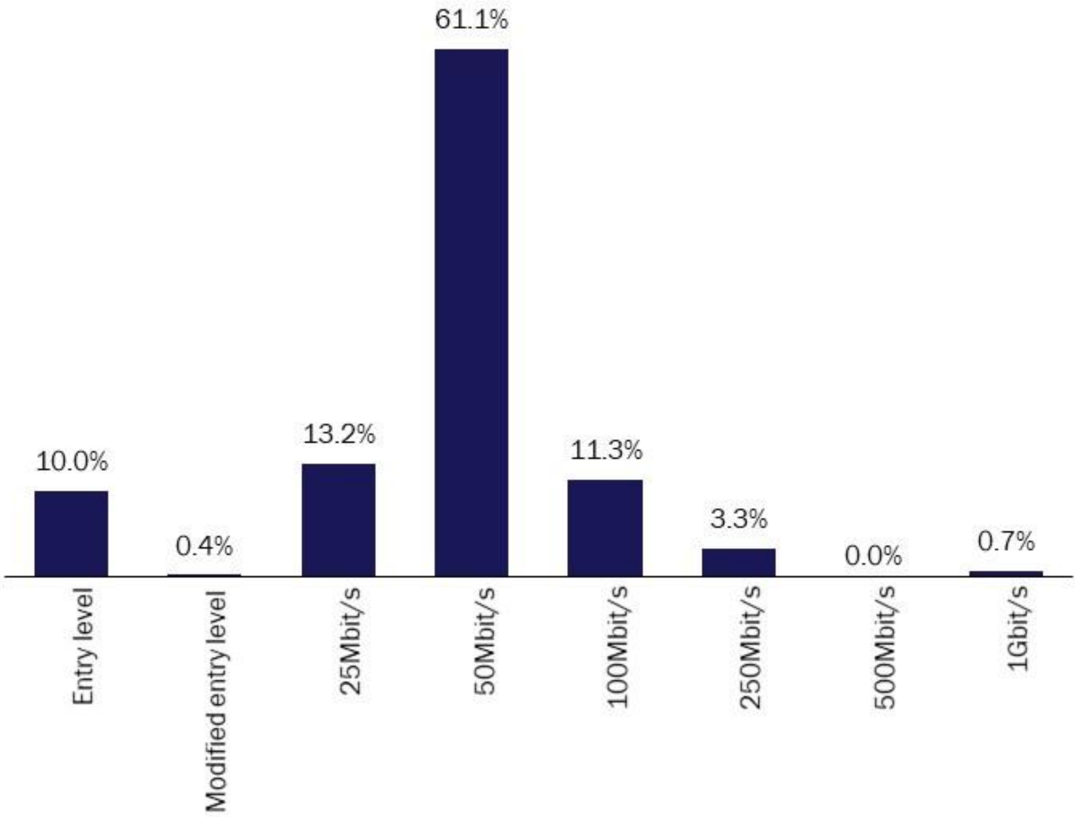
2 million FTTN premises have been identified to be upgraded as part of IAP. As of 18 November 2021, 75% of these (1.49 million premises) had their initial desktop designs completed, of which 42% (841 000 premises) had been issued to delivery partners for detailed design, of which 20% (392 000 premises) had commenced construction, and of which 24 000 premises had been completed. nbn’s plan was to complete LFN build for 100 000 premises by launch (planned for Q1 of 2022), growing to 250 000 by June 2022, and 700 000 by December 2022. nbn acknowledges that it will be a challenge to increase the build rate four-fold between 2022 and 2023, but it thinks the build is on track to be completed by December 2023 and has said it is currently tracking to budget.

7.3 Customer demand considerations for technology upgrades

7.3.1 Current headline speeds taken by nbn end customers

The current breakdown of speeds taken by nbn customers is as shown in Figure 7.5.

Figure 7.5: Breakdown of current headline speeds for nbn customers [Source: nbn, 2021]



7.3.2 nbn drivers for FTTP technology upgrades

nbn is upgrading its network to FTTP in order to meet end customers' future needs. It has identified that the main drivers for increased bandwidth leading to a requirement for FTTP include the increased number of devices connected to the internet in homes and businesses plus the increasing use of several data-intensive applications concurrently, including online gaming, UHD television streaming, large file sharing and live video streaming in general. In addition, once deployed, the FTTP network will be capable of being upgraded to other fibre-based higher-capacity technologies in the future to meet further needs as they develop.

As well as enabling higher speeds, FTTP services also provide customers with greater certainty over the speed they can expect from the service compared to copper-based services that degrade based on the length of the copper line and quality of the installation. FTTP is more reliable with lower fault rates which leads to a better customer experience.

nbn's network upgrade strategy also considers the needs of RSPs and it has identified the following drivers:

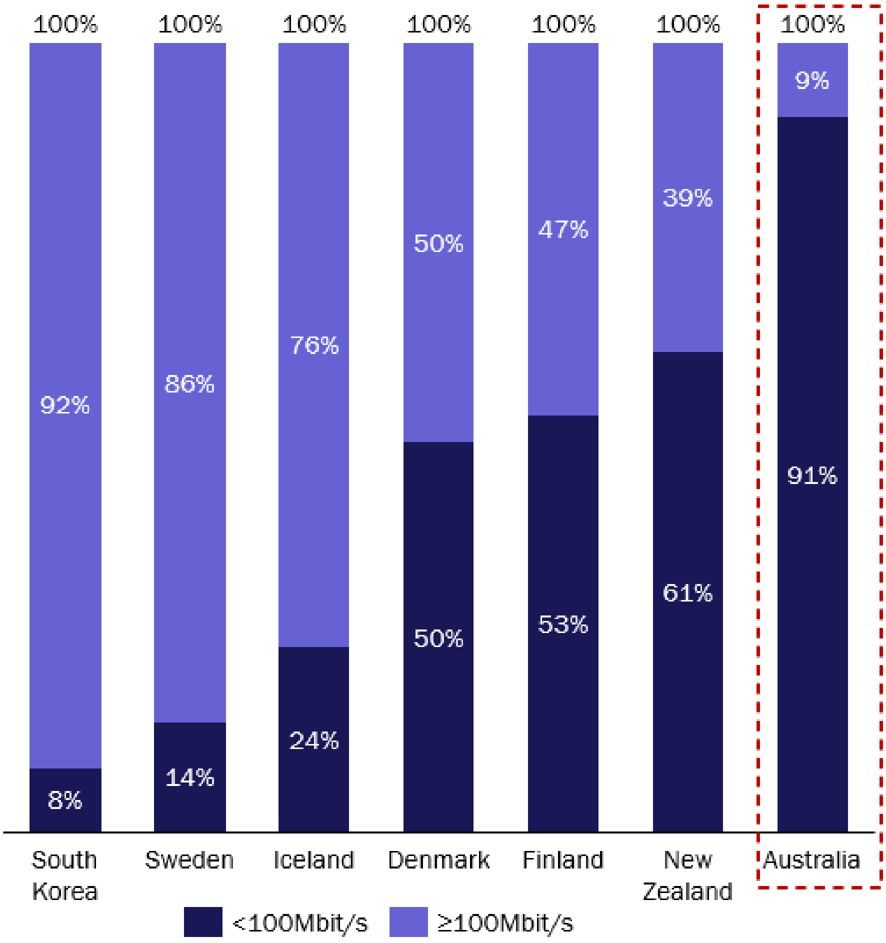
- greater availability of higher bandwidth profiles increasing the effectiveness and return on marketing of higher speed tiers by RSPs
- simpler sales message that focus on customer speed needs as FTTN-specific network constraints and performance uncertainties are removed
- increased sales conversion rate as speed availability is more certain than for copper-based services
- increased RSP ARPU and margins from upsell of customers to higher speeds
- improved customer experience from a more reliable and higher-quality product designed to meet broadband needs
- increased network stability resulting in reduced customer service resource requirements and improved customer experience.

The ARPU, improved customer experience and network stability benefits also apply to nbn itself as well as meeting its overall goal of improving the digital capability of Australia, resulting in Australians having access to a fast, reliable broadband network.

7.3.3 nbn's future demand forecast for higher headline speeds

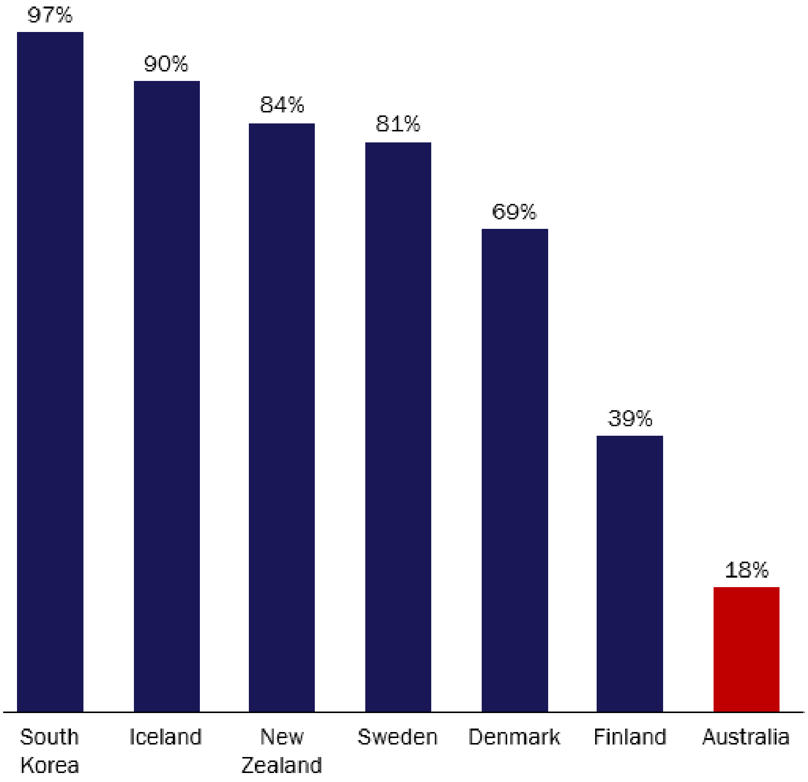
While nbn currently sees relatively low demand for services above 100Mbit/s, experience in other countries, particularly where FTTP is rolled out more extensively and/or HFC networks are more prevalent, is that customer demand will develop if the network capability is available. Figure 7.6 gives examples of other developed countries in Europe and the Asia–Pacific region where the take-up of services of 100Mbit/s or over is significantly above the 9% of subscriptions seen in Australia.

Figure 7.6: Fixed broadband subscription by speed [Source: National regulatory authorities, OECD, Latest available data (2020 or 2021)]



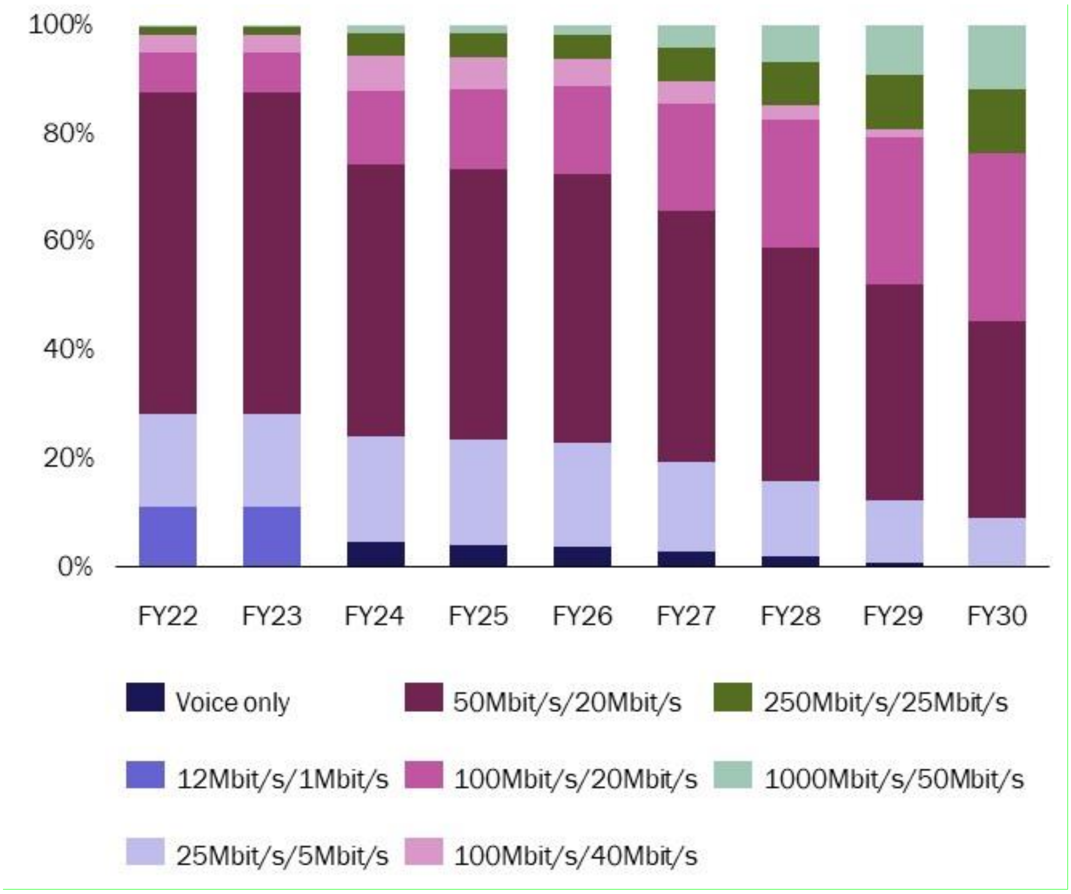
Overall there is a close correlation between the availability of FTTP technology and the take-up of services of over 100Mbit/s for the comparator countries as shown in Figure 7.7, although the presence of cable networks offering services greater than 100Mbit/s may also be a service take-up factor.

Figure 7.7: FTTH coverage as a proportion of premises passed [Source: FTTH Council, Analysys Mason Research, 2021]



nbn has undertaken its own analysis of how it expects the speed tier mix to evolve over the coming years and has made the forecast shown in Figure 7.8. It concludes that there could be demand for 2Gbit/s downstream tier in FY2024 and a 5Gbit/s downstream tier in FY2030.

Figure 7.8: nbn forecast of end customer headline speed evolution [Source: nbn]



7.3.4 Options for PON technology upgrade paths

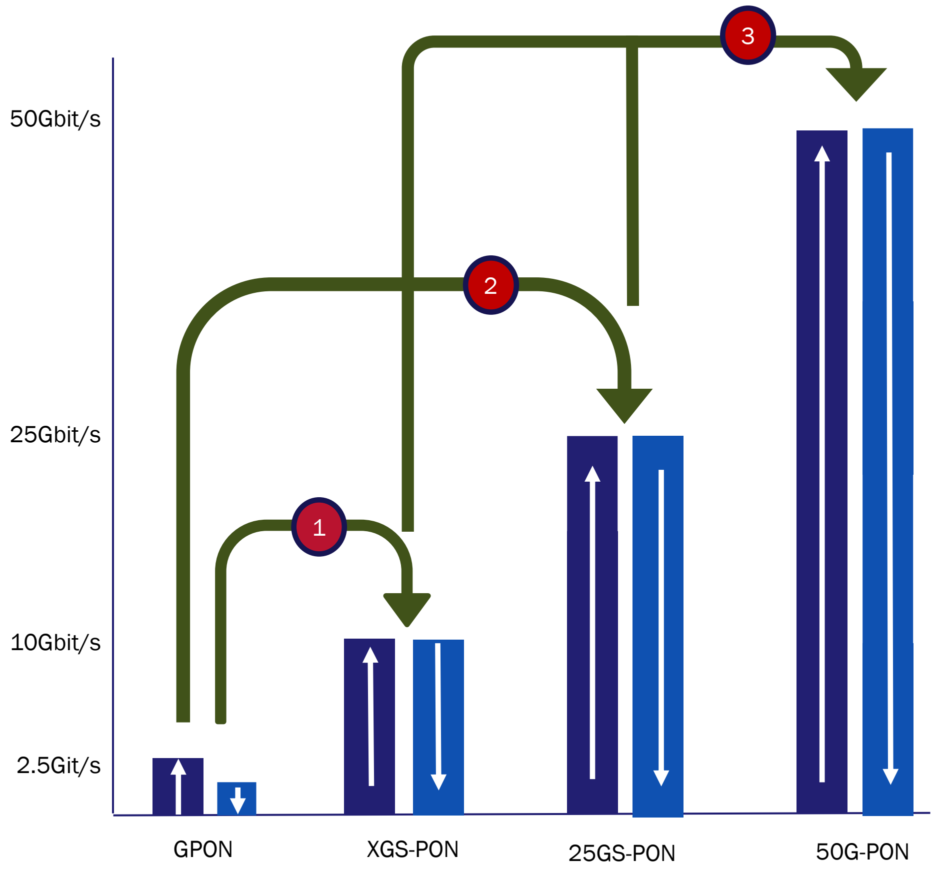
Most operators building FTTP networks in recent years, including nbn, have deployed GPON technology. The active GPON equipment costs represent only a small portion (typically 20% and often less) of total FTTP capex in developed economies; the passive fibre network and the support physical infrastructure account for the rest. Next-generation PON technologies, which support increased bandwidth, are overlays, and represent an additional active equipment cost (new OLTs and new ONTs), but involve no change to the passive fibre network, protecting operator's investment as described in Section 4.3.6.

There are essentially three main options for PON upgrade for operators:

- Option 1: GPON to XGS-PON
- Option 2: GPON to 25GS-PON
- Option 3: XGS-PON/25GS-PON to 50G PON.

These options are illustrated in Figure 7.9.

Figure 7.9: PON technology upgrade options [Source: Analysys Mason]



Option 1 (i.e. upgrade to XGS-PON) is the current most likely upgrade option. It has already been standardised and is now considered to be a mature technology. It is also now popular amongst new FTTP operators making their first technology choice.

Option 2 (i.e. upgrade to 25GS-PON) is also gathering some momentum as it is considered as a technology that could leapfrog XGS-PON, by providing more than twice as much bandwidth (see Section 4.3.4 for more details). Although still a nascent technology and not standardised by the ITU, it is of interest to nbn as demonstrated by nbn's participation in the 25GS-PON MSA industry-standard group. We expect the adoption of 25GS-PON to significantly increase in the next few years, as the technology matures.

Finally, the adoption of Option 3 (i.e. upgrade to 50G PON) will become an option as the first version of the standard was released by ITU-T in September 2021 and we expect the first 50G PON roll-outs could start being commercially deployed in the next two to three years (see Section 4.3.4 for more details).

Note that there are also NG-PON2 (TWDM-PON) options (e.g. 4x10Gbit/s channels), but use remains limited as the requirement for WDM tuneable lasers means that this technology remains too costly for the residential market with more focus is being placed on the 25GS-PON and 50G PON technologies.

We believe that there will be an upgrade path for the foreseeable future in PON networks as future-proofing is a key consideration for ITU/FSAN when developing GPON standards and associated roadmaps.

7.3.5 Analysys Mason’s estimate of bandwidth demand and technology requirements

In this section, we assume that the bandwidth requirements from end customers drive the supply of broadband services in terms of headline bandwidth. In reality, the supply of broadband services is also driven to some extent by competition between operators and headline bandwidth is increasingly perceived as a differentiator.

Bandwidth requirements can be considered as ‘comfort speed’ and ‘headline speed’ requirements. Comfort speed is the amount of bandwidth required to support the typical usage at peak time of an end customer actively using the service, while headline speed is the maximum speed that the end customer can achieve from the service. The headline speed which can be provided for the different PON technology was discussed in Section 4.4.

Downlink bandwidth demand

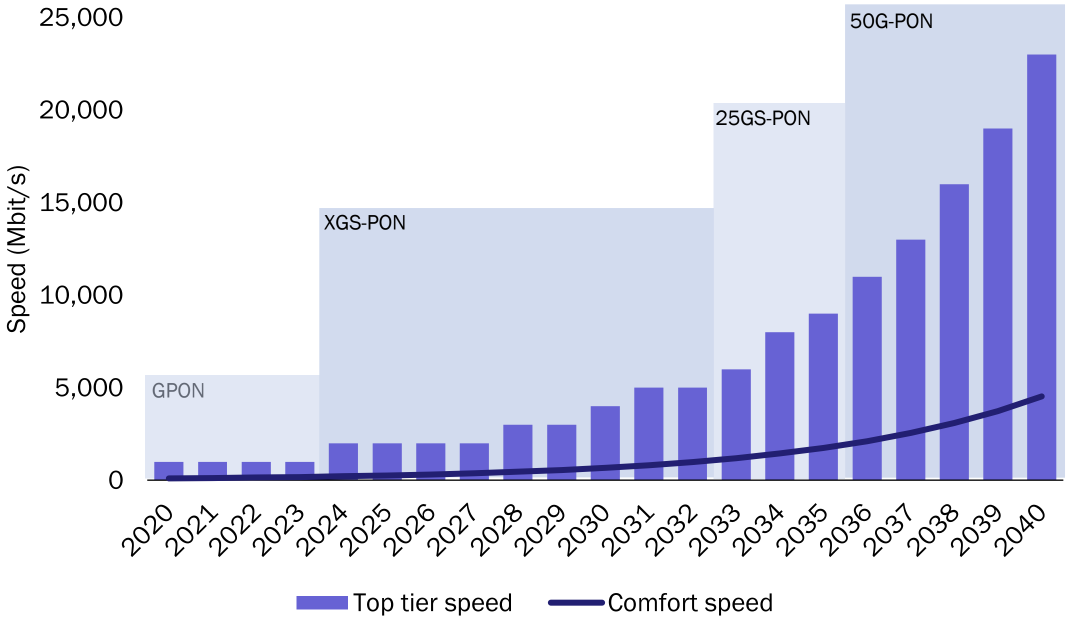
In our previous report, we estimated that by 2020 the comfort speed requirement of the top 1% of households would be 100Mbit/s (‘high-end customer’). We still consider this to be a reasonable case given a typical high user profile of:

- 2 × 4K UHD television using 30Mbit/s per stream
- 2 × HD television using 12Mbit/s per stream
- 1 × SD television using 3Mbit/s per stream
- 1 × internet browsing using 10Mbit/s.

This mix of usage results in a comfort speed requirement for high-end customers of around 100Mbit/s. However, we can expect a customer with such usage demands to take a service with significant headroom above this. We consider a headline speed of five times the comfort speed to be a reasonable representation of the service a high-end customer would likely procure.

In August 2021, Analysys Mason produced a report titled ‘Fixed network data traffic: worldwide trends and forecasts 2020–2026’ which includes a forecast of Australian network traffic growth between 2021 and 2026. On average, it forecasts that traffic will grow at 21% per annum over that period. Taking the above information and assuming traffic growth continues at the same rate to 2040, the bandwidth demand of a high-end customer would be as shown in Figure 7.10.

Figure 7.10: Analysys Mason forecast of high-end customer bandwidth requirements for Australia [Source: Analysys Mason]



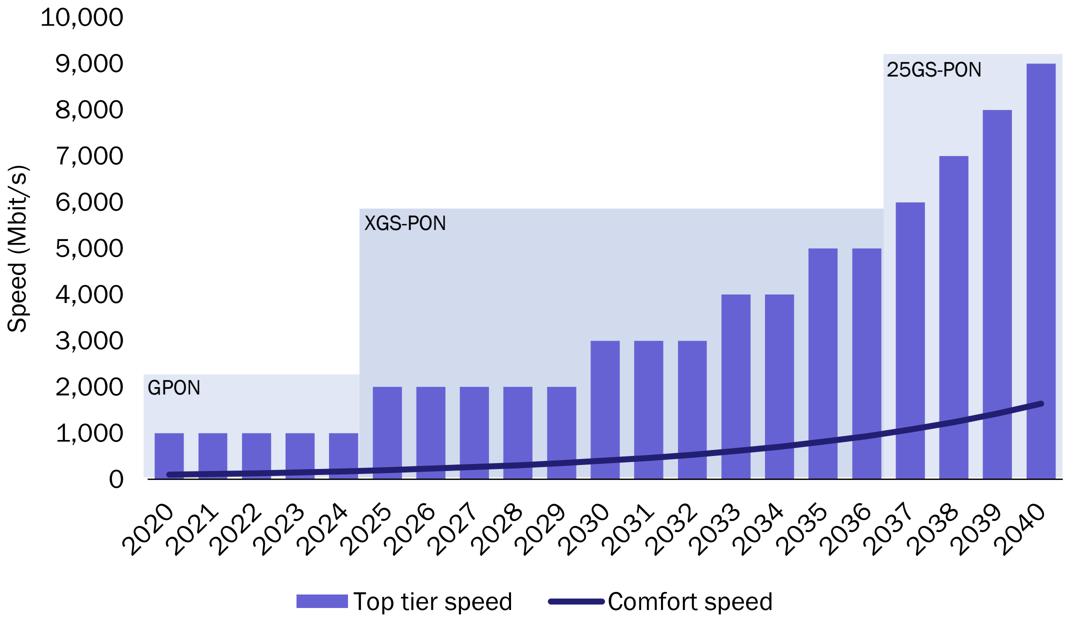
Using the capability data of different PON technologies set out in Figure 4.10 that defines the top tier headline speed that can be offered by each technology, the chart shows when technologies will need to be available in the network to meet the needs of high-end customers.

Based on Analysys Mason forecasts, the analysis suggests that XGS-PON technology will need to be available in the network by 2024, when a headline speed of 2Gbit/s will be needed. Similarly, 25GS-PON technology will need to be available by 2033 when the headline speed requirement exceeds 5Gbit/s. The traffic forecast suggests the lifetime of 25GS-PON will be short, lasting just three years before 50G PON technology is needed. However, in reality, it may make sense to introduce 25GS-PON in preference to XGS-PON, lengthening the GPON replacement technology lifetime from 9 to 12 years. Alternatively, if XGS-PON technology is deployed, it could make sense to start deploying 50G PON technology from 2033.

Whichever path is taken, the deployment of FTTP provides a pathway to meet the end customers bandwidth demands to 2040 and beyond. It should be noted that there is scope for PON technologies to co-exist in the same spectrum as described in Section 4.3.6 which allows upgrades to be completed incrementally, driven by customer demand rather than by a forced technology migration process.

nbn has also undertaken its own traffic forecast up to 2030 which equates to traffic growth on average of 15% per annum. Applying this growth rate to a high-end customer's bandwidth requirements in the traffic growth results in the bandwidth requirement profile shown in Figure 7.11.

Figure 7.11: Forecast of high-end customer bandwidth requirements using nbn growth rate [Source: nbn, Analysys Mason]



A difference in bandwidth CAGR growth rate of just 6% has a significant impact on technology upgrade timing in the longer term. For both projections (i.e. Analysys Mason's forecast and nbn's forecast) the technology upgrade path is the same, it is the timing of the upgrades is different. However, in either case we expect the future technologies to be readily available when they are needed.

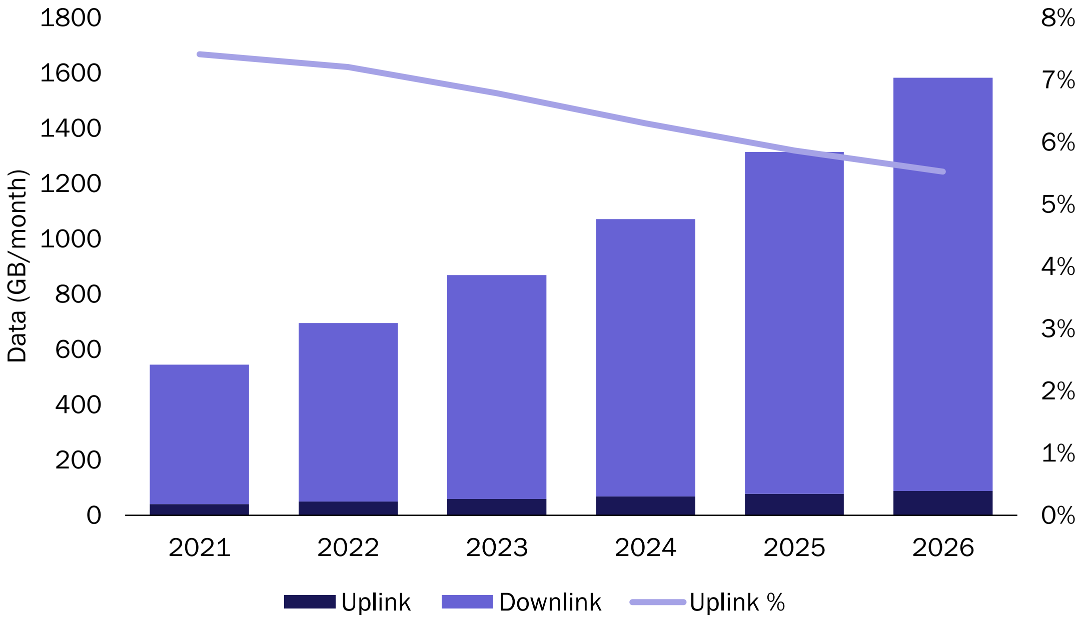
It should be noted that for either forecast, the technology upgrade path up to the early 2030s is very similar; beyond that time frame, the uncertainties are too uncertain to be able to make pronouncements with confidence. In any event (whether the nbn or Analysys Mason forecasts are more accurate) the necessary technology to support bandwidth requirements up to June 2040 should be available in time.

Uplink bandwidth demand

Bandwidth demand is primarily driven by downlink requirements, but uplink requirements also need to be considered to ensure the technology is suitable for supporting both downlink and uplink capacity. GPON technology is designed to support uplink bandwidth up to one-third of the total bandwidth available (1.25Gbit/s out of the 3.75Gbit/s available combining uplink and downlink capacity on each PON). The subsequent PON technologies being considered have symmetric capability meaning there is as much uplink capacity as downlink.

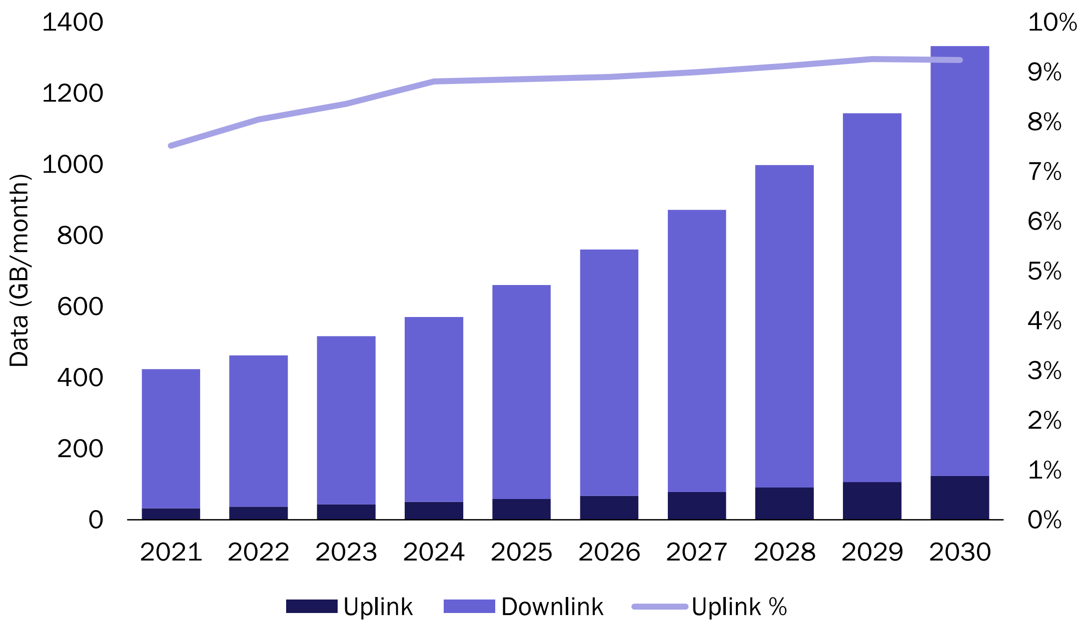
In 2021, Analysys Mason forecast that uplink bandwidth would account for 7.4% of the total bandwidth for a typical broadband connection which correlates closely with nbn's own figures of 7.5%. Figure 7.12 shows Analysys Mason expects this figure to drop steadily to 5.5% by the end of its forecast period in 2026. The dominance of downlink bandwidth is driven by use of video streaming by end customers which Analysys Mason forecasts will grow even more over time as traditional linear TV consumption is replaced by services provided over the internet.

Figure 7.12: Analysys Mason forecast of uplink bandwidth as a proportion of total bandwidth for Australia [Source: Analysys Mason]



nbn has developed its own forecast up to 2030, which, as illustrated in Figure 7.13, shows an increase in the proportion of uplink traffic rising to 9.2% of total traffic in 2030.

Figure 7.13: nbn forecast of uplink bandwidth as proportion of total bandwidth for Australia [Source: nbn]



In its forecast, nbn appears to be putting more weight on end customers using applications that require greater use of the uplink or has an expectation that video streaming will be less of a factor driving the dominance of downlink use over uplink. The fact that it assumes data consumption will grow at a lower rate than the Analysys Mason forecast is consistent with the latter point. However, both forecasts indicate that uplink bandwidth use is below 10% of total use meaning that for both the asymmetric GPON and symmetric future PON technologies, uplink bandwidth requirements are unlikely to be a significant driver of technology upgrades.

This means we can conclude that the deployment of FTTP and nbn's intention to upgrade the active PON equipment to meet downlink bandwidth requirements will also allow the anticipated demand for uplink bandwidth to be met up to 30 June 2040.

7.4 FTTP end-to-end service availability

nbn needs to provide an end-to-end service availability sufficient to ensure nbn delivers a reliable wholesale service that enables RSPs to provide a reliable service to end customers.

End-to-end service availability is defined as the amount of time the service will be operational for the end customer under normal operating conditions and is an important metric for assessing the reliability of the service. Typically, any planned service downtime (e.g. for network maintenance or upgrades) is not counted as network downtime.

Operators normally define end-to-end service availability based on the type of products provided and the market segment targeted. Once the end-to-end service availability is defined, operators have then to design their network architecture in such a way that this level of availability is met, taking into account any network redundancy that is required for passive network elements (i.e. alternative diverse physical paths) and active components (e.g. hot-standby configured or pooled network elements). Defining end-to-end service availability is always a compromise between service availability (quality) and costs: it is more expensive to build a resilient network supporting a high end-to-end service availability, mainly because additional redundant links and network components are required.

nbn has developed a comprehensive methodology for modelling the end-to-end service availability of its network following the Australian Communications and Media Authority (ACMA) National Reliability Framework (NRF) and the MEF Forum Technical Specification 10.3. This has been applied to the end-to-end service availability of the different MTM networks including FTTN, FTTC and FTTP. The chart in Figure 7.14 shows the relative availability modelling for the FTTN, FTTC and FTTP delivered services.

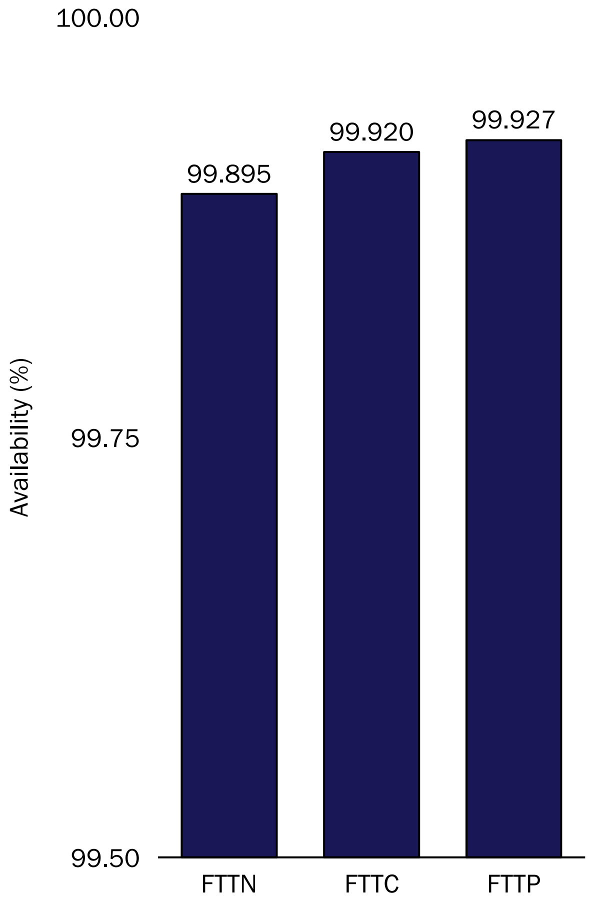


Figure 7.14: Modelled availability of end-to-end service availability [Source: nbn]

The chart shows that the upgrade from FTTN or FTTC to FTTP has been modelled to show an improvement in availability indicating that the upgrade should lead to an improvement in service reliability. The presence of the DSLAM in FTTN deployments and DPUs in FTTC deployments provide an additional point of network failure and as they are both active elements, they are also susceptible to power failure. In contrast, FTTP access networks are completely passive and do not require power between the exchange and the customers' premises. The improved availability aligns with feedback we have seen from other incumbent operators that have rolled out FTTP networks which have resulted in a reduction in overall fault rates. For example, in the UK, Openreach reported FTTP fault rates of less than half those of VDSL2-based access lines in the 12 months up to September 2021 in its November 2021 business briefing.

7.5 Analysys Mason assessment of nbn's decisions

Analysys Mason has been asked to review the prudency and efficiency of nbn's current methodology and processes for determining upgrades from FTTC and FTTN to FTTP under nbn's IAP. The analysis is required to consider whether such upgrade methodologies and processes provide a sufficient upgrade path to meet the anticipated bandwidth demand, functionality, flexibility and reliability up to 30 June 2040.

In Sections 7.2 and 7.3, we described and reviewed the processes and timelines being adopted for the IAP FTTN and FTTC upgrades to FTTP.

Analysys Mason's assessment of the methodology and processes for the upgrade from FTTN to FTTP

For the upgrade from FTTN to FTTP, the key activity is deploying fibre from the FTTN node to the DP in the LFN close to the end customer ready for the fibre lead-in to be installed on demand. The areas selected for the upgrade under the IAP are those with the most attractive return on investment determined by the comprehensive selection process known as RIPE. The FTTN to FTTP IAP programme is currently progressing to plan and on track to be completed by December 2023. We consider the methodology and processes being followed for determining FTTN to FTTP upgrades under nbn's IAP to be prudent and efficient.

Analysys Mason's assessment of the methodology and processes for the upgrade from FTTC to FTTP

As the FTTC network already makes use of the GPON network for backhaul from the DPU containing the FTTC VDSL2 DSLAM, with fibre already deployed in the LFN, the process for upgrading from FTTC to FTTP is more straightforward than for FTTN to FTTP. This will allow nbn to enable FTTP to be ordered for the majority of FTTC premises (approximately 900 000) by the end of 2022. The remainder of FTTC premises will be eligible for an FTTP upgrade in 2023 once additional solution elements have been designed, built and launched. We consider the approach to the original FTTC roll-out, in particular the use of GPON backhaul, plus the approach to the process for upgrading from FTTC to FTTP as prudent and efficient.

Analysys Mason's assessment of whether FTTC/FTTP upgrades meet anticipated bandwidth demand till June 2040

As we described in Section 7.3, the deployment of an FTTP network provides much greater scope for enabling higher-bandwidth services to be offered. Once the FTTP network is in place it is possible to meet the expected demand for increased bandwidth by simply upgrading the active equipment technology layer rather than needing to implement more costly passive network upgrades. We examined two scenarios, one based on an Analysys Mason forecast rate of traffic growth of 21% and one based on nbn's more conservative rate of 15%. We found in both cases that technology available today (or currently being developed by standards bodies, and able to be deployed by nbn when needed) is capable of meeting the projected bandwidth demands till June 2040. Making FTTP available across the network would represent a prudent and efficient approach to ensuring that nbn is able to meet anticipated bandwidth demand at least up to 2040.

Analysys Mason's assessment of whether FTTC/FTTP upgrades meet the functionality and flexibility required till June 2040

It is a requirement for nbn to support the functionality needed to support typical and expected future applications which typically include SIP-based voice services, interactive data services, and best-efforts internet access. Such applications are supported by the existing FTTN and FTTC technologies albeit with some limitations in headline speed to support the most bandwidth-intensive applications. The upgrade to FTTP will allow these applications to be supported with the added benefit that existing and new applications that require higher-speed connections will be more easily accommodated by the FTTP technology. Figure 7.6 and Figure 7.7 demonstrate the path being taken by other developed countries to supporting higher headline speeds over FTTP networks, and the FTTN and FTTC upgrade programme will mean that nbn follows the same path providing the functionality required till June 2040.

It is a requirement of nbn's SoE to ensure it maintains flexibility to adapt to and adopt future advancements and innovations. The upgrade to FTTP supports higher-speed connections while maintaining the underlying IP-based network that we expect to continue to be the basis of internet connectivity. We expect this combination will provide nbn with the flexibility its needs to support future advancements and innovations till June 2040 in a prudent and efficient way.

Analysys Mason's assessment of whether FTTC/FTTP upgrades meet reliability requirements till June 2040

As shown in Section 7.4, the move from FTTN and FTTC technology should see an increase in the end-to-end service availability that will lead to a more reliable network, meeting reliability needs up to 2040. Indeed, our experience is that FTTP networks have materially lower fault rates than the copper networks that precede them, which we expect will ensure that the FTTP upgrades will enable reliability expectations to be met till June 2040 in a prudent and efficient way.

Annex A Principal authors of this report

Dr Matt Yardley

Position: Managing Partner, Analysys Mason

Project role: Project Director

Qualifications: PhD, BSc (Honours)

Matt is one of Analysys Mason's most experienced consultants, having joined the company in 1997. He has been a leading adviser on broadband and business connectivity to private and public sector clients around the world. He is a member of the senior management team and the Head of Analysys Mason's Manchester office. He is the Project Director for this report which means that he will have the responsibility to deliver the quality expected by nbn.

Matt has over 24 years' advisory experience at Analysys Mason. He has directed hundreds of projects at Analysys Mason and participated in many more. Matt has advised at Board and Ministerial level on a wide range of telecoms issues for clients around the world. He has developed a particular specialism in strategy and policy development, as well as being a lead advisor to investors. He has directed strategy projects for telecoms operators and media companies; led regulatory projects for national regulatory authorities; developed national broadband plans and strategies for governments; provided commercial and technical due diligence support for investors; and acted as an expert witness in competition and commercial arbitration cases.

In recent years, he has led much of our technical and commercial due diligence projects for infrastructure investors in Europe, with a major focus on fibre networks covering B2C, B2B and pan-European assets. Examples projects include:

- Directing our work as technical adviser to the Irish government on its National Broadband Plan
- Directing a project for the UK Government (DCMS/BDUK) relating to its GBP5 billion 'outside in' procurement strategy, and regarding understanding potential constraints in the supply chain (ongoing)
- Directed a project for the European Commission on estimating the costs of the proposed gigabit connectivity targets
- Directed numerous buy-side commercial and technical due diligence projects for investors in fibre and fixed wireless access networks in the UK and Europe
- Directed a due diligence project for a European investor in relation to an established alternative fibre network operator in Western Europe

- Directed a strategy project for an alternative operator to assess the market opportunity for business connectivity in UK cities and towns
- Directed a project for a development company to assess the opportunity for a new kind of data-centre facility in the UK
- Directed a strategy project for a UK fibre operator in relation to fibre for multi-dwelling units (apartment blocks)
- Directed a series of strategy projects for a new-entrant fibre operator in the UK; the client has existing operations in several overseas markets
- Directed a project for a global pension fund to investigate the opportunity and risks associated with investing in a major European telecoms operator
- Directed a project for the UK's Department for Digital, Culture, Media and Sport (DCMS) to assess the benefits of expanding UK mobile coverage under different deployment scenarios
- Advice to a UK pension scheme in relation to UK market developments (investment, competition, regulation and policy issues)
- Directed a project for a UK operator on key market trends in the business connectivity sector
- Expert witness in a commercial arbitration relating to a fibre network deployed along a national railway network
- Directed a project for a European government to help it assess a submarine cable investment opportunity
- Directed a project for a global client to review the state of play on EU broadband targets and provide policy guidance on options to make progress
- Expert witness in two competition cases at the Competition Appeal Tribunal relating to the UK wholesale connectivity market
- Directed a series of projects for a UK operator in relation to the UK business connectivity market, covering leased lines, dark fibre and duct access for corporate access, and fixed and mobile backhaul
- Directed a broadband USO cost modelling project for DCMS and Ofcom
- Directed two projects for the Broadband Stakeholder Group on lowering barriers to infrastructure investment in the UK, covering fixed networks and 5G
- Directed a project for a UK operator on international benchmarking of passive infrastructure access (ducts and poles).

Dr Franck Chevalier

Position: Co-Head of Technology Consulting, Analysys Mason

Project role: Project manager

Qualifications: PhD, BEng. (Honours), IET Chartered Engineer, Member of Ofcom advisory committee for Scotland between 2008 and 2012

Franck was the project manager for this report, and as such was responsible for the day-to-day running of the project and preparation of the deliverables.

Franck is Analysys Mason's Co-Head[32] of Technology Consulting and, together with Rod Parker, is the most experienced technical consultants in the technical analysis of NGA networks. Franck has 20 years' experience in telecoms, spanning research, pre-sales and consulting. Franck's experience includes providing specialist strategic and technical advice to operators and governments. Franck managed the previous independent expert review of the efficiency and prudency of NBN Co's FTTN, FTTC, HFC, fibre, wireless and satellite network design, which was used by NBN Co to support its original Special Access Undertaking followed by its variation application to the ACCC in 2012 and 2016 respectively. Other notable projects of note include the following:

- Lead technical adviser to the Irish Government for the National Broadband plan since January 2015, which aims at delivering NGA broadband services to 100% of the population in Ireland
- Managing a project for Spark in New Zealand to assess the resiliency of its network
- Managing a number of projects for Chorus in New Zealand to review its FTTP and FTTN network design to ensure it was cost-effective and met the Crown's objectives for the ultra-fast broadband network and the rural broadband initiative network
- Working on a number of relevant projects for Ofcom (the UK regulator), including on GPON competition models. He managed a highly technical report on the capacity of future optical access networks, which was used by Ofcom to inform its review of wholesale local access. He also managed the duct survey projects commissioned by Ofcom in 2008 and in 2009, and the development of operational models in shared infrastructure, which resulted in Ofcom mandating duct and pole access in the UK to remove entry barriers for NGA alternative operators
- In addition, in the past three years, Franck has been involved in over 20 technical reviews of fixed national networks throughout the world.

Prior to joining Analysys Mason in 2005, Franck worked for Nortel Networks as the design authority for optical networks in the UK, France, the Middle East and Africa.

---

[32] The other Co-Head of Technology Consulting at Analysys Mason is Rod Parker mentioned below.

Rod Parker

Position: Co-Head of Technology Consulting, Analysys Mason

Project role: FTTC and FTTN upgrade to FTTP review lead

Qualifications: BEng. (Honours), IET Chartered Engineer

Rod was the technical advisor for this report. In this role, Rod primarily contributed to the review of nbn's design of its HFC networks.

Rod is Analysys Mason's Co-Head[33] of Technology Consulting and is one of the most experienced technical consultants in the technical analysis of HFC networks. Rod has 25 years' experience in telecoms, spanning system design, pre-sales and consulting. Rod's experience includes providing specialist strategic and technical advice to operators and governments. Rod was technical advisor on the previous independent expert review of the efficiency and prudency of NBN Co's FTTN, FTTC, HFC network design, which was used by NBN Co to support its variation application to its SAU to the ACCC in 2016 (which has since been withdrawn). Other notable projects include the following:

- Managing a study into the capability of cable network architectures, particularly focusing on their ability to deliver broadband services for the UK regulator, Ofcom. The study reviewed the capability of cable network architectures and the capability of the DOCSIS 3.0 specification and the potential capability of the DOCSIS 3.1 specification and its potential to meet evolving broadband needs over the coming years
- Leading a network due diligence project of an Indian broadband operator with HFC, GPON and Ethernet access networks, on behalf of a private equity company in India
- Developing a broadband deployment strategy for a South-East Asian fixed operator considering the relative merits of FTTP, HFC and FTTN network roll-out
- Managing the technical work stream for the development of an FTTP strategy for an electricity company in the Middle East
- Leading a detailed design review of an FTTN-based NGN (covering access, core transport and MPLS and voice network) for an incumbent operator in the Middle East which required an independent view of its design strategy
- Managing projects for Ofcom, the European Commission, the Welsh Government and the European Investment Bank examining areas relating to broadband network deployment, plus national mobile roaming and VoIP
- In addition, in the past three years, Rod has been involved in eight technical reviews of fixed national networks throughout the world.

Prior to joining Analysys Mason in 2006, Rod was a network design consultant in the UK and Asia, while working for Marconi.

---

[33] The other Co-Head of Technology Consulting at Analysys Mason is Dr Franck Chevalier mentioned above.

Annex B Declaration

B.1 Declaration

Analysys Mason has made all the inquiries that Analysys Mason believes are desirable and appropriate and 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.

Mr Matt Yardley for Analysys Mason Ltd

Date: 20 June 2022

Annex C Glossary of terms

The acronyms given here are those principally used in this report. Where an acronym is defined in another entry, it is given in italics.

ACMA	Australian Communications and Media Authority
ADA	Access deployment areas
ADSL	Asymmetric digital subscriber line
ATA	Analogue telephone adapter
AUD	Australian dollars
AVC	Access virtual circuit
BJL	Break out joint location
BNG	Broadband network gateway
CAN	Copper access network
CIR	Committed information rate
CoS	Class of service
CPE	Customer premises equipment
DA	Distribution area
dB	Decibel
DFN	Distribution fibre network
DJL	Distribution joint location
DL	Downlink
DP	Distribution point
DPU	Distribution point unit
DSL	Digital subscriber line

DSLAM	DSL access multiplexer
DWDM	Dense wavelength division multiplexing
EAS	Ethernet aggregation switch
EPON	Ethernet passive optical network
ESA	Exchange serving area
EVC	Ethernet virtual connection
FAN	Fibre access node
FD	Frequency division
FDA	Fibre distribution area
FDD	Frequency division duplexing
FDH	Fibre distribution hub
FEXT	Far-end cross-talk
FJL	Flexible joint location
FSA	Fibre serving area
FSAM	Fibre serving area module
FSAN	Fibre service access network
FTTB	Fibre to the building
FTTC	Fibre to the curb
FTTP	Fibre to the premises
FTTx	Fibre to the x
FWA	Fixed wireless access
GBE	Government business enterprise
Gbit/s	Gigabits per second
GNAF	Geocoded national address file
GPON	Gigabit PON

HD	High definition
HDTV	High-definition television
HFC	Hybrid fibre coaxial
IAP	nbn’s Investment Acceleration Program
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
Mbit/s	Megabits per second
MDF	Main distribution frame
MDU	Multi-dwelling unit
MPLS	Multi-protocol label switching
MTM	Multi-technology mix
NBN	National broadband network
NCD	Network connection device
NG PON	Next-generation passive optical network
NNI	Network-network interface

NRF	National Reliability Framework
OCR	Optical consolidation rack
ODF	Optical distribution frame
OFDF	Optical fibre distribution frame
OLT	Optical line terminal
ONT	Optical network terminal
OSI	Open systems interconnection
OTT	Over-the-top
P2P	Point-to-point
PCP	Primary connection point
PIR	Peak information rate
PoI	Point of interconnect
PON	Passive optical network
POP	Point of presence
PSTN	Public switched telephone network
QoS	Quality of service
RIPE	Return on investment process evaluation
RFP	Request for proposal
RGW	Residential gateway
SAU	Special access undertaking
SDU	Single-dwelling unit
SINR	Signal-to-interference noise ratio
SIP	Session initiation protocol
SME	Small/medium-sized enterprise
SMP	Splitter multi-port

SNR	Signal-to-noise ratio
SoE	Statement of expectations
SP	Service provider
TC_1	Traffic class 1
TC_2	Traffic class 2
TC_3	Traffic class 3
TC_4	Traffic class 4
TD	Time division
TDM PON	Time division multiplexing PON
TDM	Time division multiplexing
UNI-D	Data UNI
VDSL	Very-high-bit-rate digital subscriber line
VLAN	Virtual LAN
VoD	Video on demand
VoIP	Voice over internet protocol
WDM PON	Wavelength division multiplexing passive optical network
WDM	Wavelength division multiplexing
XG PON	10G PON