NBN Capacity Requirements

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1. Introduction

Australia's National Broadband Network (NBN) is one of the most visionary, Government and industry funded national infra-structure programs since the end of the 2nd World War when the Snowy Mountains Hydro-Electric Scheme was conceived. The world has changed a lot since those days – now it is a "market driven" economy for which all investments, both Government and private are expected to yield a return over some reasonable period of time. Additionally, we now live in a very competitive enterprise market where the needs of the few (business enterprises and their investors) sometimes seek to outweigh the needs of the many. As a result, considerable propaganda is appearing in the press and from politicians. Many are calling for a cost-benefit analysis to justify the NBN investment whilst the ACCC are rightfully saying that it is up to Governments to make the long term investments that businesses are unwilling to make.

The purpose of this paper is to help verify, irrespective of the propaganda, that the Government's NBN vision is justified. This paper will cut through the propaganda by presenting multiple sources of statistical data on capacity growth; broadband capacity requirements based on multimedia device performance and human capabilities to receive and process information; and realistic applications that are truly enabled by faster broadband to mobiles and the premises, both residential and non-residential. Finally, a short review of wireless and Fibre to the Premises (FTTP) network architectures for the NBN is presented to demonstrate how the next generation broadband network will deliver by 2020, the mobile and fixed applications and capacities required.

Whilst a cost/benefit analysis is also required to put the nay-sayers to rest, it is expected that the information presented in this paper will contribute to this cost/benefit analysis. Additionally, a mathematical model and packet queuing analysis of the end-to-end national network is required to determine the core infra-structure upgrades needed to meet packet throughput and delay requirements of next generation applications and devices. For those mathematicians who will pursue this analysis for NBN Co and the Retail Service Providers (RSPs) such as Telstra, Optus, VHA and others, it is hoped that this paper provides a well-informed technical framework for their network modeling and analysis so that we avoid the potential garbage-in / garbage-out scenario.

2. Statistical Analysis

When all the statistics line up - their conclusion is undeniable

The purpose of this section is to present and compare multiple sources of statistics regarding network capacity growth over time so that an unbiased conclusion can be reached regarding the expected data rates required to the premises by 2020 when the NBN rollout is substantially complete.

2.1 Residential Modem Data Rates and Growth

The first network capacity vs time graph shown in Figure 1 is based on Infonetics data[1]. The graph plots the actual US fixed-line residential offered data rates for residential modems used between 1987 and 2009. The Compound Annual Growth Rate (CAGR) for this period is ≈52%. Infonetics then forecast the likely years, being 2014 and 2018 respectively, that the offered data rates will reach 100Mbps and 1Gbps. It is the purpose of the Applications Analysis section of this paper to determine if this modem data rate growth rate will need to continue post 2010.

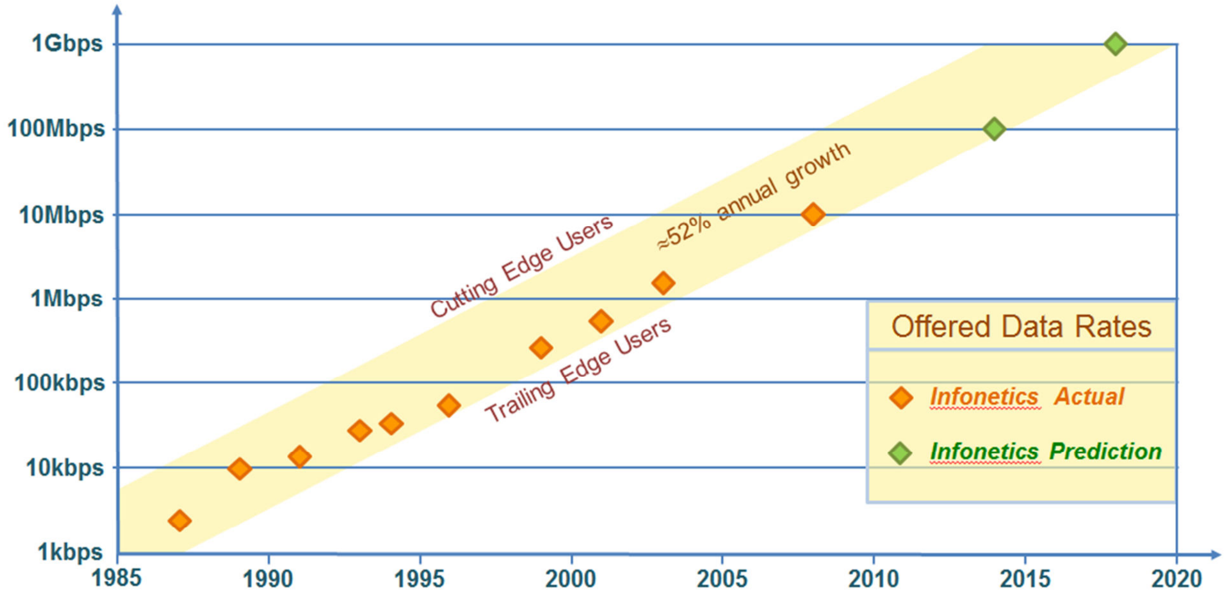


Figure 1 Fixed-line US residential "offered data rate" trends from 1985 to 2020

Figure 2 presents similar network capacity growth trends over the period 1980 to 2010 for US residential modems, based on a 2nd independent source, being Technology Futures Inc[2]. In this case, the CAGR is estimated to be 42%. A technology jump is shown in this graph from 56kbps dial-up modems (which unfortunately some remote communities still have) to broadband modem technologies such as ADSL and Cable modems. Whilst the average growth rate is lower, extrapolation of the broadband growth trend still indicates that 1Gbps may be required to the premises by 2018 (due to the higher broadband modem rates plotted).

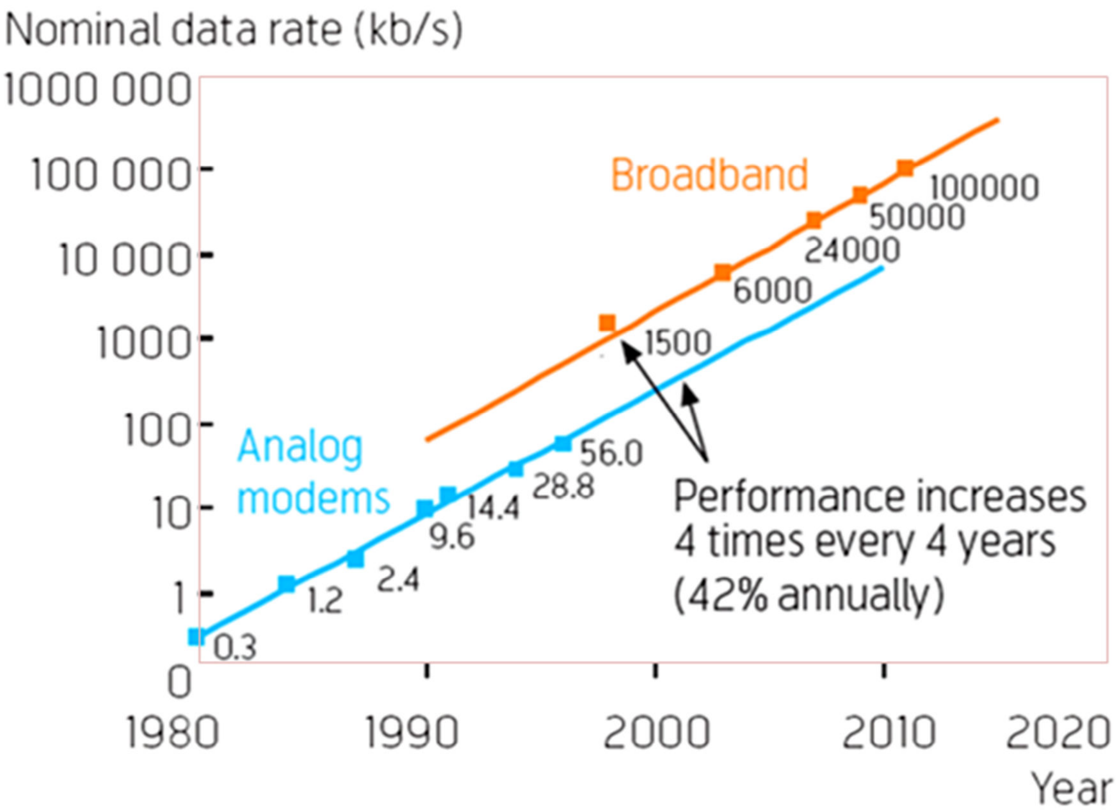


Figure 2 Trends in US residential access data rates (Technology Futures, Inc.)

2.2 Submarine Optical Cable Network Capacity and Growth

In the DCITA International Internet Connectivity (IIC) Report[3] dated 31May2004, it is shown that over the period 1997 to 2003, the CAGR for international traffic was approx. 70%. The US traffic represented 80% - 95% of all international traffic to/from Australia. Much of non-US traffic such as to/from Europe also passed through the US. For Internet traffic between the US and Australia, the level of asymmetry was 40% to the US and 60% from the US.

In February 2008, Pipe Networks' Half Year Investor Presentation[4] illustrated the "Historical used international bandwidth for Australia, 2002 – 2007". This graph, prepared by TeleGeography Research for Pipe Networks shows that there has been 65% CAGR in international bandwidth from 2002 to 2007, with over 75% being Internet traffic; less than 5% being switched voice traffic; and the remaining 20+% being private business and government data traffic.

The following Figure 3 titled "Worldwide international bandwidth growth, 2002-2009" from the TeleGeography Global Bandwidth Research Report GB10[5], illustrates the global international traffic growth from 2002 to 2009. Over this entire period, the CAGR is ≈50%, however, over the period 2007-2009; the annual growth rate had risen to between 60% and 65%.

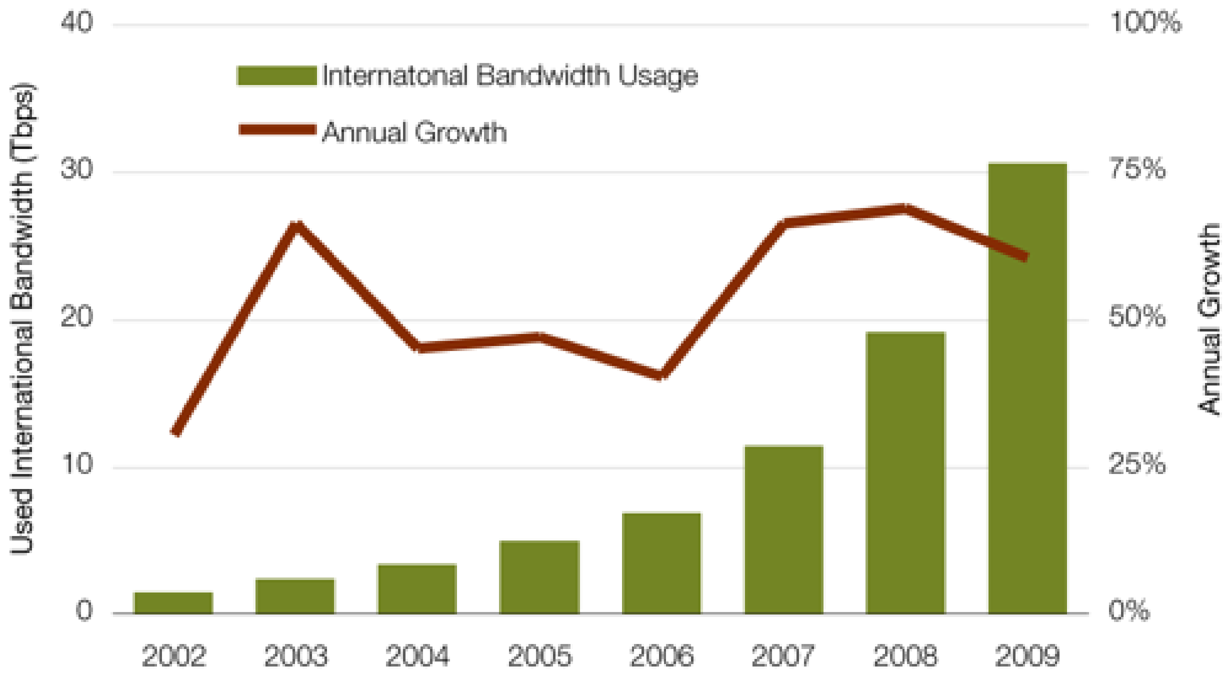
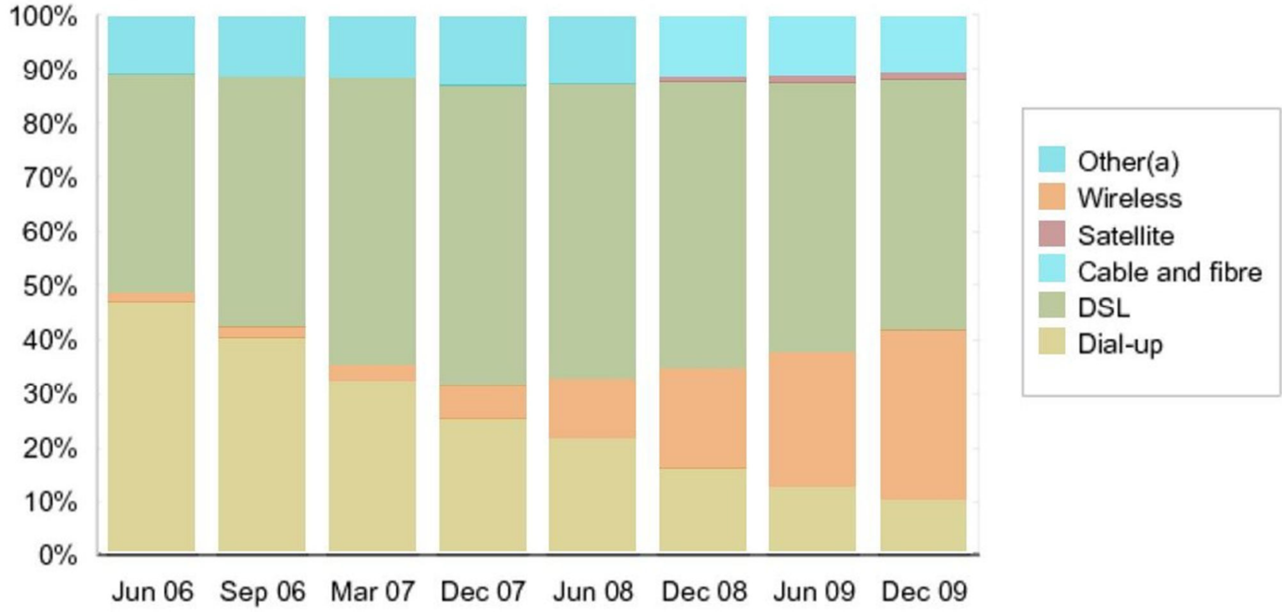


Figure 3 Worldwide international bandwidth growth, 2002-2009

The much higher growth rate over the past 3 years for international bandwidth usage can be largely attributed to the growth of broadband Internet traffic to/from AsiaPac. Given the growth rates for 2008-2009 shown in Figure 3, it is reasonable to extrapolate the Pipe Network's data to conclude that Australia's annual growth rate in international traffic continued at the 65% level for this entire period 2002-2009.

2.3 Australian Fixed-Line and Wireless Capacity Growth

Given the above sources and trends, it is clear that over the period 1997 to 2009, there has been consistently high growth in international traffic to/from Australia, exceeding 65% CAGR. This is equivalent to 150x capacity increase per decade. This traffic had to come from and go to somewhere (such as businesses, homes, schools and increasingly mobile devices after 2007 as per Figure 4) and we know that 75% of this traffic was Internet based. For an already broadband-connected country such as Australia, a larger proportion of the 65% annual capacity growth rate can be attributed to increased broadband capacity per connection with a lesser proportion attributable to an increased number of broadband connections. This is substantiated by Figures 4 and 5 which illustrate that whilst the proportion of Internet subscriber connections post 2007 has become increasingly wireless, the actual downloaded capacity attributed to them is only 15.4% with the large majority (84.6%) of downloaded capacity going to the premises via fixed-line broadband.



Prior to December 2008, "**Other**" includes satellite, cable (HFC) and fibre (FTTP)

Figure 4 Proportion of subscribers by connection type

Based on Source: ABS 8153.0 - Internet Activity, Australia, Dec 2009

Volume of data downloaded (b)	**Dec-08**	**Jun-09**	**Dec-09**		**% Total**
Dial-up	1,079	466	325	Tbytes	84.6%
Fixed line broadband **(c)**	na	na	114,426	Tbytes	
Wireless broadband **(d)**	na	na	20,923	Tbytes	15.4%
Total download volume	81,352	99,249	135,674	Tbytes	100.0%

(b) Data collected for the 3 month period prior to the reference date.
(c) Fixed line broadband includes DSL, cable, fibre and other wired broadband.
(d) Wireless broadband includes satellite, fixed wireless, mobile wireless via a datacard, dongle or USB modem and other wireless broadband. Excludes subscriptions via a mobile hand-set.

Figure 5 Volume of data downloaded

Based on Source: ABS 8153.0 - Internet Activity, Australia, Dec 2009

Note that in Figure 5, wireless broadband does not include 802.11 WiFi within the premises. Today, such on-premises wireless networks are mostly connected by a wireless router to fixed-line broadband networks such as ADSL, Cable and Fibre. This is often a point of confusion, so going forward WiFi within the premises will be referred to as a “Cordless” technology which connects to a fixed-line broadband connection, with “Wireless” technology corresponding to 3G/4G connections to a carrier’s base station outside the customer’s premises. This is consistent with the basis of the statistical data presented in Figures 4 & 5. For the case (referred to as “MiFi”) where WiFi connects via a router to a 3G/4G base station, then this will also be considered a “Wireless” connection.

It is also evident from Figure 5 that the annual growth rate in downloaded Internet data for 2008 to 2009 is 67% which further substantiates other annual capacity growth sources.

In summary, the following annual capacity growth rates have been identified from various sources:

Infonetics US Residential modem data rates (1987-2009):	**52%**	
Technology Futures US Residential modems (1980-2009):	**42%**	
DCITA Submarine Capacity to/from Australia (1997-2003):	**70%**	(includes connection growth)
TeleGeography Submarine to/from Australia (2002-2007):	**65%**	(includes connection growth)
TeleGeography Submarine International (2008-2009):	**65%**	(includes connection growth)
Australian Bureau Statistics data downloads (2008-2009):	**67%**	(includes connection growth)

2.4 Two Broadband Issues: Connectivity and Capacity

National network capacity CAGR, which is expected to equate to the submarine capacity CAGR figures listed in the previous section, can be attributed to both annual "Connectivity Growth" and "Capacity Growth per Connection". Connections are a combination of fixed line, fixed wireless and mobile wireless. In Australia, some of the wireless connection growth evident from Figure 4 can be attributed to our primary carrier Telstra failing to adequately extend the reach of their ADSL network with Fibre to the Node (FTTN) technologies as the US have done. Evidence of this can be found at the following Internet references: WyndhamWaters[6]; FraserCoast[7]; and AmberGate[8].

As evident from Figure 4, wireless connectivity growth has been high since 2007 due to the growth in number of mobile devices such as Laptops, iPhones and now iPads, however, Figure 5 shows that wireless connectivity only contributed to 15% of the downloaded Internet data capacity which is partly due to the capacity limitations of the 3G wireless network. Growth in wireless connectivity to overcome inadequate FTTN/ADSL connectivity (rather than mobility) arises because premises more than 3km from the Telstra Exchange cannot easily get ADSL-based fixed-line broadband. In Australia, it is now too late to fix this problem with a FTTN based NBN since the forecast capacities going forward would require FTTN cabinets to be located within 100 metres of the premises, which in turn would require a lot more power and almost as much fibre as the now-proposed, passive FTTP based NBN. To a large extent, the same argument applies to a fibre-fed, picocell based fixed-wireless broadband solution, however, this argument does not apply to mobile-wireless broadband.

The bottom line is that we as users need next generation fixed-line broadband to handle the capacity growth and associated 85% data downloads shown in Figure 5, as well as next generation (4G) wireless for mobile broadband capacity growth and associated 15% data downloads. Additionally, if capacity growth trends continue unheeded, then network upgrades post 2020 will continue to be required, consequently, it is important that the NBN architecture and technology choices take account of the need for future capacity upgrades as foreshadowed by the statistics.

2.5 Expected Capacity Demand by 2020 based on Statistical Analysis

Even a pessimistic annual growth rate of 26% will result in 10x capacity increase in 10 years. Using 10Mbps ADSL2+ as a 2010 baseline capacity for fixed-line connections to the premises, then by 2020, when the NBN fibre and wireless rollout is to be completed, at least 100Mbps fixed-line or fixed-wireless premises connections will be required. A more likely annual growth rate of 52% as shown in Figure 1 will result in an expected connection data rate to the premises of 650Mbps. An even more optimistic (but not unrealistic) 65% growth rate (as per Figures 3 & 5) will result in an expected connection data rate to the premises of 1.5Gbps by 2020, which would put Australians in the "Cutting-Edge" user category shown in Figure 1. Note that the connection data rate that will be available using NBN Co's FTTP-based "GPON" equipment is 1Gbps peak and 100Mbps average.

The benefit of a new FTTP-based wire line NBN infra-structure is that it easily supports 100Mbps average premises capacity by 2020, as forecast by pessimistic modem data-rate growth statistics, while easily catering for large increases in capacity demand over the 50-year life of the new NBN infra-structure. Using the installed fibre infra-structure, over 100Gbps capacity per premises can be supported, should this be required due to new, significantly higher quality and as yet unimaginable broadband intensive applications.

3. Applications Analysis

Next Generation Broadband - It's more about Quality than Quantity

Just as PC-based software applications require more and more memory and processing capacity, so too will future Internet-based multimedia applications require ever-increasing memory and transmission capacity. This will be driven by user-demand for greater quality and breadth of experience as evidenced by the rapid take-up of High Definition (HD) TVs and HD PC screens and the introduction of first-generation 3D HDTV faster than many of us expected.

Of course going forward, we will have access to an ever increasing number of applications, multimedia content and distributed data bases. These applications and content availability will drive up the total capacity requirements of the global Internet and associated multimedia servers, but they will have less impact on the capacity requirements of the premises and mobile connections. It is the expected quality of the experience associated with these applications that will drive up the capacity requirements of broadband connections, on the basis that most users generally only process one or two applications at a time.

There will of course be the cutting-edge users who will let their PC(s) process many bandwidth-intensive applications simultaneously in the background, while they sit back and experience one or two multimedia applications while they wait for the results.

3.1 Previous "Next Generation" Applications Forecasts

Applications forecasting is an ongoing process due to continued advancements in processor speeds, memory sizes and broadband connection data rates that drive the next generation of applications. Forecasts as recently as 2006 are now already out of date based on what we now know and experience. For example, Harrop and Armitage[9] estimated that a household of five people would require between 58Mbps and 113Mbps information capacity based on a range of video, audio and data applications.

They identified HDTV as the most bandwidth demanding application, but being written in 2006, it did not take the increasing bandwidth requirements of first generation, 3D Stereoscopic HDTV and future 3D Holographic HDTV into account. It also assumes increasing video compression ratios which is contradictory to user needs and trends towards increased TV video quality, as illustrated in Figure 6. Of course lower data rate video profiles are needed for mobile devices due to the bandwidth limitations of wireless connections and hence greater video compression is required.

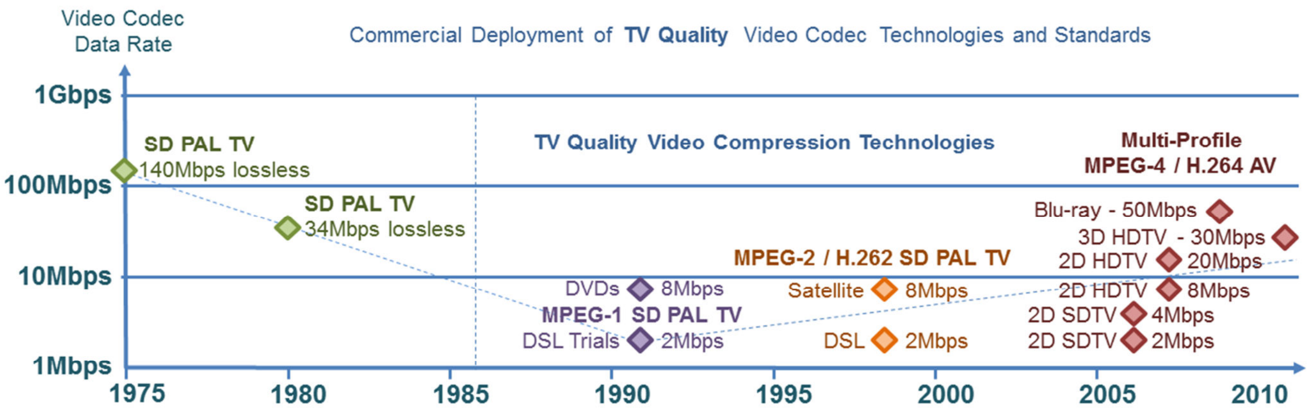


Figure 6 TV video coding evolution to higher quality – not lower data rates

3.2 Bandwidth vs Compression

For the past 30-40 years, there has been a push-pull effect between image/audio/video bandwidth and compression technologies. The bandwidth-push has strived to improve quality whereas the compression-pull has tended to constrain quality. The compression rate per application should ideally match the capacity of the human brain to perceive the information, no more and no less.

Over the past two decades, insufficient bandwidth to the premises has resulted in increasing image, audio and video compression rates using more efficient coding techniques – which have also resulted in improved quality for the same bandwidth. However, along this journey, we as users have increasingly sacrificed quality for access to more content. Going forward, users don't necessarily need more content, but they do want better quality. As a result, compressed content data rates are now increasing (not decreasing) due to the need for better video quality (viz, 2D-HD & 3D-HD); audio quality (viz, HiFi with surround sound); and image quality (eg, 10-20 MegaPixel photos). These factors are in turn contributing to the annual increase in fixed premises and mobile connection data rates.

3.3 Connection Symmetry

Going forward, broadband connections need to become more symmetric due to users generating more multimedia content and not just downloading it. Greater user participation in the generation of content will drive a commensurate increase in upstream data rates. The first roll-out NBN and subsequent generations of equipment connected to it needs to take this into account. To this end, the FTTP based NBN supports an asymmetry ratio of 2:1 (downstream/upstream capacity) which is significantly (5x-10x) better than existing ADSL, Cable Modem and 3G wireless connections. Additionally, the FTTP based NBN supports future upgrades to full symmetric (1:1) connections.

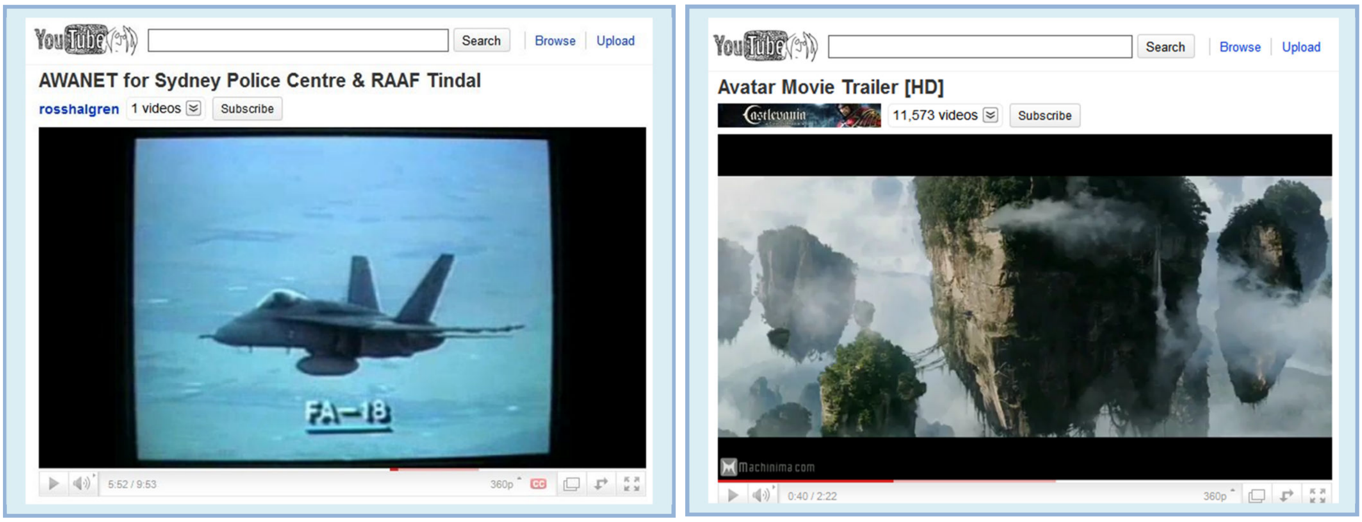
3.4 Current Applications that will drive Premises, Mobile & Network Capacity

There a many new devices and applications that are already driving up premises, mobile and overall network capacity. Examples include:

- **Internet Entertainment Meets TV** - such as Over the Top (OTT) Video-on-Demand (VoD) which is downloaded over the Internet to a Set-Top-Box and HDTV. Telstra's T-Box™ and iiNet's FetchTV are examples. With today's HDTV video quality and 10Mbps fixed-line downstream rates, a typical video can be downloaded within a few minutes and viewing can commence before the download is complete. The Telstra T-Box™ for example enables viewing of YouTube videos on your HDTV, such as shown in Figure 7a. As a result of such OTT Internet TV services, YouTube HD quality videos of 1Gbyte size can now be uploaded and downloaded, as shown in Figure 7b. Such HD YouTube videos stream at an average data rate of approximately 13.3 Mbps for 10 minutes video duration.

  Unlike Telstra's VoD service which is unmetered in terms of BigPond data usage, access to the YouTube VoD service is metered. As stated in Telstra's T-Box™ User Guide[10], the premium BigPond Internet plans are recommended for faster downloading and a BigPond Cable or ADSL fixed-line connection is required. If you exceed your monthly data usage allowance on your BigPond broadband plan, the Telstra VoD movies may take an excessive amount of time to download. Downloads can also be slow if WiFi cordless connections rather than Ethernet 100BaseT premises cables are used within the premises and if the WiFi signal strength is poor. Note that bandwidth intensive video services like this don't work on lower capacity, 3G wireless Internet connections since if too many subscribers did so, the total average capacity demand would be too great for the local Telstra 3G cell tower to deliver while still providing an adequate service to other Telstra 3G mobile users.

  Just this application alone indicates that if three TVs / PCs in the home were simultaneously being used to watch YouTube HD videos, the premises fixed-line capacity required today would be 40Mbps average, providing more evidence that 100Mbps is just around the corner.



a. *Standard Definition* b. *High Definition*

Figure 7 YouTube now available on Telstra T-Box and in HDTV quality

- **Digital Cameras and On-Line Photo & Video Sharing** – These days, just about every mobile phone includes a 3-5 MegaPixel digital camera and increasingly, video recording. This market is led by mobile devices such as the Apple iPhone4. For example, the iPhone4 with both WiFi cordless and 3G wireless connectivity enables photos and videos to be immediately uploaded from virtually anywhere to social Internet sites such as Facebook, Picassa and YouTube. The upload application may as a default option, further compress the photo or video to reduce upload/download capacity/duration and to save on-line storage space, but increasingly, user-demand for better quality is resulting in photos and videos being uploaded with their original digital quality, ie, a 5MegaPixel photo is stored as a 5MegaPixel photo and all the user's friends get to see the photo/video in its original format.

  It has only been a matter of time for the digital camera market to catch on to the benefits of WiFi-cordless and wireless technologies. One of the first is the Samsung ST80 Wi-Fi (802.11b/g) enabled 14MegaPixel digital camera (Figure 8), announced in July 2010[11]. This camera also includes HD video recording using H.264 video/audio compression and both photos and videos can be uploaded immediately to Facebook, Picassa and YouTube.

Figure 8 Samsung Wi-Fi enabled ST80 Digital Camera & HD Video Recorder

In terms of on-line network storage and capacity, a 14MegaPixel digital photo stored in uncompressed TIFF format (with 24 bits/pixel) requires 42Mbytes per photo. With JPEG compression, this can be reduced to 6Mbytes per photo. To upload a high quality 42Mbyte photo in 10 seconds requires a WiFi hot-spot & fixed-line connection data rate of 33.6 Mbps.

The introduction of stereoscopic 3D HDTV has been quickly followed by the introduction of Panasonic's world-first 3D HD Camcorder, announced in Jan 2010. Once products like this drop in price to a level that the average consumer can afford, demands on Internet capacity will be 2-3x greater than they are today using 2D HD cameras such as the Samsung ST80.

It's a small evolutionary step from the technology now available to imagine a future holiday in South Africa with your family and friends back at home watching on their 3D HDTV, a live video (with audio commentary) that you are taking on your 3D HD camcorder fitted with WiMAX broadband wireless connectivity, of an approaching lion or elephant – as if they were there with you, sharing the experience.

- **Video Calling** – the latest mobile phones such as the iPhone4 support high quality video calling using H.264 compression. On release of the iPhone4 by Apple, their "FaceTime" video chat application was announced at the same time. Whilst the compressed video/audio data rate is only a few hundred kbps for video calling applications, Apple's FaceTime video chat application works only via a Wi-Fi premises or hot-spot and associated fixed wire line connection at each end. "We need to work a little bit with the carriers" before video calling can migrate to cellular data networks[12], Steve Jobs (CEO of Apple) admitted due to the potentially crippling effect on AT&T's cellular network.

  As for Telstra's T-Box application, carriers can't afford to have bandwidth intensive video applications consuming their 3G wireless capacity. In the case of video calling, it is not the downstream bandwidth that is the problem; it is the identical upstream bandwidth usage which is more of an issue due to the highly asymmetric design of 3G wireless networks. Of course, the software hackers have managed to defy Apple's 3G restriction using a jail-breaking application (which by the way voids the warranty of the Apple device). However, this only works for a few Facetime users at a time on the same wireless cell. Jail-breaking software does not overcome the bandwidth crippling issue for 3G wireless networks – it just exacerbates it. Nor does it overcome the high 3G wireless capacity usage costs.

- **Working, Training and Education from Home** – More time spent working from home is now common-place and is reducing stress, reducing travel time and reducing or potentially reducing various costs, including: parking fees; speed-infringements; road tolls; traffic accidents; car insurance; child-care; restaurant meals; and the cost of local and global infra-structure and resources such as road construction, road repairs and last but definitely not least, the consumption and cost of limited resources such as oil. Businesses have adjusted to core days and core times for face to face meetings and social interaction. At home, we can upload and download documents and large files via fixed-line or wireless connections. This is enhanced by PC/Laptop based video conferencing and iPhone4-based video calling applications - both of which perform better and at lower cost on WiFi / fixed line connections.

  Whether at home or the office, high speed broadband enables on-line virtual-presence for meetings and discussions with peers, both locally, inter-state and overseas. Stereoscopic 3D HD video cameras are already available and their migration to video conferencing applications will further enhance the virtual presence experience to the extent that working from home will become the norm, with only a couple of core periods per week at the office.

  The above benefits are increasingly being realized for training and education from home. Whilst this is the norm for remote communities due to the exacerbated travel issues, it is becoming more relevant to city dwellers as well. The additional infra-structure cost benefits of increased training and education from home will include the long-term deferment in the construction of more secondary school; TAFE; and university buildings for example.

- **Surveillance Video** - Greater access to more CCTV cameras[13] from home connected to clever RTA traffic management data bases (Figure 9) is allowing us to better plan our trip to work on those core days that we do need to travel. Traffic accidents are now known in advance before we leave home and wasted time, fuel and other travel costs are avoided.

Currently the RTA's live CCTV video is only available to the public as still-images that are refreshed every 60 seconds. However, with ubiquitous high speed broadband, they can be made available to both fixed and mobile devices as live, good quality colour video. The quality of the video will depend on whether the user has a WiFi/fixed-line or wireless broadband connection (such as to your integrated GPS map and video screen in the car).

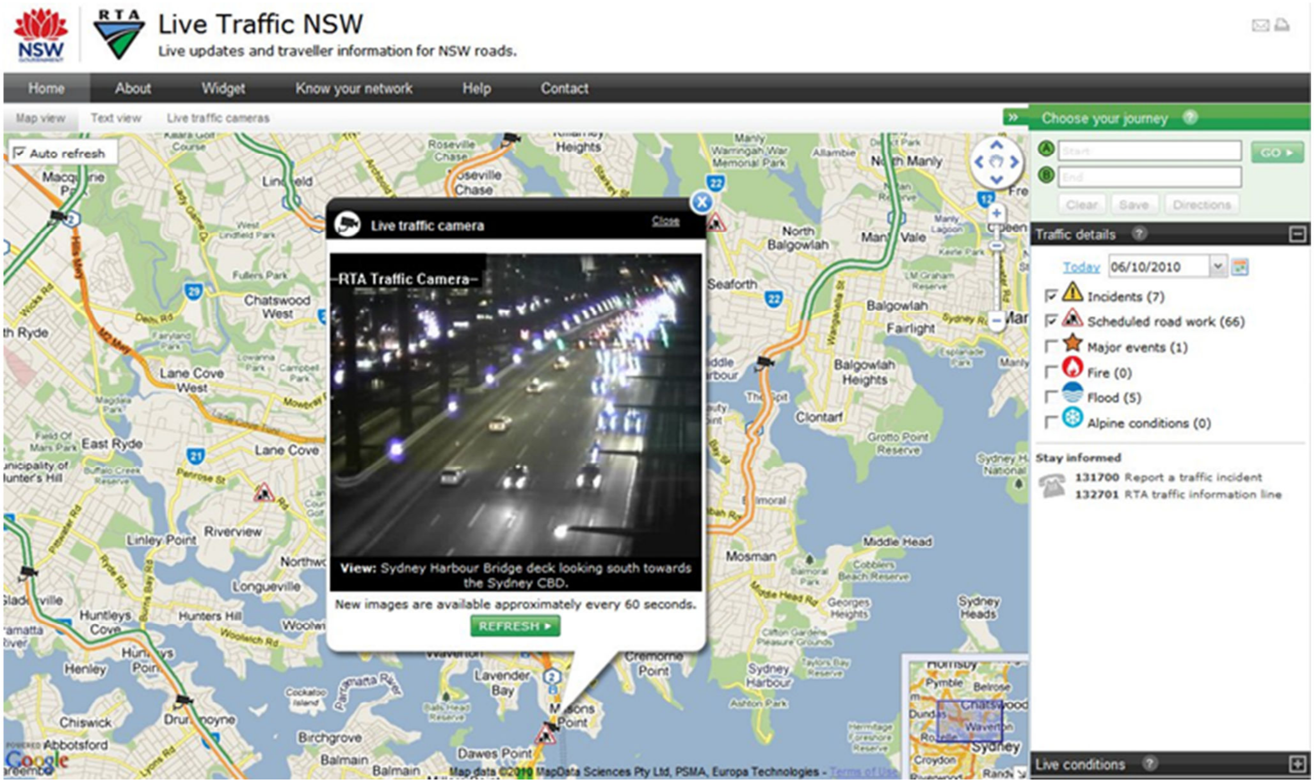


Figure 9 RTA Live Traffic NSW Website with access to their CCTV Camera Network

3.5 Internet Speed Tests

To understand if and how various applications will be supported by broadband network connections, it is important to clarify the difference between peak and average data rates for communications interfaces and networks. To this end, refer to Figure 10 which illustrates the results of a Speedtest.Net application that is widely used across the globe and is hosted by local Retail Service Providers (RSPs) such as Internet Service Providers (ISPs). This test was run on a Sunday afternoon from a desktop PC with an Intel™ Core™2 Duo CPU @ 2.66GHz with 2GB RAM and Windows7 / 32-bit OS over a 100BaseT cable and an Optus Cable Modem based fixed-line connection. The speed test measures the time to download and upload a fixed size file (estimated to be 23.8Mbyte in this case for the downloaded file). The test results were: 19.06 Mbps download speed and 0.49 Mbps upload speed. The time taken to download the test file was 10 seconds. This is a good result, but not unexpected given that the speed test server is hosted by Optus.

It is important for the reader to appreciate that a very short, 10-second speed test, even if repeated regularly every 15 minutes as some ISPs do for network performance monitoring, is by definition a measure of the peak data rate, not the average or sustainable data rate of a connection. It does not reflect the average data rate needed to support broadband applications that run over a longer period of time, such as when streaming video or uploading and downloading multiple large video files for example. This is because the Optus Hybrid Fibre Coax (HFC) network for example, to which a Cable Modem connects, shares the available 20Mbps peak capacity across hundreds of premises in the same metro area.

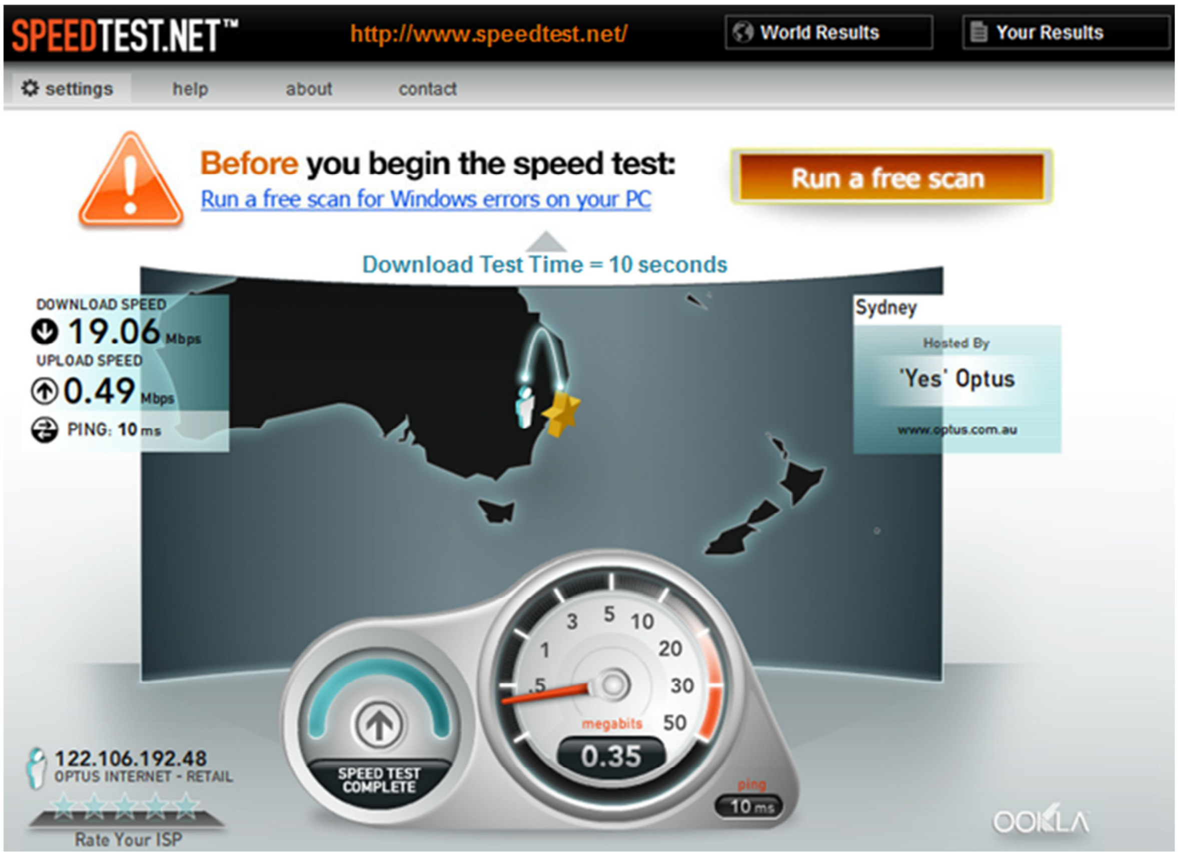


Figure 10 Internet Speed Tests Measure Peak not Average Data Rates

The local speed test also does not take into account the speed limitations that occur as the data source gets further away from the user. For example, a 17.6MByte zipped data file stored on a server in the USA took 165 seconds to download under the same PC test conditions mentioned above, which equates to an average data rate of 850kbps. The same 17.6MByte file stored on a local Aussi WebHost server (rather than a local Optus server) took 17 seconds to download, which equates to a data rate of 8.7 Mbps. A 176 MByte download (containing 10x the same file content) from the same local Aussi WebHost server took 3 minutes and 10 seconds to download, equating to a data rate of 7.4Mbps. None of these measurements actually reflect the average or sustainable data rate of the Cable Modem connection, since this will be highly variable depending on the week-day; time; number of users online and connected to the same HFC network segment; and the applications that each of the users are running at the same time. Under peak usage conditions, it is possible for the average data rate for a Cable Modem connection to drop below 500kbps.

As a comparison with the above network speeds, NBN Co are commissioned by the Government to build a predominantly FTTP based NBN that provides up to 100Mbps sustainable data rate and up to 1Gbps peak data rate to the premises. For locations where FTTP is too expensive to deploy initially, such as in remote rural and regional areas, NBN Co are commissioned to build a 12Mbps per premises wireless access network based on new 4G technologies, with new Satellite technologies for the really remote areas of Australia that cannot get fibre or wireless.

3.6 Data Transfer Speeds of Fixed and Mobile Devices

For general Internet applications, it is the application software and/or general purpose processor capacity that limits the data rate requirements for a fixed or mobile device. However, for standards-based applications such as H.264 video/audio compression and JPEG image compression, most fixed and mobile devices also have hardware co-processors that reduce the load on the device's general purpose processor. As a result, it is often found that a fixed or portable device supports higher data transfer speed connections for video than for proprietary data applications.

When neither the general purpose processor nor a co-processor is the limiting factor, then it is the device's communications interface hardware and software itself that limits the data rate capability of the device. This section focuses on the interface specifications and application testing undertaken by others that will determine the current and future network capacity requirements of fixed and mobile devices.

- **PC/MAC Data Transfer Rates** – Various Internet blogs have addressed this issue. The general consensus is that 64Mbps – 80Mbps is a typical maximum transfer rate for data applications, such a PC-PC file transfers over 100BaseT Ethernet. With the support of video co-processors and 1000BaseT Ethernet interfaces, higher data rates are quoted. For example, a MAC was tested and found to transfer a large iMovie video project at a peak data rate of 216Mbps. A DVD drive supports 80Mbps transfer rates and a Hard Disk drive supports at least 480 Mbps transfer rates. Using Windows7, remote streaming, uploading or downloading of data off a Hard Disk at home would require a 1000BaseT PC local network interface, which is normal these days for new equipment.

- **Network Attached Storage (NAS) Transfer Rates** – A typical NAS was quoted as being readable with a data transfer rate of 248Mbps over a 1000BaseT Ethernet switch and cabling. NAS data transfer rates will continue to increase over the next 10 years, driven by distributed (cloud) computing applications, users working from home or wanting remote access to files and multimedia content stored at home.

- **Apple iPad Wi-Fi/3G/A-GPS** - supports both 3G (UMTS/HSDPA @ 7.2 Mbps peak data rate) and GSM/EDGE (GPRS) wireless data networks. All iPad models support 802.11a/b/g/n WiFi communications interfaces (at up to 72Mbps interface rate). MP3 audio transfers at up to 320 kbps. MPEG-4 Simple Profile 48kHz stereo audio at up to 160kbps; and 640 x 480 pixels resolution, 30 frames per second video with video download rates of up to 2.5 Mbps. Motion JPEG (M-JPEG) supports up to 35 Mbps video transfer rates, comprising 1280 x 720 pixels, 30 frames/sec and PCM stereo audio. Note that Best Buy CEO Brian Dunn stated recently[14] that Apple's iPad is cannibalizing 50% of Laptop sales, according to The Wall Street Journal.

  As mentioned for the iPhone4 and Apple Facetime, third-party video streaming applications might not work at all on the iPad with Wi-Fi + 3G in cellular mode. According to one source[15], loading the ABC Player for instance brought up a message reading, "Please connect to a Wi-Fi network to use this application. Cellular networks are not supported at this time.

- **Apple iPhone4 Wi-Fi/3G** – the following review of the iPhone4 was reported by Krug and Shimpi at Anandtech[16]. The iPhone 4 brings HSUPA class 6 for upload speeds of up to 5.76 Mbps. This is a 15 fold improvement over the 384 kbps maximum of the iPhone 3G and 3GS. Downstream HSDPA speeds remain unchanged from the 3GS, supporting up to 7.2 Mbps HSDPA. For WiFi connections, the iPhone4 associates at the same 72 Mbps connection speed as the iPad.

- **Mobile Device Upload/Download Tests** - As shown in Figure 11, iPhone4 tests[16] on an 802.11n WiFi connection achieved 29.6Mbps data throughput with application co-processor support. The iPad was only slightly faster on the same connection. Figure 12 shows another set of data-file transfer tests undertaken by Gizmodo[17] to illustrate 3G and WiFi download and upload performance for the Apple iPad and iPhone3GS.

  The take-aways from these graphs are as follows:

  - Mobile devices such as the iPhone4 and iPad are capable of download speeds of up to 30Mbps (with co-processor support) over WiFi/fixed-line premises & hot-spot connections;
  - Mobile devices such as the iPhone4 and iPad are capable of data-file download speeds of up to 2.4Mbps over 3G wireless and 1.6Mbps over MiFi (WiFi/3G) connections;

- Mobile device applications requiring high speed broadband capacity in excess of 7Mbps are best served by Wi-Fi connections when used within range of a WiFi hot-spot or at home where there is a fixed-line connection. Neither 3G nor 3G-based MiFi are suitable wireless connections for nextgen broadband applications. New 3.5G (42Mbps peak HSPA+/MIMO) is an interim solution, however, 4G (100+Mbps peak WiMAX/LTE/MIMO) and 4G-based MiFi are essential going forward where no WiFi/fixed-line (FTTP) connection is available.

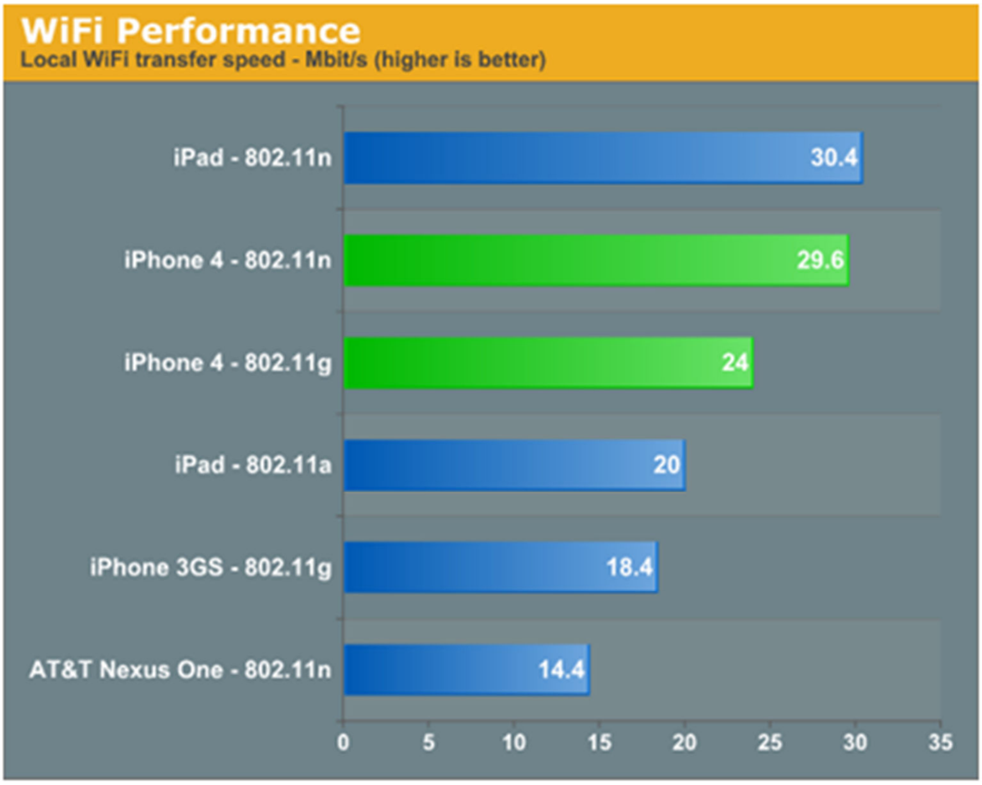
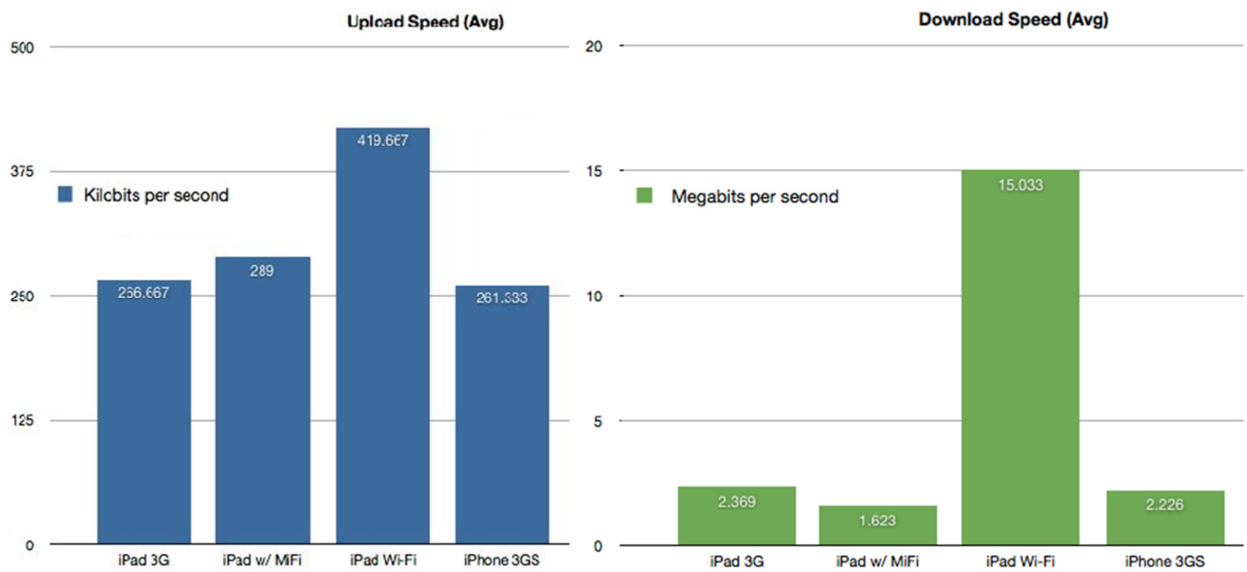


Figure 11 WiFi Performance for Various Mobile Devices



a. Upload Tests *b. Download Tests*

Figure 12 Upload and Download Speed for Various Mobile Devices and Interfaces

3.7 Future Applications Enabled by High Speed Broadband

Section 3.4 focused on current (2010) applications that are driving high speed broadband and forecast near-term application upgrades that are likely. For this section on Future Applications, the reader is referred to The University of Melbourne, Institute of Broadband-Enabled Society (IBES) Annual Report 2010 (introduced by Professor Rod Tucker, Director of IBES), which outlines a range of applications that are enabled by high speed broadband and which IBES are investigating using their FTTP based test bed. The following are some extracts and highlights for those without access to this report.

Ubiquitous high speed broadband provides a way to build the capacity of teachers, students and the wider community through increased learning opportunities and choices. Access to educational opportunities will be improved, regardless of location. High speed broadband has the potential to provide learners with a range of educational opportunities beyond their local environment. Students, regardless of their location, will be able to take classes with specialist educators and adults will have access to further learning and higher education. The following are examples:

- **UniTV project** - IBES are bringing together a huge variety of both existing and newly created customised content from numerous sources at the University of Melbourne and combines them with interactive applications such as shared learning and virtual workspaces;

- **The digital panopticon** (a room for the exhibition of novelties) - providing access for remote education and the world to scanned copies of Australian historical records and research data;

- **Virtual presence for children who cannot attend school** - Children with chronic health problems who spend months in hospitals without access to proper educational facilities will now be able to get access remotely. (Author’s extension of this: now with high speed broadband to homes, schools and hospitals, there will no longer be any impediment to their education while they are being treated and cannot attend school. Additionally, by linking them by HD video and audio to their own classroom, their education will be seamless no matter where they are located. Virtual reality training with 3D HDTVs will further improve the remote learning process).

- **Broadband enabled collaborative learning system** - connecting schools in remote and rural locations with urban school children. Teachers and students from schools in Australia with sister schools in Japan, Indonesia, Korea and China for example (Author’s comment - could also include European and US schools for example. Additionally there is a related secondary school project in Tasmania whereby Japanese classes in Australia converse in real time over HDTV video-conference links with English classes in Japan - both learn to communicate better in each other’s language. Similarly, individuals can get involved in similar classes from home with high speed broadband).

- **Smart grids project** - will investigate electricity load rationing with greater user-control rather than an authoritarian approach (Author’s comment: whilst a FTTP based NBN is not a pre-requisite for smart grids to evolve, the ubiquitous connectivity provided by a Fibre, Wireless and Satellite based NBN designed under common principles, will make it easier for smart grids to evolve).

3.8 Interface and Processing Capacity Limits of the Human Brain

Up to this point, this paper has focused on the various networks, applications and devices used for users to communicate and to be entertained, both now and in the near future. However, it is often stated that there is no point in designing the next generation broadband networks to upload and download information at a rate which exceeds the ability of all users on a given premises to generate and receive. This statement is fundamentally correct, however, it is subject to interpretation.

For example, in the future, a user at home may run a new high performance PC application that can gather all 3D HD video, audio & data from multiple sources around the globe that is relevant to some narrow area of interest; process and correlate all this video, audio and data in real-time; and then present a compilation to the user as a high quality 3D multimedia presentation on the user's 3D HDTV. In this future application, there are three interface capacities to consider:

1) The interface capacity between the broadband network and the PC;
2) The interface capacity between the PC and the 3D HDTV; and
3) The interface capacity between the 3D HDTV and the user(s).

It is not possible without detailed knowledge about this future application (or a crystal ball) to determine the broadband network capacity requirements of the 1st interface; however, it is fair to say that it is going to be many times the capacity requirements of the 3rd (user) interface. This is possible because, in contrast to the human brain, PC processor speeds and memory sizes continue to double every two years in accordance with Moore's Law. The PC is a tool which we continue to use to pre-process information and reduce it to a form that we as users are capable of visualizing and understanding. The PC thus extends the capacity limits of the human brain and will similarly extend the capacity of the network interface from which it gathers its information.

It is possible however, to estimate the capacity limits of interfaces 2) and 3) which will in-turn provide some insight into the future network interface capacity requirements for the simpler user applications, such as watching a 3D educational video or playing a 3D game. The following review focuses on near real-quality video as the dominant information capacity that users will process.

Video Capacity Estimates for the Human Retina and Brain

The term HDTV in this review is a generic term that includes stereoscopic HDTV today and higher information capacity holographic HDTV in the future.

The bandwidth of HDTV screens and associated HDMI/optical interfaces to the Video Decoder (Set-Top-Box or PC) aims to match the visual resolution and persistence of the human retina to a large HDTV display located at a typical 2 metre viewing distance. Video codecs on the other hand seek to match the coding rate to the capacity of the human brain to process the video information received from both retina, which for all intents and purposes may be considered the actual 3D video information rate as perceived by the user (in contrast to a PC video processor for example).

To better understand this, consider the scenario of a "perfect" 3D HD television camera recording a fast-moving football match using a "perfect" variable rate video codec where the coding rate is gradually increased until the human brain can no longer perceive any spatial or temporal difference between the video as seen on a 3D HDTV screen and the original scene that is being televised (assume the user is at the football match and can see both the HDTV screen and the original scene). The video data rate sent by the "perfect" video codec in this scenario is effectively the maximum video information rate perceivable by the human brain. Of course, no video codec is perfect, so to achieve near perfect HDTV quality requires a higher video coding rate than the maximum video information rate finally delivered to the user by the 3D HDTV screen.

As a starting point to estimate the video information processing capacity of the human brain, consider the simpler case of two dimensional (2D) TV. This effectively uses the capacity of only one eye since the video signal sent to the 2nd eye is identical and thus conveys no new information. In 2006, the 2D video capacity conveyed to the human brain by effectively one eye was estimated by Koch etal to be 10Mbps[18]. This outdated reference is often used to justify why we will never need 100Mbps to the premises. However, with 3D HD TV now commercially available, we need to re-evaluate both individual and group-viewing video capacity requirements.

Currently, 3D HDTV is based on stereoscopic technology which means that additional phase information (albeit rudimentary) is conveyed to the brain through the 2nd eye. The technology is based on stereoscopic imaging which was first invented by Sir Charles Wheatstone in 1838, so this is not a significantly new technology. Since 3D stereoscopic video now conveys additional phase information to the human brain using the full capacity of both retinas, the total video information capacity conveyed is expected to be around 20Mbps. One could argue that in addition to phase information, additional amplitude information is also conveyed to the brain via the 2nd eye, but such information is highly correlated to the amplitude information conveyed to the 1st eye, so this does not equate to much more information capacity. Overall, 20Mbps is a reasonable estimate for the video information capacity sent to the brain by 3D stereoscopic HDTV and is consistent with user's perception of 20Mbps 3D HDTV being much better in quality than 10Mbps 3D HDTV for example.

The next major technology step is holographic 3D HDTV. Holography was invented in 1947 by the Hungarian-British physicist Dennis Gabor. Anyone who has seen a hologram will know that 3D holographic video technology will convey more information to the brain than 3D stereoscopic video technology. If it didn't, then we would say right now that 3D stereoscopic video quality is a near perfect replica of reality. This is far from the truth, since like reality, 3D holographic technology will enable us to move our heads side-ways to see behind an object that is on the 3D HDTV screen. You can't do this today with 3D stereoscopic video – there is just not enough phase information extracted from the original scene by the 3D HD video camera to achieve this.

If we consider video quality (and associated information rate) to progressively increase from 2D (10Mbps) to 3D stereoscopic (20Mbps) to 3D holographic to 3D reality, then it is reasonable to expect that the brain can perceive 3D reality in terms of at least 30Mbps peak capacity. I say peak, since the human brain also has great potential to lose concentration or to focus-in on specific aspects of a video scene, in which case the useable capacity being processed by the brain will vary over short time intervals. However, we must design for the peak capacity since we as transmission engineers have no control over which aspect of a video scene the brain will be focused on at any one time. Additionally, when multiple people in a room are watching the same 3D video program, they will all be focusing in on different aspects at different times; so again, we can't afford to exclude anything through some form of predictive video coding based on artificial intelligence and knowledge-base of each person's individual viewing and focusing habits.

For the purpose of estimating the future capacity requirements of each person in the home and the total capacity required per premises, it will be assumed going forward that life-like video quality based on future 3D holographic video technology, needs to have a capacity of at least 30 Mbps. Of course, since no video coding technology, such as based on the H.264 standard, is perfect, then to achieve excellent quality 3D holographic video as perceived by the human brain, with few spacial and temporal imperfections, will require that the compressed video stream have a higher encoded data rate, between 30Mbps and 50Mbps for example, which is the data rate that the broadband network will need to deliver to each 3D holographic HDTV decoder.

3.9 Information Transmission and Application Processing Paths

Based on information presented in the previous sections and from other sources, the following Figures 13, 14 and 15 illustrate diagrammatically, the paths and data rates through various network interfaces; fixed and mobile devices; codecs; display screens; and ultimately, the user's eyes and brain; for various multimedia applications.

Figure 13 illustrates a typical range of video, audio and data applications that an Apple iPhone4 provides to a single user from its internal memory or from a cordless or wireless network.

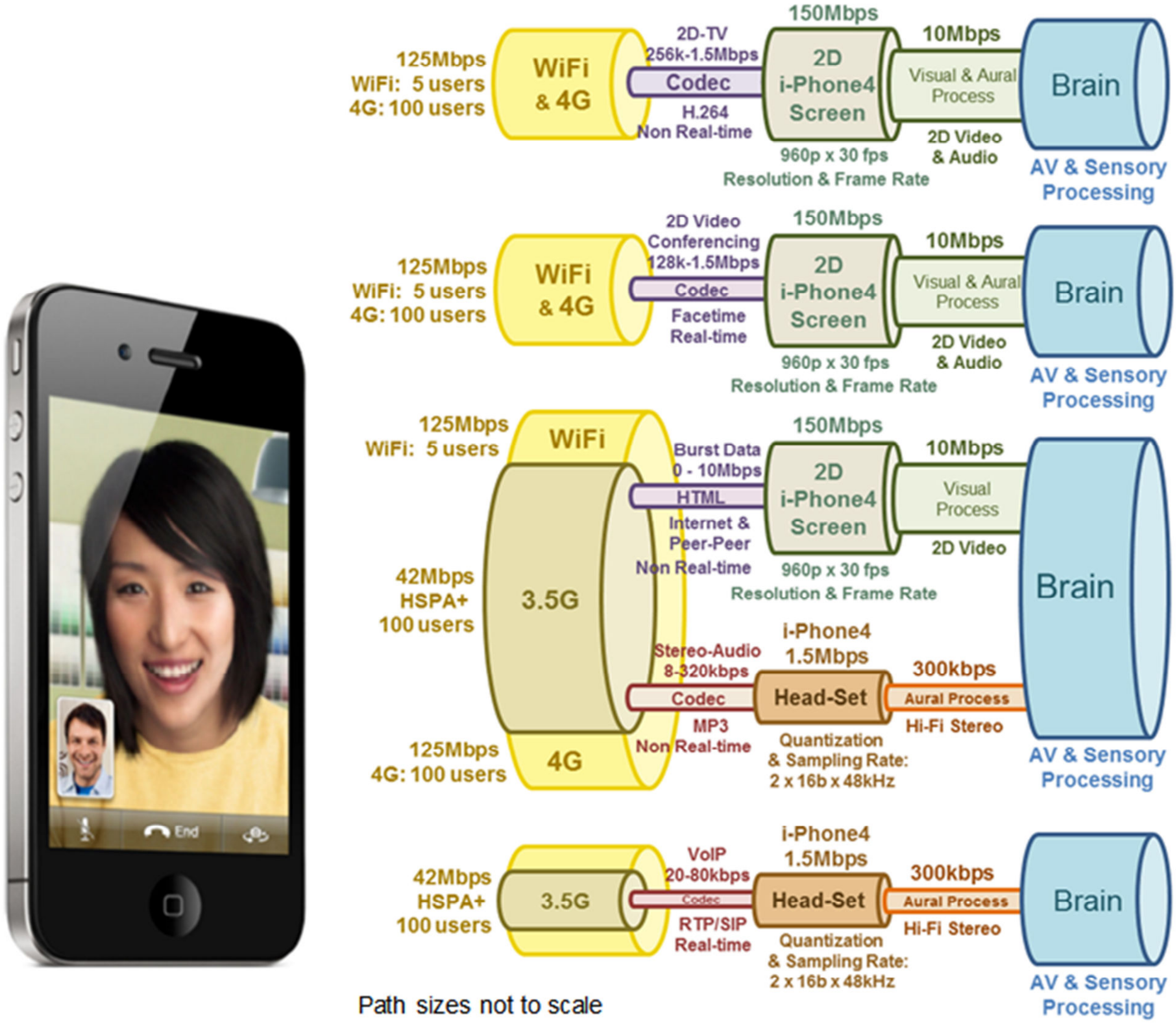


Figure 13 Single user iPhone4 Applications and Path Capacities

The diagrammatic representation uses a transmission pipe analogy to demonstrate the relative capacities (albeit not to scale) of each transmission element; coding/processing element, transducer element (screen, headset, eyes, ears, etc) and by the human brain as the final audio, video and sensory processing element.

One of the objectives of the next generations of broadband networks is to progressively deliver increasing quality and breadth of experience to the user, to the extent that the video, audio and sensory transducers create a virtual reality environment in which the user is immersed.

The iPhone4 and the cordless and wireless networks to which it connects would not pretend to or even aim to achieve virtual reality, but it does represent one of many steps that will lead towards this objective, including high quality screen resolution; high quality stereo audio; and high quality video conferencing when connected to a WiFi cordless network.

Identified in Figure 13 are the relative capacities of various wireless and cordless network technologies. WiFi (802.11n) cordless and 4G networks have approximately the same peak capacity (approx.125Mbps), however, WiFi networks in the home only have to share this capacity across 5 users for example, whereas 3G, 3.5G & 4G wireless access networks are often dimensioned by the carrier to share this capacity across hundreds of users. Premises and hot-spot WiFi networks are therefore better able to deliver the 10Mbps capacities required to immerse the user in a 2D form of virtual reality. Note that the iPhone4 only supports 3G (7.2Mbps) at this time.

Figure 14 illustrates a typical range of video, audio and data applications that a 100Mbps broadband network interface can provide via 100BaseT Ethernet and 802.11n WiFi cordless connections to multiple users at the same premises. Note that if all users are watching separate, high quality (eg, 20Mbps) 3D HDTV programs or on-line 3D HDTV games, the entire 100Mbps network capacity will be consumed. Observe that whilst the video information processing capacity of the brain is 30Mbps, the "uncompressed" video data rate to and from the 3D HDTV screen is 8Gbps. This is required to match the resolution and persistence of the human retina.

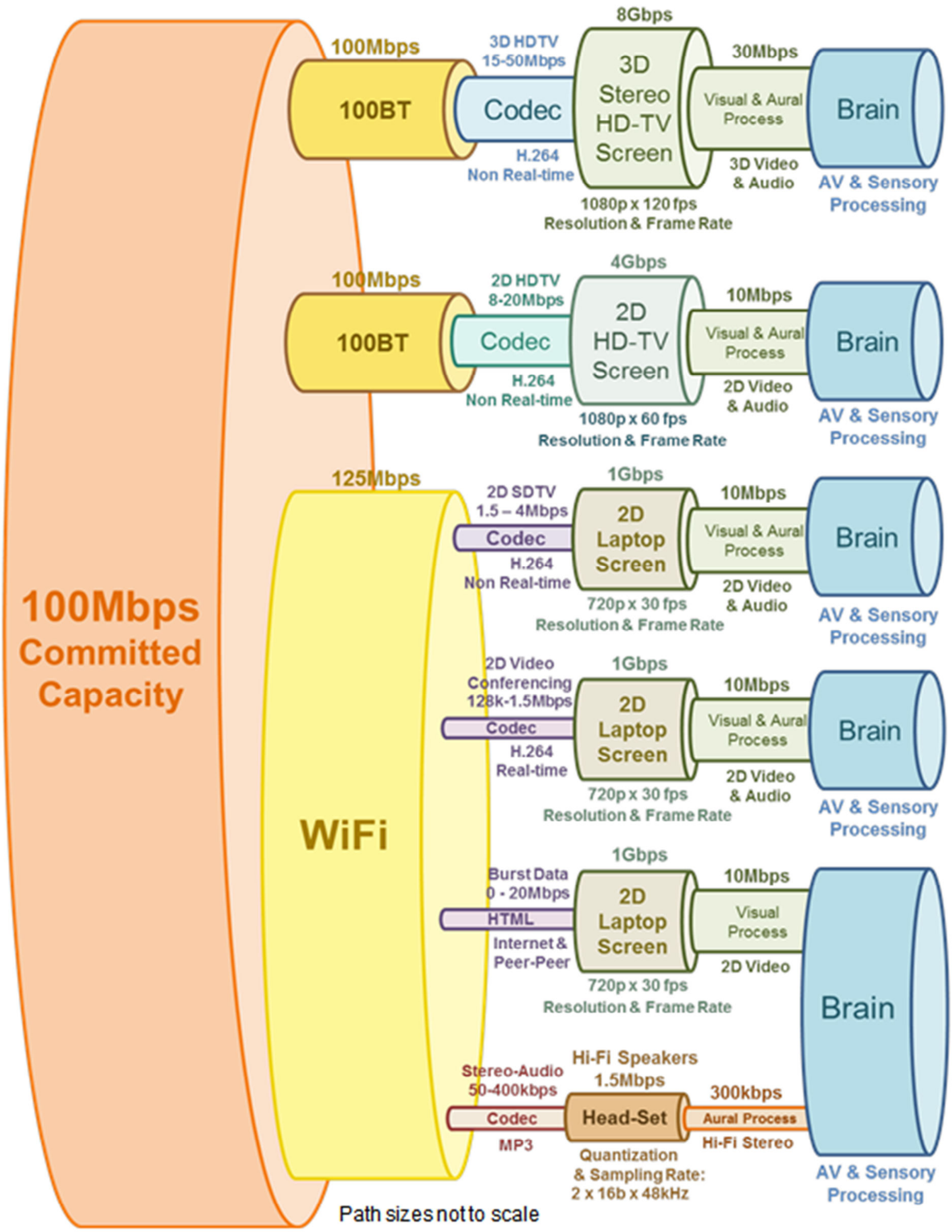


Figure 14 Multi-user Premises Applications and Path Capacities

Figure 15 illustrates a near virtual reality “3D Multimedia Video Glasses” product available from Zetronix, which retails for US$300. These are not just 3D glasses for looking at a 3D TV, they are the 3D TV. They aren’t yet HD quality but they give the impression that the user is watching a 172cm TV screen from a distance of 2 metres. They include stereo headphones as part of the device. Evolutionary quality and connectivity upgrades for products such as this are likely to include: HDTV quality; 802.11n cordless connectivity; and eventually holographic 3D HDTV quality.

Figure 15 also illustrates how a single user could draw more capacity from the global Internet than they themselves are able to consume. This illustration reflects the multi-stream application previously mentioned in section 3.7. Here, the PC or other CPU processes in real time, 4 x 20Mbps multimedia streams and condenses the combined information in some way that conveys more useful information to the user than watching all four streams simultaneously on a video wall for example. The actual information rate finally sent to the user does not need to be any greater than the user can absorb (eg, 30Mbps of 3D video and 300kbps of HiFi surround sound audio).

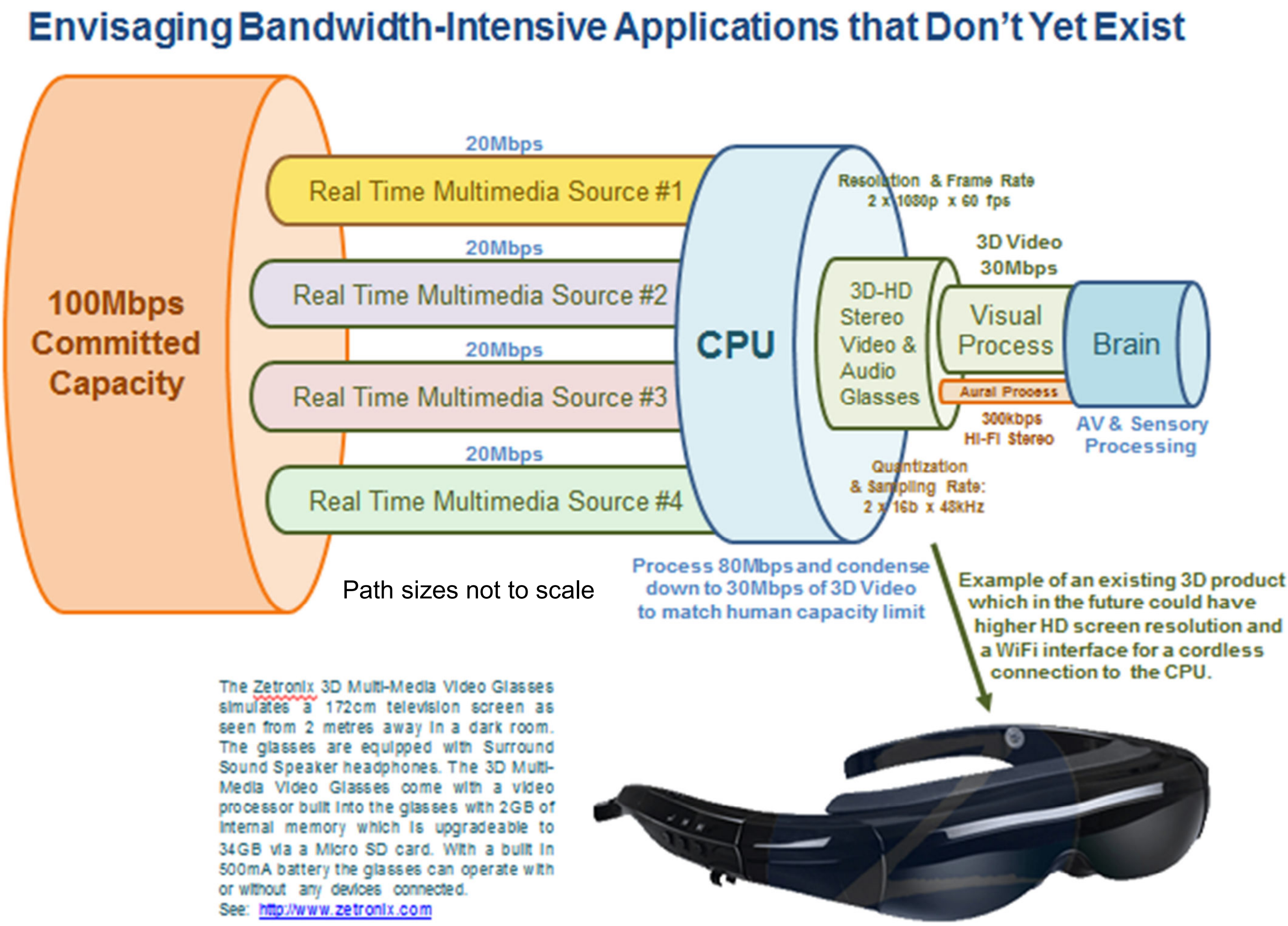


Figure 15 PC Processing and Compression of Data to Match the Human Brain’s Capacity

Other similar, bandwidth-intensive, multi-stream applications in the future could include a simple video wall, eg, for sports events, multi-venue virtual conferences, virtual meetings, etc; and multi-user games. The bottom line is that the estimated 30Mbps capacity limits of each user in no way reflect the maximum network interface data rate required per user per premises. With each user having Multimedia 3D HDTV Glasses, it is now understandable how 5 users on the same premises could require an average download capacity of 400Mbps.

Clearly, these are cutting-edge users and applications, but they provide support to the case that the average premises will require 100Mbps average broadband capacity in the near future based on next generation applications and user devices. In summary, both the statistical analysis and the applications analysis lead to the same conclusion regarding the need for 100Mbps data rate.

4. Access Network Architectures

To put the previous network capacity analysis into perspective, the following sections provide a short overview of existing, 3G/4G wireless macro-cell networks and forthcoming 4G pico-cell wireless and fibre access network architectures for the NBN rollout.

4.1 Generic 3G/4G Macro-Cell Network Architecture

Existing 3G (including 3.5G) and new 4G wireless access networks are generally designed by mobile carriers using architectures similar to that shown in Figure 16. In high-density metro areas, each radio base station serves a macro-cell comprising thousands of premises. Each cellular base-station has 3-sets of antenna pointing in 3 different directions and each of which may operate at the same frequency without interference. Multiple mobile carriers often share the same tower, but each licenses a different part of the frequency spectrum.

All base stations are backhauled by either optical fibre, microwave radio or a mix of both to a central office exchange which is where the mobile radio network controllers and switching equipment will be located. Where possible and cost-effective, protection rings are used to provide fault tolerance to the wireless networks.

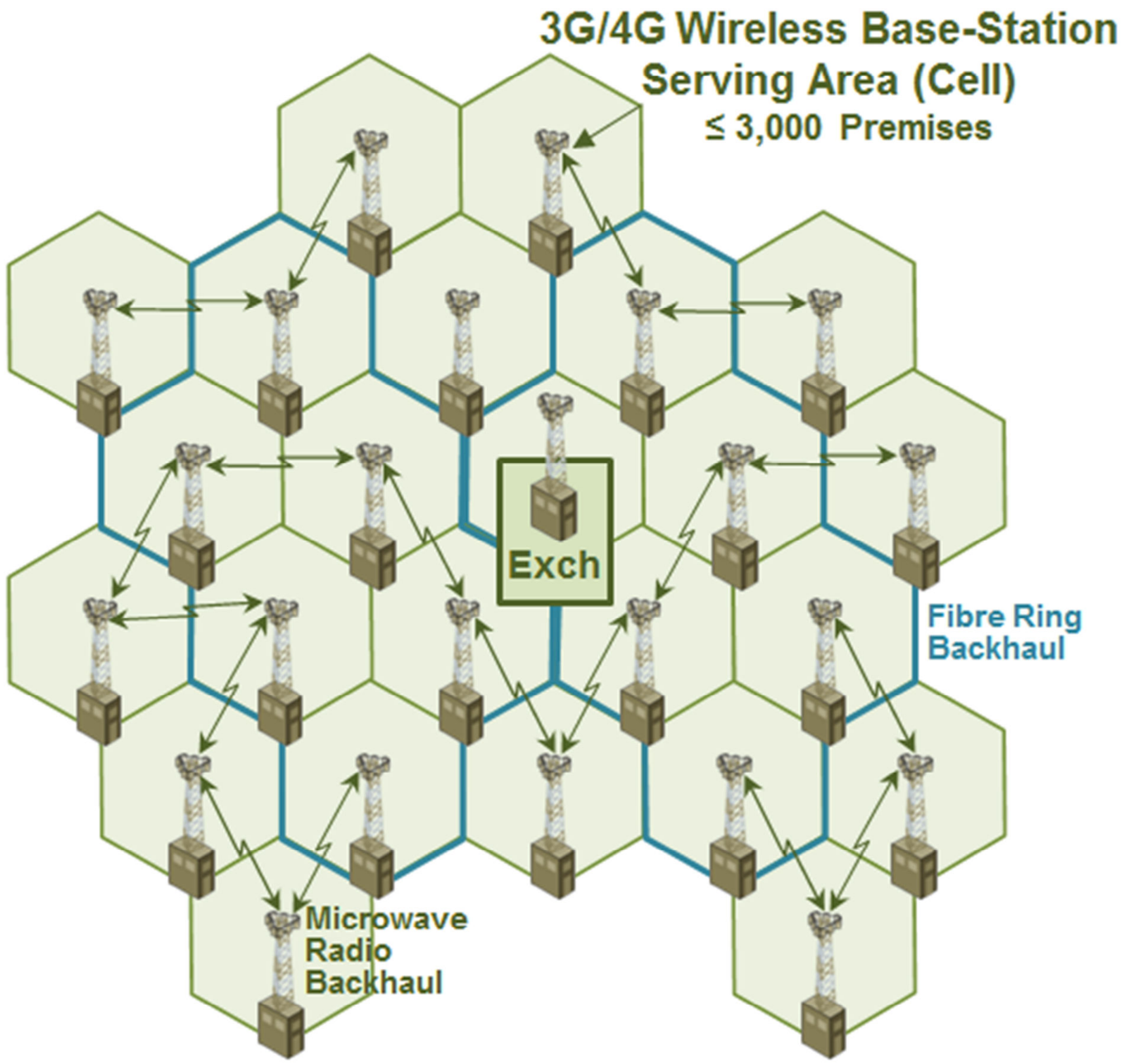


Figure 16 3G/4G Macro-Cell Wireless Access Network Architecture

4.2 Actual Macro-Cell Wireless Network

For the purpose of representing an actual wireless access network and estimating the average capacity available to the mobile users, Figure 17 draws on macro-cell base station data available from the web site http://spench.net for the Sydney suburb of Dee Why, which comprises a broad mix of single-dwelling residential premises, high density Multi-Dwelling Units (MDUs), small businesses and light industry. In this map, each Telstra, Vodafone/3 and Optus base station was identified and 3G frequency data tabulated.

A total population of 18,000 and an area of 4 sq.km are found to be served by a total of 26 x 3G non-overlapping frequency cells. Assuming 2,600-5,200 x 3G mobile broadband users and 8Mbps data capacity per 3G frequency, the average number of mobile users per frequency is 100-200 and the average capacity per user is 40-80 kbps. From another perspective, carving the area of Dee Why into typical 20m x 50m lots yields an average wireless network capacity of 52kbps per lot.

Clearly, with the current 3G/8Mbps (or even 3.5G/42Mbps) wireless access networks, we have a long way to go before we get to the capacities required to support the next generation of mobile broadband applications, let alone premises broadband applications.

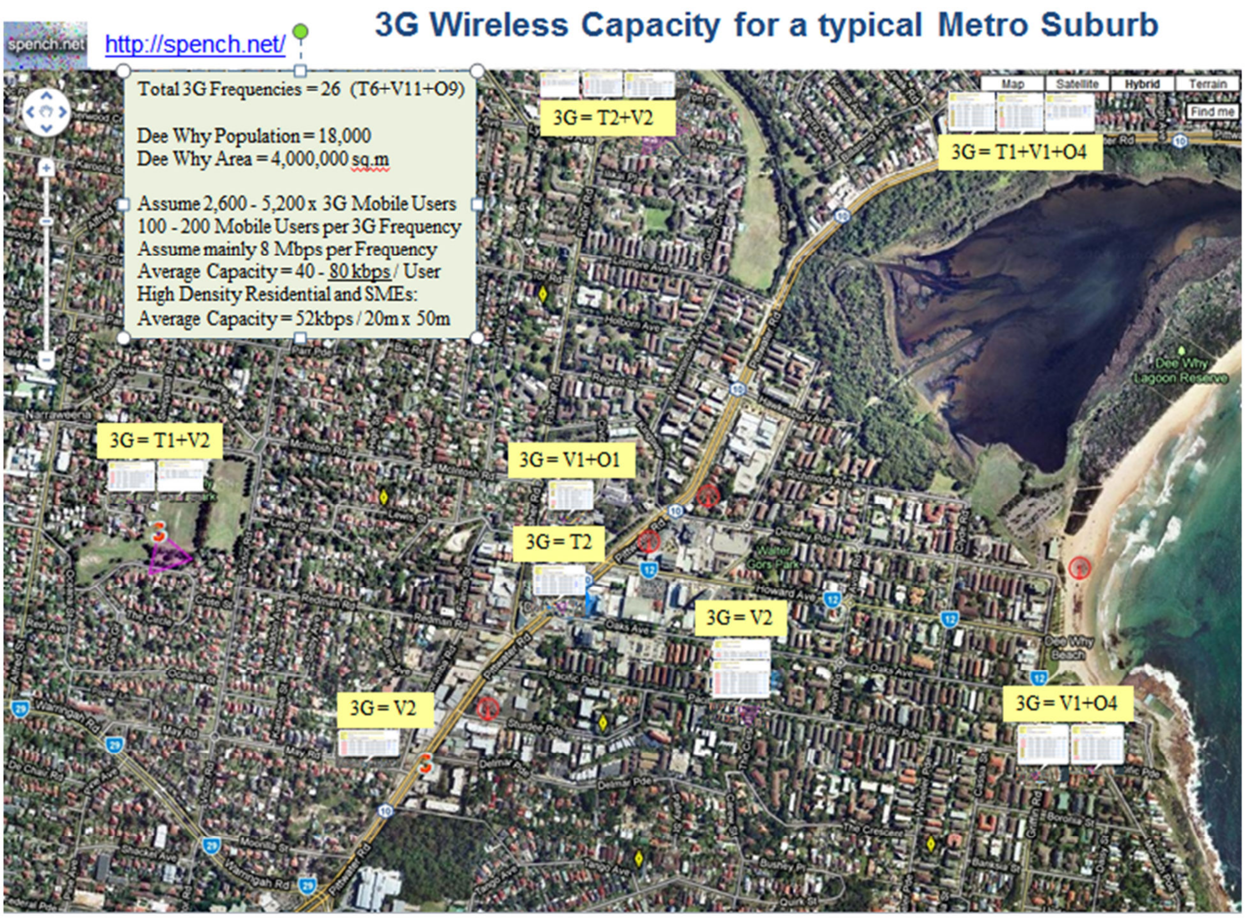


Figure 17 Representative 3G Cellular Networks and Capacities for a Metro Area

4.3 Wholesale Broadband 4G Fixed Wireless Access Networks

The broadband, 4G fixed-wireless access networks as proposed by NBN Co for remote & rural areas have sufficient capacity to enable the wireless capacity pie to be carved in a different way to how it is carved today. As discussed in the previous section, mobile carriers currently purchase their own spectrum licenses and often install their own 3G or 3.5G base station equipment. This results in larger radio base stations which consume a lot of power and are an eye-sore to the environment. However, as shown in Figure 18, there is now a better and more efficient method for each carrier (now referred to as a Retail Service Provider or RSP) to share the frequency spectrum and associated capacity.

For remote & rural communities, NBN Co as a wholesale carrier, will deploy smaller, lower footprint and lower power-consuming 4G fixed-wireless pico-cells, each supporting a capacity of 100+Mbps (let's say 126Mbps for mathematical convenience). As shown in Figure 18, instead of three RSPs deploying three separate Layer-1 3.5G (42Mbps) frequencies and associated equipment, NBN Co will instead carve the 126Mbps capacity of each 4G frequency into three Layer-2 Connectivity Virtual Circuits (CVCs), each of the same capacity (42Mbps) or different capacities, depending on each RSPs' customer-base and capacity requirements. From so many perspectives, this Layer-2 capacity leasing approach is much more efficient that Layer-1 spectrum licensing, and is totally consistent with the way that NBN Co's fibre access network capacity will be leased.

There are no free lunches however. NBN Co's 4G wireless access network approach sounds so good, why not deploy it everywhere? If it was to be used to rationalize the mobile broadband network, then this would be an excellent idea. However, it is only to be used for the fixed-wireless network to the premises and for this market, the premises density needs to be sparse so that the 126Mbps cell capacity is not unduly diluted. For example, a 4G cell that services 100 premises would only offer 1.26Mbps average capacity per premise, which is a long way from the 12Mbps target for remote & rural communities, let alone the 100Mbps target for metro communities. Consequently, for metro areas, fibre access networks are essential to deliver the 100Mbps committed data rate to the premises requirement. In this case, mobility within the premises is achieved using 100+Mbps 802.11n WiFi cordless cells, these essentially being femto-cell access networks as shown in Figure 19. Note that in the US, some large mobile carriers deploy 3.5G femto-cells on the customer's premises, backhauled by the customer's own wire-line broadband network. This is to gain or retain the customer's mobile business rather than let the ISPs get it.

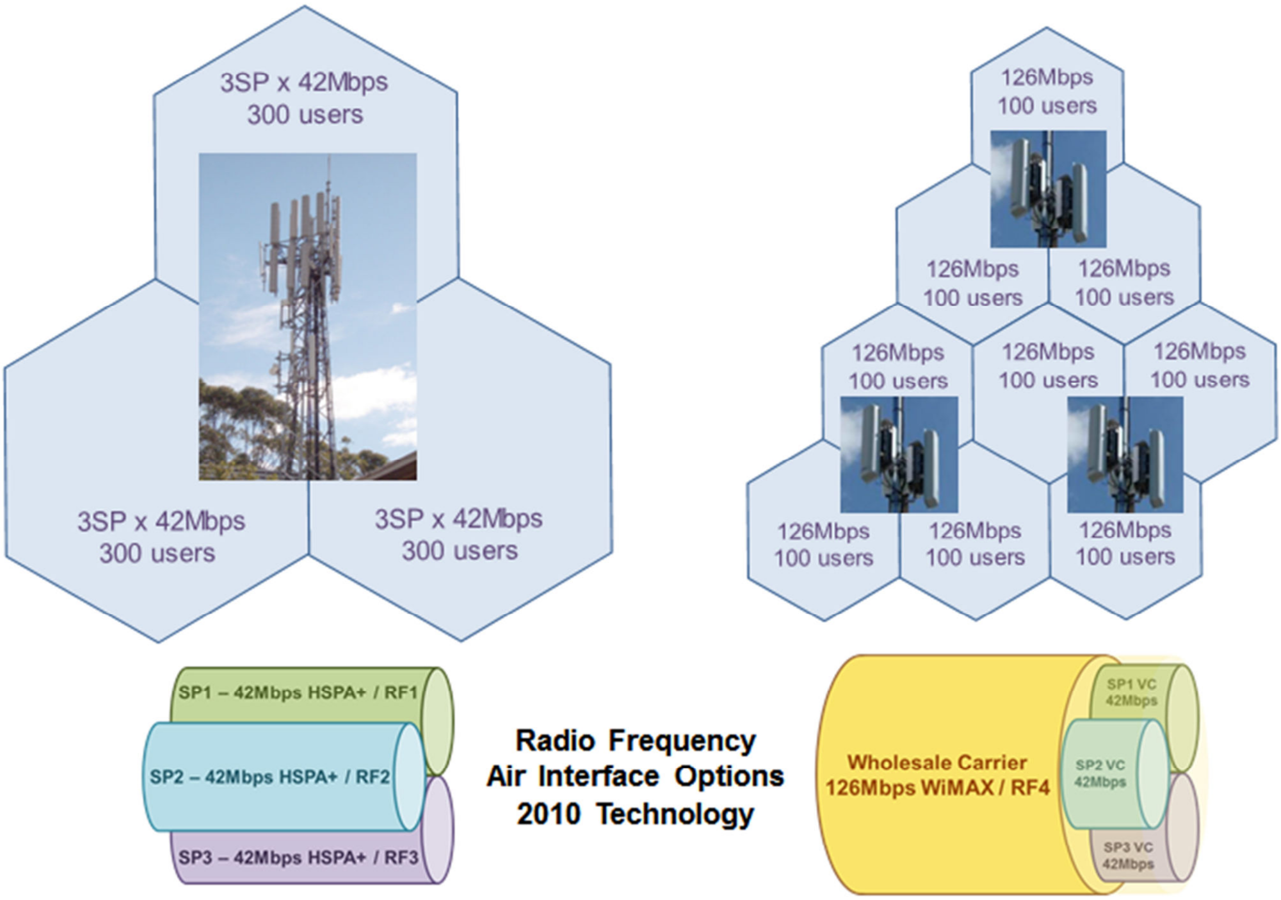


Figure 18 Multi-Provider 3G and Wholesale-Provider 4G Broadband Wireless Solutions

4.4 NBN Co's Fibre Access Network Architecture

Illustrated in Figures 19 and 20 is NBN Co's cellular-like Fibre Serving Area (FSA) architecture for its fibre access networks. Each FSA comprises a Fibre Access Node (FAN) which supports up to 24 Fibre Serving Area Modules (FSAMs). Each FSAM in turn supports up to 16 Fibre Distribution Hubs (FDH) where 32-port GPON fibre splitters are installed. Each FDH supports up to 200 premises. For network resilience and fast restoration in the event of buried cable damage, the FDHs are fed by a ring-based fibre distribution network, each of which connects back to the FAN site where the GPON Optical Line Terminals and Ethernet Fanout Switches (EFS) are located.

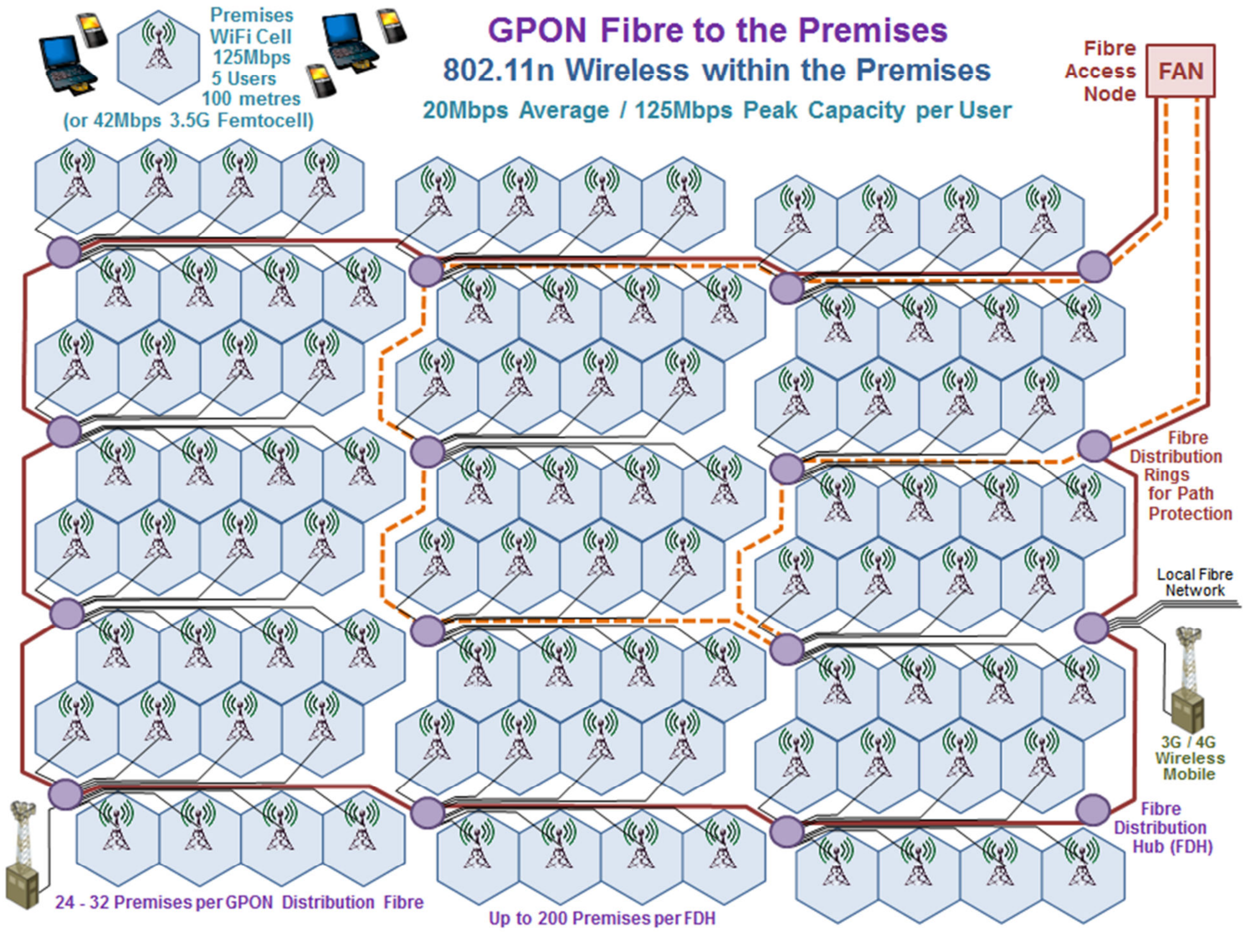


Figure 19 Fibre Serving Area Module (FSAM) and Premises 100+Mbps WiFi Cells

As shown in Figure 19, each premise is connected to the associated FDH via a GPON Optical Network Terminating Unit (ONT or NTU) and a local fibre network, which may be aerial or buried, depending on the features of the local area. The number of premises connected to each GPON splitter will be dimensioned to meet the 100Mbps committed data rate requirement for each premise. Each local fibre network of up to 200 premises is not protected.

For each FSAM, the premises may be single-premise residential, MDUs, businesses, schools, hospitals, shopping complexes, industrial estates and mobile carrier's 3G/4G wireless base stations. GPON backhaul to wireless base stations is becoming common in the US.

Each FDH is fed by typically twice as many distribution fibres than there are splitters. In addition to point-to-multipoint GPON fibre connections for most single premise residential applications, this fibre over-build is to support a proportion of point-to-point connections for higher-end customers or higher-density premises, such as business enterprises, schools, hospitals and MDUs. Patching of fibres at an Optical Distribution Frame (ODF) within the FDH supports these options.

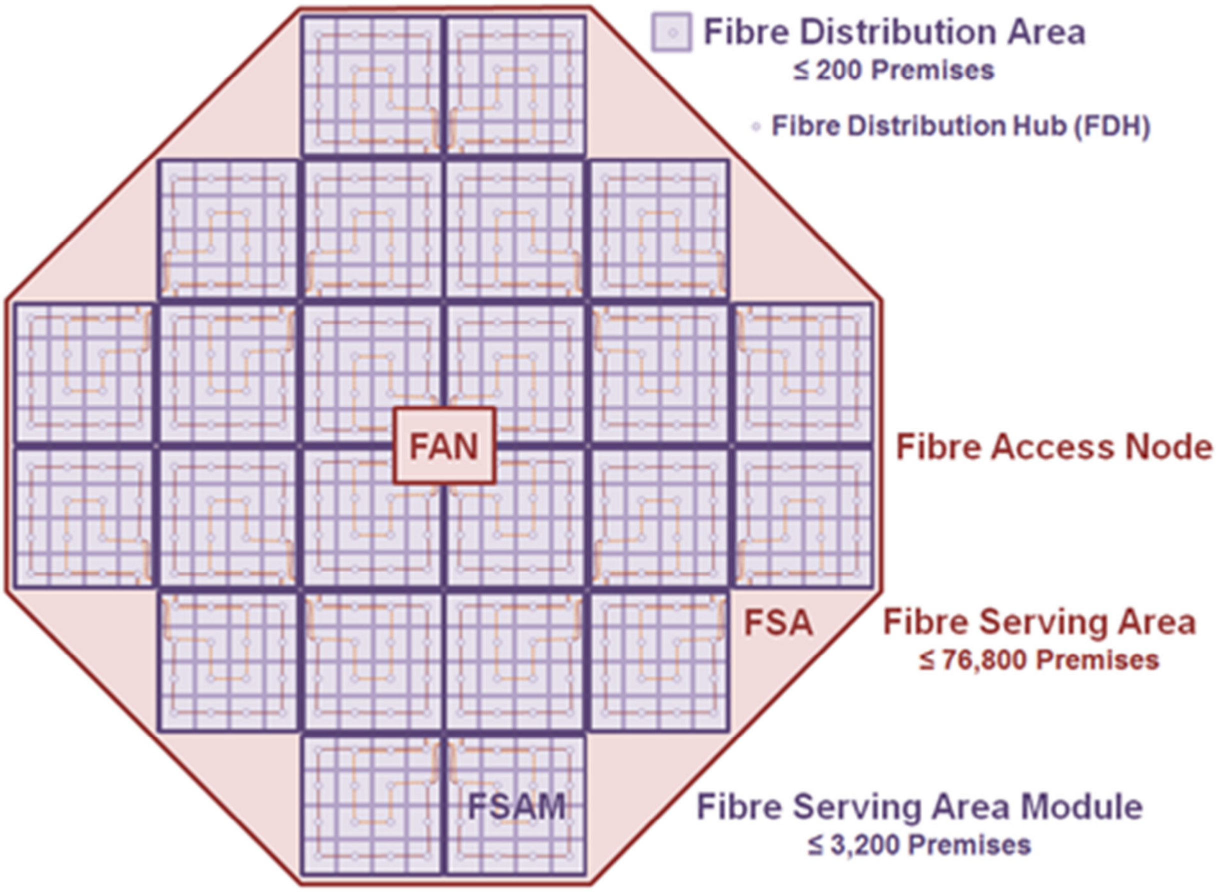


Figure 20 Fibre Access Network Architecture

4.5 NBN Co's End-to-End Fibre / Wireless / Satellite Network Architecture

Shown in Figure 21 is an end-to-end view of NBN Co's wholesale access network architecture, which is essentially the same irrespective of whether the access network is fibre, wireless or satellite. This common Layer-2 approach for allocating CVC capacity makes it simpler for both NBN Co and the RSPs to manage.

At the customer's premises, RSPs connect their service (Internet, Video or Telephone) to the customer's equipment via Access Virtual Circuits (AVCs) which can have various capacity options and standard wholesale pricing for capacities up to 100 Mbps committed information rate in the case of fibre access networks or up to 12Mbps peak information rate in the case of 4G fixed wireless access networks. For fibre access networks, multiple RSPs can connect to each customer's premise via 4 x 100/1000BaseT Ethernet ports on the NTU. The NTU includes battery backup for emergency services support (which is more than many cordless phones have).

At the FAN sites, the Ethernet Fanout Switches aggregate and fanout RSPs traffic which is connected back to the nearest Point-of-Interconnect (POI) site via a fault-tolerant fibre Transit Network. There will be just over 200 POI sites distributed throughout Australia, where by definition; a POI site is located where there is contestable backhaul.

Traffic on the NBN Co wholesale network is mapped to the various RSPs switching equipment and associated backhaul networks for transport back to their Point-of-Presence (PoP); major Central Office (CO) switching centres; video servers; and International Gateways.

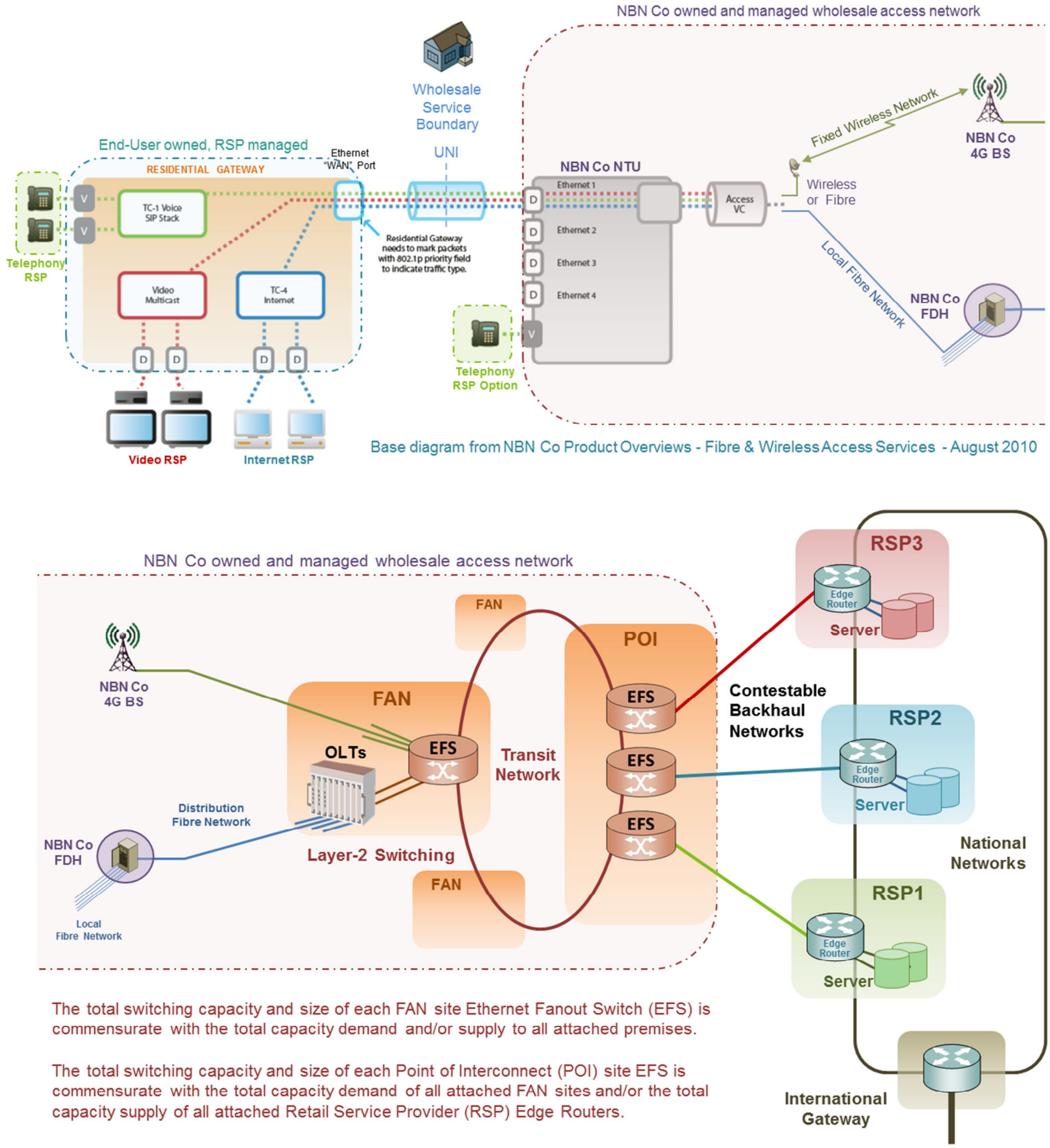


Figure 21 NBN Co's End to End Fibre / Wireless / Satellite Access Networks

5. Conclusion

The purpose of this paper was to verify through statistical, application and network analysis that 100Mbps average capacity to the premises is required and can be supported by 2020 when the NBN will be substantially rolled out. The outcome of this analysis has demonstrated that at least 100Mbps average capacity will be required and more likely by 2015, based on capacity growth statistics. The capacity limitations of wireless access networks have also been demonstrated by this paper. Whilst essential for off-premises mobility and for remote areas with sparse premises distribution where fibre is impractical or not cost-effective, it is an inadequate solution for high-density metro areas where the peak capacity gets too diluted by too many users to be useful.

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