How much bandwidth does an NBN really need to be useful?

Professor Grenville Armitage
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Predictions are hard....

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“The Americans have need of the telephone, but we do not. We have plenty of messenger boys.” (Sir William Preece, chief engineer of the British Post Office, 1876)
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Let us continue with that in mind....
A peek at my conclusion / challenge / opinion....
A very rough, ball-park conclusion....

A typical home needs > 60Mbit/sec inbound and roughly 5 - 15 Mbit/sec outbound (using today’s guesses)

<table>
<thead>
<tr>
<th>Activity</th>
<th>In (Mbit/sec)</th>
<th>Out (Mbit/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Online games</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Streaming audio</td>
<td>1.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Streaming/on-demand video</td>
<td>30</td>
<td>0.1</td>
</tr>
<tr>
<td>Telephony</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Email, file sharing, web surfing, video conferencing</td>
<td>25</td>
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</tr>
</tbody>
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(“in” and “out” speeds in Mbit/sec)
Talk overview

- Background – “the internet” and the NBN
- What does “network speed” even mean?
- What do higher speeds do for us?
- Relationship between speed and distance
- Consumer consumption and 'useful' speed

Today: Concepts rather than simple conclusions
I'm surprised the Internet works at all

Many, many millions(+) of loosely co-operating, mostly de-coupled devices....
I'm surprised the Internet works at all

Many, many millions(+) of loosely co-operating, mostly de-coupled devices....

All trying to locally optimise for their preferred mix of speed, responsiveness, consistency, 'quality' price....

I'm surprised the Internet works at all

Many, many millions(+) of loosely co-operating, mostly de-coupled devices....

All trying to locally optimise for their preferred mix of speed,

  responsiveness,

  consistency,

  'quality'....

  price....

What could possibly go wrong?

This is not the internet :-)
Homes & small business – internal

Cloud-based applications

Office Applications

IP

Telephony

Email

File servers

Social media

VPN / Telecommuting

File Backups

Web

Video conferencing

Internal Network (intranet)

Online Commerce

Internet Service Providers
Homes & small business – external

- Cloud-based applications
- Web
- Video conferencing
- Internal Network (intranet)
- Email
- File servers
- IP Telephony
- Office Applications
- Telecommuting
- Social media
- Online Commerce
- File Backups
- VPN / Telecommuting

Internet Service Providers

- EC2
- S3
- Glacier

- Google
- Cloud Platform
- Rackspace Hosting
- Amazon Web Services
- Ninefold

- Skype
- Gmail
- Outlook 2010
- Yahoo Mail
- Hotmail

- eBay
- PayPal
- Amazon
- LinkedIn
- Facebook
- Twitter
- Google Apps for Business
Access Link speeds….

NBNCo's fiber service is a seriously fast Access Link to the Internet

Internet (Retail) Service Providers
Uplink & downlink speeds differ

Downlink (in to your office)
NBN fibre: 100, 50, 25 Mbps

Uplink (out of your office)
NBN fibre: 40, 20, 5 Mbps

Internet (Retail)
Service Providers

Office
Applications

File Backups

Social media

Online
Commerce

Email

File servers

Telephony

VPN / Telecommuting

Cloud-based
applications

IP

Web

Video
conferencing

Internal
Network
(intranet)
Uplink matters when *pushing* data

- **Uplink (out of your home/office)**
  - NBN fibre: 40, 20, 5 Mbps
  - Internet (Retail) Service Providers
  - (Shared among multiple people and machines....)

- **Downlink (in to your office)**
  - NBN fibre: 100, 50, 25 Mbps
  - Office Applications
  - Cloud-based applications
  - IP
  - Telephony
  - Email
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- **Uplink matters when pushing data**
- Internet (Retail) Service Providers
- NBN fibre: 40, 20, 5 Mbps
- (Shared among multiple people and machines....)
When everyone talks to everyone...

Home Network (intranet)

The Internet (Internet Service Providers)

Home Network (intranet)
Packets flow almost everywhere

Traffic load within and between homes and businesses

Home Network (intranet)

The Internet (Internet Service Providers)

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Traffic load within and between homes and businesses

Traffic load across and between service providers
NBN is only part of the picture

The Internet (Internet Service Providers)

Traffic load within and between homes and businesses

Traffic load across and between service providers

NBN carries data between premises and (retail) service providers – “last mile”
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Speed can mean many things #1

• The time it takes to
  • ...download a movie DVD to my laptop
  • ...upload a collection of photos from my camera
  • ...download an electronic book to my e-reader
  • ...retrieve an email with photo or file attached
  • …send the characters in an SMS or instant message
  • ...send “bits” or “bytes”
Speed can mean many things #2

- How fast the network must be so that
  - ...IP television, YouTube (or similar) video services are delivered without shuddering or pausing
  - ...IP telephony (or “Voice over IP”) is clear and consistent
  - ...Skype (or similar) services are clear and consistent
  - ...Online interactive games are smooth and don't shudder
  - ...Medical telemetry provides un-interrupted monitoring
  - ...Web pages download promptly after each 'click'
  - ...etc
Terminology: Bits and bytes

- Bits and bytes → quantity of information
  - One *bit* can be “1” or “0”
  - Eight bits → one *byte*
- Bits/sec and bytes/sec → “speed” (information over time)
- “K” (kilo, or 'thousand')
  - Kbits/sec – thousand bits per second
- “M” (mega, or 'million')
  - Mbit/sec – million bits per second
## Example: Skype bandwidth

<table>
<thead>
<tr>
<th>Call type</th>
<th>Minimum download / upload speed</th>
<th>Recommended download / upload speed</th>
</tr>
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<tbody>
<tr>
<td>Calling</td>
<td>30kbps / 30kbps</td>
<td>100kbps / 100kbps</td>
</tr>
<tr>
<td>Video calling / Screen sharing</td>
<td>128kbps / 128kbps</td>
<td>300kbps / 300kbps</td>
</tr>
<tr>
<td>Video calling (high-quality)</td>
<td>400kbps / 400kbps</td>
<td>500kbps / 500kbps</td>
</tr>
<tr>
<td>Video calling (HD)</td>
<td>1.2Mbps / 1.2Mbps</td>
<td>1.5Mbps / 1.5Mbps</td>
</tr>
<tr>
<td>Group video (3 people)</td>
<td>512kbps / 128kbps</td>
<td>2Mbps / 512kbps</td>
</tr>
<tr>
<td>Group video (5 people)</td>
<td>2Mbps / 128kbps</td>
<td>4Mbps / 512kbps</td>
</tr>
<tr>
<td>Group video (7+ people)</td>
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<td>8Mbps / 512kbps</td>
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- What do higher access speeds do for us?
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- Consumer consumption and 'useful' speed
Impact of network speed on lifestyle

- How do online activities intrude on our life?
  - Changing channel on IP TV
  - Downloading new podcasts
  - Sync'ing our phone's photos “to the cloud”
  - … and so on…

- As speeds go up, these tasks take less time
  - The internet begins to satisfy our transient curiosity
  - Spur-of-the-moment activities become practical

- What speed is “sufficient” and worth the cost?
What can we do with NBN speeds?

- Web-based services
  - Faster page loading & response times
  - Improved ease-of-use & customer experience
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  • Increasing image quality / realism
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- Practical off-site file backups
  - Disaster recovery / mitigation
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[insert imagination here...]
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NBNCo's proposed speeds

- On offer: 100/40, 50/20 & 25/5 Mbit/sec

- These *significantly improve on* ADSL2+
  - 'traditional' broadband over copper phone wires
  - Best speeds are roughly 20/1 Mbit/sec
Optical fibre: speeds vs distance

• Using optical fibre means speed is constant versus usual customer distance from the local 'exchange'

• cf. speed over copper wires drops off with distance
  • e.g. ADSL2+ can easily be down around 2/0.5 at edges of service areas, or where copper wiring is degraded by weather

• cf. speed over wireless drops off with distance and the number of other wireless customers in your locality
Impact of distance #2

- There's also the matter of total “distance” to the online service(s) you are using
  - Well outside the NBN, and possibly outside your ISP
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• Impacts total performance of networked application
  • Mere 100s of milliseconds degrades *apparent* bandwidth
    • e.g. North America is a 180ms to 250ms 'round trip' for data
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• For example: your “Cloud” service provider's location can really make a difference
  • On-shore providers will perform better than ones in the northern hemisphere
The heady benefits of speed....
The heady benefits of speed....

Uplink range for common copper-pair links (e.g. ADSL)
The heady benefits of speed....

Time to transfer content with local AU site

- Uplink range for common copper-pair links (e.g. ADSL)
- Uplink range for NBN fiber
When data is in smaller chunks...

Time to transfer content with local AU site

Time to transfer content in 256kByte chunks (AU Site)
When data is in smaller chunks...

At high speeds, sending data in large blocks is noticeably faster than lots of sequential small transfers.
The headache of latency....

Time to transfer content when the bandwidth is 8Mbps

- West coast USA
- Europe

On-shore

Delay

Time to transfer (s)

- 2 MB
- 8 MB
- 32 MB
The headache of latency....

Time to transfer content when the bandwidth is 8Mbps

<table>
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<tr>
<th></th>
<th>2 MB</th>
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<th>32 MB</th>
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Time to transfer (s) vs Delay (RTT) (ms)

- West coast
- USA
- Europe

On-shore
Latency, and data in smaller chunks

Consider locating remote data storage in Australia vs the west coast USA

---

Time to transfer content in 256kByte chunks (AU Site)

Time to transfer content in 256kByte chunks (California)
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What dictates our need for bandwidth?
What are people doing in their homes?

- TV / Video playback
- Radio / Audio
- Phone
- Internet / Web
- Telecommuting
- Medical Telemetry
- Remote security monitoring
- Mp3 player, iPod...
- Online games
- (Stereotyped adult pair)
- (Obligatory 2.5 kids)
Pressures on consumer demand

- Upward pressure
  - Desire
  - Convenience
  - Capability

- Downward pressure
  - Financial costs
  - Availability / (in)convenience
  - Ability to consume
Creation, delivery and presentation

• **Creation:**
  - Audio/video from live action, Studio-based TV, retrieval from DVD / HD storage, game servers
Creation, delivery and presentation

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• **Presentation:**
  - Media players, TV, Hi-Fi Stereo systems, iPods, mp3 players, online games, on-screen chat room interfaces, news websites, etc
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• Creation and presentation occur at the network 'edges'

• **Delivery is where network resources are consumed**

• Bandwidth requirements during delivery depend on the temporal relationship between creation and presentation
Further decoupling of each step

- Creation ➤ immediate or delayed delivery
  - Real-time streaming (immediate delivery)
  - Participatory virtual game worlds (immediate delivery)
  - Retrieve-on-demand, such as VoD or common web surfing (delayed delivery)
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- **Delivery ➤ immediate or delayed presentation**
  - Real-time streaming or watching 'on demand' content (immediate presentation)
  - Participatory virtual game worlds (immediate presentation)
  - Download into (optionally portable) device for later use (delayed presentation)
Or more succinctly...

- Delivery may be required at:
  - Faster than, at or slower than real-time
Or more succinctly...

- *Delivery* may be required at:
  
  Faster than, at or slower than real-time

- 'Faster than' can imply *any* attainable speed...
  
  - Pragmatically it will be bounded by available technology and a consumer's personal cost-benefit trade off
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• 'Faster than' can imply *any* attainable speed...
  
  • Pragmatically it will be bounded by available technology and a consumer's personal cost-benefit trade off

• The last two are bounded by content encoding and a person's ability to consume the presentation
  
  • Let's consider these in more detail....
What can a typical home consume?

- 'Slower than' is less than or equal to 'at real-time'

- Just how much content can a home consume at real-time?
What can a typical home *consume*?

- 'Slower than' is upper-bounded to 'at real-time'
- Just how much content can a home consume at real-time?

- Constraints include:
  - Number of occupants
  - Number of rooms
  - Concurrent visual media consumption
  - Concurrent audio media consumption
  - Concurrent telemetry, immersive 'game' participation, etc
A person consuming visual content

- Not an unbounded system
  - We tolerate various sizes and quality (vs cost or convenience)

- Visual resolution limits
  - Ability to resolve pixels
  - Screen sizes limit the required resolution
  - Home theater screens in *typical* homes are bounded by possible seating arrangements

Webcam, Youtube, etc
PAL / NTSC
DVD
High Def
Home Theater
Some visual limits

- Bandwidth of a human eye-brain connection ...
  ~10Mbit/sec
  Koch et al., "How Much the Eye Tells the Brain", Current Biology 16, pp.1428-1434, July 25 2006

- Optimal viewing distance for current HD content (at 1888x1080) is ~3 to 4 times the height of the screen
Video on Demand / Streaming

- Consumed in real-time, and no need to deliver faster than it is consumed
  - If you need it now then download in real time, if you need it later then we download at \( \leq \) real time
- Compression is common and improving:
  - E.g. Apple's H.264 literature claims: 1-2Mbps for 640x480@24fps, 5-6Mbps for 1280x720@24fps and 7-8Mbps for 1920x1080@24fps
  - Perhaps 3 concurrent HD channels? < 30 Mbit/sec
    - Or perhaps 3 concurrent regular TV channels and some 'youtube'-style video? < 10 Mbit/sec
A person consuming audio content

• Not an unbounded system
  • We tolerate various levels of quality and 3D immersion (vs cost or convenience)

• Spatial and frequency resolution limits of hearing
  • How many channels?
  • In how many rooms?

Skype, VoIP, etc
PSTN & mobiles
Stereo, 5.1, 7.1, ...
Home Theater
Streaming audio

- Consumed in real-time, and no need to deliver faster than it is consumed
  - If you need it now then download in real time, if you need it later then we download slower than real time
- Under 0.5 Mbit/sec for ridiculously good quality
  - Large market happy with CD-quality @ 128Kbit/sec
    - (smaller markets of audiophiles notwithstanding)
- Perhaps 5 concurrent channels? -> 2.5 Mbit/sec
Voice and Games

- Voice over IP / Telephony
  - Primary requirement is low loss/latency
  - Worst case ~100kbit/sec per active call
  - perhaps 4 concurrent calls? -> 400kbit/sec
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- Online games
  - During periods of activity the multiplayer games typically aim for well under 100kbit/sec per player
  - During game update (non-playing) periods perhaps one or two megabit/sec is desirable, but 100-300kbit/sec tolerable
  - Perhaps 4 concurrent players? -> 400 to 1200kbit/sec
Email and File Sharing

- Email
  - Fast as possible, but we tolerate 10s of seconds delay
  - e.g. 5 Mbyte email in 30 secs (1.3 Mbit/sec) is okay
  - Allow extra, so perhaps 4 Mbit/sec per user and 2 concurrent emails at any given time -> 8 Mbit/sec
Email and File Sharing

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• File sharing
  • Fast is good, but tolerate 1000s of seconds delay
  • e.g. 400 Mbyte file in 30min (1.8 Mbit/sec) is okay?
  • So perhaps 4 Mbit/sec per user and 4 concurrent full-rate sharing at any one time -> 12 Mbit/sec
Web surfing and ???-casting

• Web surfing
  • Goal is to render pages 'fast', but diminishing returns
    • Does the user care about 0.1sec vs 0.3 sec render time?
    • For pages under 80Kbyte in 0.3 sec -> 2.1 Mbit/sec
    • Allowing for multiplexing of users, perhaps 5 Mbit/sec?
      • Linked content falls under previous categories
Web surfing and ???-casting

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- ???-casting (podcasting, etc....)
  - Download content for later playback/consumption
    - "Need it now, am going mobile in XX minutes"
    - Genuine case for download speeds faster than rate at which the content can be consumed by human
  - Difficult to characterise realistic bandwidth need...
A modest house, perfect b/w sharing

- Voice over IP 0.4 Mbit/sec
- Online games 1.2
- Video on Demand 30
- Streaming Audio 2.5
- Email 8
- File sharing 12
- Web surfing 5

A grand total of ~60 Mbit/sec

(assuming worst-case high quality video, no guesses for pod-cast style downloads, all services in use at once)

(and yes, I'm waving my arms vigorously – approximations abound....)
My “60 Mbit/sec” estimate assumes each class of application has a protected slice of bandwidth

Is perfect bandwidth sharing realistic?
Is perfect bandwidth sharing realistic?

- Short answer: No
  - File transfers, sync'ing of phones, etc collide with online games and voice/video at your home gateway...
So, bump up the speed estimate

• Provide > 60Mbit/sec ?
  • Previous estimate up by factor of 5-6? -> 360+Mbit/sec

• Opportunistic data-/file-transfer traffic flows can still cause transient starvation of capacity to other apps
  • But the impacts will be of much shorter duration

• Or traffic sharing technology in home gateways
  • ("quality of service", QoS)
    • Well beyond scope of this talk / difficult in consumer products
How much for 'Faster than real-time'?

- A difficult category to predict
- Download content into portable device, quickly, so delayed presentation (playback) can occur while disconnected from the network
  - e.g. Podcasts, personal CD collection, ...
  - Download size bounded by presentation medium
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• What is this worth to a customer?
  • ~1.5Mbit/sec to load 6Hrs of 128bit/sec audio in 30min
  • ~15Mbit/sec to load 6Hrs of 128bit/sec audio in 3min
  • What would customer pay for higher-speed physical layer just so they can burst for 3 – 30min once or twice a day?
What could I do with 20:1 Mbit/sec?

- 20 down and 1 up is plausible with ADSL2+
  - IF we had perfect bandwidth protection between classes of IP traffic, we might provide:
    - 4 concurrent SD TV channels (H.264) (10 Mbit/sec down)
    - 2 concurrent 'radio' stations and 2 high quality streaming audio stations (1.5Mbit/sec down)
    - 2 concurrent VoIP calls (0.2Mbit/sec up/down)
    - 2 concurrent online game players (0.2 Mbit/sec up/down)
    - ~8Mbit/sec down and 0.6Mbit/sec up for other elastic, non-realtime applications (email, web, etc...)
What *could* I do with 20:1 Mbit/sec?

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    - 2 concurrent VoIP calls (0.2 Mbit/sec up/down)
    - 2 concurrent online game players (0.2 Mbit/sec up/down)
    - ~8 Mbit/sec down and 0.6 Mbit/sec up for other elastic, non-realtime applications (email, web, etc...)
  - But *practical* bandwidth protection doesn't exist....
  - And home users need to *push* (video calls, upload their latest creations to YouTube, etc), so "1 up" isn't enough
A very rough, ball-park conclusion....

A *typical home* needs more like 60Mbit/sec inbound and 5 - 15 Mbit/sec outbound  
(using today’s guesses)

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(“in” and “out” speeds in Mbit/sec)
Questions...