DEPLOYMENT COSTS OF RURAL BROADBAND TECHNOLOGIES

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The penetration of broadband services in rural areas is constrained by the cost of network deployment. Deployment costs are higher than in urban areas due to the lower population density. In this paper, we examine the deployment costs of three broadband access technologies; passive optical network (PON), fibre-to-the-node, digital subscriber line (FTTN DSL) and broadband wireless (WiMAX). We show that access technologies with a range of 60 km can reach most rural customers (99% in Victoria). We have demonstrated that long-range PON can provide error free service at this range.

Based on a number of assumptions, we have calculated the deployment cost of optimised networks for each technology for a range of rural areas in Victoria. A geographic information system was used to identify actual household locations and distances along roads. The deployment of optical fibre is the largest single cost component for both PON and FTTN DSL (and is significant for wireless) because the broadband access networks must be node based to span the distances needed. Consequently, the cost differences between the alternative technologies are not as great as might be expected.

For broadband services with access rates around 20 Mbit/s without contention, FTTN DSL offers the lowest deployment cost for most rural households. For 50 Mbit/s and above, PON offers the lowest deployment costs for rural households.

INTRODUCTION

The Australian Federal Government’s commitment to build a National Broadband Network (NBN) recognises the increasingly important role that broadband telecommunication services play in modern society. The Government is targeting a fibre-to-the-premises (FTTP) network, capable of delivering 100 million bits per second (Mbit/s) to 90% of Australian homes and business premises. Of the many issues involved in realising this goal, perhaps the most problematic is how to deliver broadband services to rural areas. Cost modelling for urban areas has been previously undertaken (Weldon 2003; Banerjee 2003) and has shown the benefit of passive optical networks for high capacity broadband provision. However the low population densities of rural areas and the greater distances involved pose problems for all broadband access technologies.

In this paper we examine three feasible access technologies and compare deployment costs in several rural areas in Victoria. For each area, we have used actual household and road locations provided by a geographic information system (GIS) (PSMA 2008a; PSMA 2008b; Pitney Bowes 2008) to design access networks that are optimised for each technology. We have compared the costs of these alternatives to measure the relative merits of each approach.
PASSIVE OPTICAL NETWORKS (PONS)

A PON provides a high capacity optical communication access path between a household or business premises and the edge of the core telecommunication network. As shown in Figure 1, dedicated fibres connect each of typically 32 customer premises to a passive optical splitter. The splitter combines the optical signals onto a single shared fibre terminating in an optical line terminal (OLT), at a telephone exchange. Sharing the fibre between the splitter and the exchange reduces the amount of fibre and the number of optical line terminals needed. It also results in the total capacity of the PON being shared amongst these customers. Eavesdropping is prevented by encryption of the downstream traffic.

The advantage of an access network based on fibre-to-the-premises is that it is future-proof. As demand grows, the capacity of the network can be increased by changing only the equipment at both ends of the fibre, i.e. in the exchange and in the home or business.

![Figure 1 Passive Optical Network (PON)](image)

**Figure 1** Passive Optical Network (PON)

A PON provides a high capacity optical communication path over a dedicated fibre from each customer's premises to a passive optical splitter which combines the signals onto a single shared fibre to the core telecommunication network. 

AT&T & Verizon (2009)

**TYPES OF PON**

Several types of PON have been deployed and new standards are evolving (see Table 1). In the Broadband PON or BPON (ITU 2001) the downstream direction from the OLT to the customer uses a wavelength of 1490 nanometres (nm) and the upstream path from the customer to the network operates at 1310 nm. The downstream bit rate is 622 Mbit/s, shared amongst the 32 customers; giving each an access rate of nearly 20 Mbit/s.

The Ethernet PON or EPON provides a usable capacity of 1 Gigabit per second (Gbit/s) (IEEE 2004) and is widely deployed. (The EPON is sometimes referred to as the Gigabit Ethernet PON or GEAPON). In the last two years, the Gigabit PON or GPON that provides a shared downstream bit rate of 2.5 Gbit/s (ITU 2004) has become more popular.

The 10 Gbit/s EPON is in the final stages of standardisation and should see some commercial implementation in 2010. Because 10 Gbit/s electronic and optical equipment is considerably more expensive than 1 Gbit/s or 2.5 Gbit/s equipment, the GPON standard may continue to be widely deployed for several years.
Even higher customer capacities can be provided by increasing the number of wavelengths on the fibre using wavelength division multiplexing (WDM) (Lin 2008). The entire capacity of a wavelength, 1 Gbit/s or beyond, can be made available to each of the premises. There is currently no standard for WDM PON and the components are considerably more expensive than for lower capacity PONs.

| PON Standards and their features | Downstream | Upstream |
|---------------------------------|------------|----------|
| ITU, 2001; ITU, 2004; IEEE, 2004 | 622 Mbit/s | 155 Mbit/s |
| Ethernet PON                    | 1 Gbit/s   | 1 Gbit/s  |
| Gigabit PON                     | 2.5 Gbit/s | 1.25 Gbit/s |
| 10G-EON                          | 10 Gbit/s  | 1 or 10 Gbit/s |
| WDM-PON                          | Not standardised | Not standardised |

Table 1 PON Standards and their features
PON Standards often provide some choice in parameters. This table contains the most common implementations.
ITU, 2001; ITU, 2004; IEEE, 2004

**RURAL BROADBAND SERVICE REQUIREMENTS**

To compare broadband access technologies fairly, we need to select a user bit rate and performance level. We also need to design and cost networks for each technology for a diverse range of rural locations.

**TYPES OF SERVICE**

High definition video is the currently the most demanding broadband service in terms of bit rate. A Blue-ray Disc streams data at 36 Mbit/s (Blue-ray 2004) while the VC-1 video coding standard uses 20 Mbit/s for full high-definition video (Microsoft 2006). The commonly used MPEG-4 video coding standard can operate at a variety of bit rates below 20 Mbit/s, depending on the quality of the video desired (ITU 2003).

As well as providing capacity for a high-definition video channel, people in a rural household may concurrently need capacity for other activities such as telephony, Internet surfing, downloading software and music and peer-to-peer file transfer. We have therefore assumed that the minimum capacity per household should be 20 Mbit/s, which is a relatively conservative estimate (Ram 2006).

Some video services such as free-to-air television are broadcast to multiple premises at the same time, which lowers the total traffic load on the network. However, future video-on-demand services will permit every customer to view a different high-definition movie or television station. To accommodate this, the rural network must be capable of providing different 20 Mbit/s services to every premises at the same time and without contention. This increases the load on both the access and core networks.

If the network is to cater for future growth, a higher access rate may be required so we have also performed a network cost comparison for an access rate of 50 Mbit/s. Although this is less than the NBN target of 100 Mbit/s for 90% of Australian premises, it is likely that most of the premises that are unable to achieve this target will lie in rural areas.
RANGE OF RURAL SERVICES

The cost of network deployment in rural areas is quite variable due to the diverse nature of country towns and their surrounding service area. For this reason, the concept of a typical rural town is not useful. Instead, we have used a geographical information system (GIS) to identify the precise locations of each household and each road in a number of country areas of Victoria. Networks are generally deployed along roadways, using existing power poles, to simplify access and to avoid issues with rights of passage over private property.

Figure 2 is a map showing how households are spread in the area surrounding the rural town of Nhill in western Victoria. Figure 3 shows an expanded view of the township of Nhill.

In Victoria, small exchanges are located approximately 15 km from the rural town centre however these exchanges typically have no broadband capability and lack the space required for racks of broadband equipment. The National Broadband Network may completely bypass these small exchanges since they will have to be significantly upgraded to be of any use. In our analysis, we have considered using only the larger exchanges in the rural towns and have assumed that any further infrastructure will need to be built as part of the new broadband network rollout.

The achievable household capacity can depend on the distance between the household and the exchange. Using the GIS, we delineated regions located within 20 km, 30 km, etc. by road from rural towns (see Figure 4) to determine the proportion of households that were located within each region. Figure 5 shows that while the standard PON range of 20 km can cover more than 91% of the households in Victoria, a range of up to 60 km extends coverage to 99% of households.
Figure 3 GIS view of Nhill
GIS map of the rural town of Nhill showing roads (thin lines) and households (dots).

Figure 4 20 km Service Area
GIS map of a rural area showing the service area (grey), available within 20 km by road from major telephone exchanges (yellow stars).
We have analysed the deployment costs of three broadband access technologies; passive optical network, fibre-to-the-node digital subscriber line and broadband wireless (WiMAX). We anticipate that, within the next two or three years, these will be able to meet our minimum requirement of a dedicated 20 Mbit/s to each rural household.

We have not considered hybrid approaches using multiple technologies. Such diversity will potentially increase costs but it may be quite sensible to use different technologies, inside and outside rural towns. Nonetheless we have adopted a single-technology approach to reduce the number of assumptions and to simplify network design.

PASSIVE OPTICAL NETWORK (PON)

We have assumed that GPON technology will be used with a maximum of 32 premises connected to each PON. In practice, PONs in rural areas may not be fully occupied since it is more economic to leave space for expansion than to deploy more fibre if growth occurs. However, this is not likely to be a significant issue since population growth in rural areas is generally slow. Also, the same issue of leaving spare capacity applies to all rural access technologies so we have assumed full utilisation in each case to make the comparisons more straightforward.

To reach all of the households in the areas we analysed, the PON technology must be capable of reaching up to 60 km from the exchange. The GPON standard permits a range up to 60 km but normally a maximum of 20 km is used (Davey 2006). Extensive work has been done on long-range PONs (Davey 2009) but most of the approaches require active elements such as amplifiers and regenerators at an intermediate point in the fibre or lowering the number of premises connected to the PON.

Our analysis of PON equipment, verified by laboratory experimentation, showed that by adding Raman amplifiers, it is possible to extend GPON range and provide error-free reception.
to 32 premises over a distance of 60 km (Lee 2009). This approach does not require any active elements in the field since the amplifiers can be located in the exchange.

Figure 6 illustrates an example of the layout of a PON fed from the telephone exchange in the rural town of Nhill in Western Victoria. This PON connects to the households that are furthest from the Nhill telephone exchange, i.e. the worst case. Optical fibre is deployed from the exchange to the splitter (red box) and then further fibre is deployed to each household served by the PON. Wherever possible, multiple fibres are gathered into a single cable to minimise deployment costs.

**FIBRE-TO-THE-NODE WITH DIGITAL SUBSCRIBER LINE (FTTN DSL)**

The second technology that we analysed is Fibre-to-the-Node with Digital Subscriber Line (FTTN DSL). This is the most commonly implemented broadband access technology in the world (OECD 2007). Its single biggest advantage is using the existing copper-pair telephone wires from the node to the house.

The signal attenuation of copper wire limits the bit rate and range of broadband signals. ADSL 2+, the latest version of ADSL has a maximum downstream capacity of 24 Mbit/s (ITU 2009). We assume that a FTTN DSL access network in rural areas can provide 20 Mbit/s at a range of approximately 2 km. We also assume that VDSL can provide 50 Mbit/s but at a range of only approximately 300 metres (ITU 2006). To provide service to households that lie outside these ranges, exchange equipment is placed in a node (typically deployed in a street cabinet) in the access network. With multiple nodes, all of the customers in the service area can be provided
with DSL at 20 Mbit/s or 50 Mbit/s. DSL nodes are connected to the telephone exchange by optical fibre; hence the name fibre-to-the-node.

To design a rural DSL network, it is necessary to place nodes within 2 km of the household furthest from the exchange. In sparsely populated areas, households are so far apart that multiple DSL nodes may be needed to cover the service area of a single PON. However in rural towns, hundreds of households may lie within 2 km of the exchange and no node may be required.

Figure 7 shows the worst case situation in Nhill; the same 32 households are served as in the above PON example. A total of 12 nodes are required and the length of fibre connecting the nodes to the telephone exchange is almost the same as in the PON approach.

Figure 7 DSL FTTN deployment in Nhill area
Optical fibre (blue line) connects the exchange to the DSL nodes (yellow box) and then existing copper pairs connect to each household.

WIRELESS BROADBAND NETWORK – WIMAX

Wireless is an obvious choice for broadband provision in rural areas since it is readily shared over large areas and requires no cable deployment to the households. The highest capacity wireless system available today is WiMAX which can provide up to 70 Mbit/s and has a maximum range of 50 km (WiMAX Forum 2005). In practice there is a trade off between capacity and distance, and we have assumed that WiMAX can supply 20 Mbit/s at a distance of up to 20 km. This will probably require tall antenna towers and high-powered radio equipment.

We assume that a WiMAX system can support only 3 households with an uncontended capacity of 20 Mbit/s. To spread the cost of the antenna tower across more households, we assume that each base station uses 16 sectors, i.e. 16 WiMAX systems on a tower with antennas pointing
in different directions, each capable of supporting 3 households. This increases the total number of households supported by each base station to 48.

To supply 50 Mbit/s to each household, it is necessary to reduce the number per sector to one. The base station can support a total of 16 households.

With 48 households on each base station, the backhaul capacity from the telephone exchange must be 48 x 20 Mbit/s = 960 Mbit/s. Each base station requires an optical fibre to the exchange to supply this capacity. It may be possible to use a wireless backhaul to the exchange however this is stretching the capability of the technology especially for remote base stations. In our cost modelling, we have used optical fibre backhaul.

Figure 8 shows the base stations located outside the town centre of Nhill. We need 10 base stations to cover the households in this area. A further 18 base stations are required inside the township of Nhill.

![WiMAX deployment in Nhill area](image)

**Figure 8** WiMAX deployment in Nhill area
Optical fibre (blue line) connects the WiMAX base stations to the telephone exchange.

**MODELLING DEPLOYMENT COSTS**

Our goal is to compare the deployment costs of PON, FTTN DSL and WiMAX systems in rural areas. By using the GIS information shown above, we are able to cost each technology for the same set of rural towns and the same service provision to each household.

The towns we have chosen are listed in Table 2. We have included the Melbourne suburb of Burwood to provide a baseline comparison with a typical urban area.
ASSUMPTIONS

To compare the costs of the alternative technologies, we need to make a number of assumptions.

The service switching, backhaul and core network equipment is common to all of the access techniques and we have excluded the cost of any necessary upgrades.

We have included the cost of terminating the access network at the customer premises and the cost of the modem which provides the telephony, video and Ethernet ports. The cost of distribution of the signals within the house has been excluded since it is likely to vary from house to house and may be borne by the householder. The cost of wireless customer premises equipment (CPE) is higher to account for the high-gain antenna that must be installed on the house roof to ensure good reception.

For DSL, we have assumed that the existing copper telephone cable can be used without modification for broadband access. In Australia, this copper is owned by Telstra and there may be some price to pay but it is difficult to quantify and subject to political and regulatory decisions. Since we are concerned with deployment, we have assumed zero cost.

Wireless systems require electromagnetic spectrum which has to be purchased or rented. Cost figures are available for previous spectrum purchases in Australia but estimating future costs is difficult. Based on these past costs we have concluded that the cost of spectrum per household could be a small fraction of the total WiMAX costs so we have set it to zero.

To minimise the costs of deploying optical fibre (for all technologies) we have assumed aerial rather than underground deployment. This is the technique used by Verizon in the USA and has been used by both Optus and Telstra in Australia when rolling out the hybrid fibre-coax network for pay television. In practice, some underground cabling will be needed where suitable poles are not available. We have used higher deployment costs inside towns to reflect this.

For wireline access, it is necessary to extend the wiring from the roadway to the actual premises. We have added an additional 100 metres of aerial deployment for households outside the town centre and an additional 15 metres inside towns.

Table 3 lists our other deployment cost assumptions.

COST CALCULATIONS

Using the above assumptions, we have calculated the deployment costs for each technology to serve all of the households both inside and outside each town. The costs have been categorised into five groups to more readily identify the relative contributions of each section of the network.
Table 3 Cost Assumptions
Assumed costs for components of each broadband access technology.

| Component                                             | Cost (US$) |
|-------------------------------------------------------|------------|
| Equipment housing in exchange                         | 30,000     |
| Optical line card in exchange                         | 4500       |
| Raman pump amplifiers                                 | 20,000     |
| Optical fibre cost/km (many fibres)                   | 2000       |
| Optical fibre cost/km (few fibres)                    | 1000       |
| Fibre deployment/km (in town)                         | 30,000     |
| Fibre deployment/km (outside town)                    | 10,000     |
| PON ONU with install                                  | 250        |
| PON splitter, including installation                  | 1600       |
| DSL modem (zero install cost)                         | 100        |
| DSL node (in town)                                    | 20/house   |
| DSL node (outside town)                               | 5000       |
| DSL node installation (with power)                    | 10,000     |
| Wireless tower                                        | 40,000     |
| WiMAX equipment /sector                               | 10,000     |
| Wireless modem and install                            | 1400       |

PASSIVE OPTICAL NETWORK

Figure 9 shows the calculated cost of PON network deployment for each of the areas considered. Note that fibre deployment dominates the total cost of passive optical networks in rural areas. Each town is represented by a different colour and the cost of fibre deployment rises as the household density (hh/km$^2$) of the town decreases.

The second largest cost is the optical fibre cable itself. The cost of the remote node is very small since the splitter is unpowered and is shared by the 32 households served by each PON.

![Figure 9 PON cost components at 20 Mbit/s](image)

Costs vary widely between the components of a broadband PON installation in rural areas.
FTTN DSL

By comparing Figures 6 and 7 above, we can see that the amount of fibre required by a fibre-to-the-node solution is similar to that required by a PON solution, especially in less densely populated areas. For this reason, fibre deployment also dominates the cost of FTTN DSL as shown in Figure 10.

![Figure 10](image)

**Figure 10** FTTN DSL cost components at 20 Mbit/s

The cost of fibre deployment also dominates FTTN DSL in rural areas.

The remote node costs become significant since many nodes are required to cover households outside the rural towns and the costs of the powered DSL node equipment and its installation are significant.

WIMAX WIRELESS BROADBAND

The cost components for wireless broadband access networks (Figure 11) are quite different from PON and FTTN-DSL. The wireless cost is dominated by the remote node because the base station is expensive and this cost is shared by relatively few households. Because the base stations are limited by the capacity of the WiMAX system rather than by the range of the equipment, the cost per household is independent of the household density. Only in extremely sparsely populated areas would it be impossible to find 48 households within the range of a base station.
WiMAX wireless broadband cost components at 20 Mbit/s

WiMAX costs are relatively uniform for the different towns because WiMAX is limited by the capacity of the base stations rather than by distance.

COMPARISON OF TOTAL COSTS

Figure 12 shows the total cost for each technology for each of the rural towns we considered.

With a 20 Mbit/s uncontended broadband service, WiMAX wireless broadband is cheapest in the most sparsely populated areas. However, very few households in Victoria fall into this region. For the majority of rural households and for all urban households, fibre-to-the-node,
digital subscriber line has the lowest deployment cost due to its use of the existing copper telephone network.

In this cost analysis, we have assumed that a capacity of 20 Mbit/s is available to each household without contention. If we allow contention, the wireless access network lends itself to supporting more customers per base station and hence lowers the cost per household. The consequence will be a quality of service that depend on the activities of other households and potentially restricts the availability of high bit rate services.

As expected, the total cost for both PON and FTTN DSL decreases as the population density increases. A comparison of the PON costs for the urban area of Burwood showed good agreement with the Verizon estimate of US$1350 per household by the year 2010 (Verizon 2006).

![Figure 13 Total cost of 50 Mbit/s broadband access](image)
Passive optical network deployment costs are lowest for 50 Mbit/s access rate in all rural areas.

Because a GPON can provide a dedicated 70 Mbit/s capacity to 32 households, the deployment costs of 20 Mbit/s and 50 Mbit/s are the same for PON. However, the FTTN DSL solution must use VDSL technology which is more expensive than ADSL. Since the range of VDSL is limited to 300 metres, the number of nodes required increases dramatically. Outside the rural towns, the households are often more than 300 metres apart and a VDSL node can serve only one household.

At this bit rate, WiMAX also becomes very expensive since only 16 households can be served by each base station.

**CONCLUSION**

The cost of broadband access in rural areas is considerably higher than that in urban areas due to the much lower rural population density. The deployment of optical fibre is the largest single cost component for both PON and FTTN DSL (and is significant for wireless) because broadband access networks must be node based to span the distances needed. Consequently, the cost differences between the alternative technologies are not as great as might be expected.
Our analysis of household distribution has shown that most of the rural customers in Victoria lie within 60 km of major existing network infrastructure. We have demonstrated that long-range PON can provide error free service at this range.

Based on a number of assumptions, we have shown that for 20 Mbit/s dedicated broadband services without contention, FTTN DSL has the lowest deployment cost for most rural households. The deployment cost of WiMAX is higher than PON and FTTN DSL except where household density is very low.

At 50 Mbit/s dedicated and uncontended, PON has the lowest deployment costs. WiMAX is more costly to deploy than PON and FTTN DSL even at very low population densities.

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Cite this article as: John Ellershaw, Jennifer Riding, Alan Lee, An Vu Tran, Lin Jie Guan, Rod Tucker, Timothy Smith, Erich Stumpf. 2009. ‘Deployment costs of rural broadband technologies’. Telecommunications Journal of Australia. 59 (2): pp. 29.1 to 29.16. DOI: 10.2104/tja090029.