Scope of this presentation

➢ Aim:
  ➢ To provide some information about the growth of the access network - past, present and future
  ➢ To show some of the key current drivers and potential future drivers in broadband services
  ➢ The current state of the Access Network
  ➢ The evolution required for future requirements
  ➢ The use of Wireless, FttH covered later in course
Growth of broadband deployments

- What is fuelling this growth?
- The current access network
- DSL deployments 1 – ADSL
- DSL deployments 2 – VDSL
- Overview of future fibre deployment options
Moore’s Law for *Commercially available* broadband services

- 2x every 18 months

![Diagram illustrating broadband access evolution](source: P. Vetter (Muse))
Current Deployment Trends - Global

- 150M broadband subscribers worldwide
  - 100M DSL subscribers Q1 2005 (62% share)
    - expected to exceed 140M by end 2005
  - DSL subscriptions grew 58% in 2004
  - Remaining 38% comprises mainly cable, although growth now low due to DSL availability
  - Some FTTH deployments, notably Japan committed to 5 million by 2006
Current Deployment Trends – by Country

- Broadband volume
  - Lines in use
  - Cable (legacy) – DSL (growth) split

Source: Point Topic 2004
Current Deployment Trends - Penetration

- Broadband penetration – Shows geographic attitude towards broadband

![Graph and Map showing broadband penetration in Europe]

Source: Point Topic 2004
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## Services and Applications

"Please indicate whether you do each of the following things online or visit/use each of the following information and entertainment sites weekly."

| Use email | Play games alone | Use Web-based email | Use instant messaging | Daily newspapers | Research products for purchase | National news sites | Use text-based chat | Stock quotes | Send electronic greeting cards | Download software | Research for free products | Enter competitions or sweepstakes | Magazines | Sports sites | Send photos via email | Look up recipes | Play games with/against others | Reference sites | Financial provider sites | Download music files | Internet Yellow Pages/phone directories | Government agency sites | Look up classifieds | Job or career information sites | Research a specific medical condition | TV sites other than news | Listen to streaming audio/audiocasts | Bid/sell in online auctions | Adult entertainment sites |
|-----------|------------------|---------------------|-----------------------|------------------|--------------------------|----------------------|------------------|--------------|-----------------------------|------------------|---------------------------|-----------------------------|----------|-------------|------------------------|------------------|-----------------------------|------------------|------------------------|------------------|----------------------------|------------------|------------------------|------------------------|------------------------|------------------|------------------------|
|          |                  |                     |                       |                  |                          |                      |                  |              |                             |                  |                          |                             |          |             |                        |                  |                             |                  |                        |                  |                           |                  |                        |                      |                          |                  |

### Bandwidth Sensitive apps
- current broadband drivers

Percent of subscribers that do each activity weekly

Base: US consumers
Consumer requirements

Current drivers – Internet traffic

- Peer to peer communication continues to dominate current network traffic
  - Symmetric load
  - Now accounts for 50-70% of all Internet traffic
- Online Internet gaming accounted for 10% of Internet traffic in 2003
  - Gaming will be >30% of US Internet traffic by 2008
  - 90% of Internet users in Korea play games
  - Revenues >$4 Bn by 2008

- File sharing shift from MP3s (3-5 MB) to DVDs (700 MB)
## Services and Applications – BW requirements

<table>
<thead>
<tr>
<th>Application</th>
<th>Downstream</th>
<th>Upstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Streaming Audio</td>
<td>128K - 384K</td>
<td>64K</td>
</tr>
<tr>
<td>Internet Access</td>
<td>256K - 1.5M</td>
<td>64K - 640K</td>
</tr>
<tr>
<td>Web Hosting</td>
<td>400K - 1.5M</td>
<td>400K - 1.5M</td>
</tr>
<tr>
<td>Video Conferencing</td>
<td>384K - 1.5M</td>
<td>384K - 1.5M</td>
</tr>
<tr>
<td>Distance Learning</td>
<td>384K - 1.5M</td>
<td>384K - 1.5M</td>
</tr>
<tr>
<td>Telecommuting</td>
<td>1.5M - 3M</td>
<td>1.5M - 3M</td>
</tr>
<tr>
<td>Interactive Video</td>
<td>1.5M - 6M</td>
<td>128K - 6M</td>
</tr>
<tr>
<td>VoD</td>
<td>1M - 18M</td>
<td>64K - 640K</td>
</tr>
<tr>
<td>Multiple Digital TV</td>
<td>2M - 8M</td>
<td>64K - 640K</td>
</tr>
<tr>
<td>Multiple VoD</td>
<td>6M</td>
<td>64K - 640K</td>
</tr>
<tr>
<td>HDTV</td>
<td>6-18M</td>
<td>64K</td>
</tr>
<tr>
<td>Gaming</td>
<td>2-20M</td>
<td>64K – 20M</td>
</tr>
</tbody>
</table>

Source: Cisco 2005
## Future bandwidth requirements - summary

<table>
<thead>
<tr>
<th>Application</th>
<th>DS requirement</th>
<th>US requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDTV (3 per home at 20 Mbps each)</td>
<td>60 Mbps</td>
<td>&lt;1 Mbps</td>
</tr>
<tr>
<td>Standard TV = 4.5 Mbps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Online Gaming</td>
<td>2-20 Mbps</td>
<td>2-20 Mbps</td>
</tr>
<tr>
<td>VoIP (3 per home)</td>
<td>0.3 Mbps</td>
<td>0.3 Mbps</td>
</tr>
<tr>
<td>Data/Email etc</td>
<td>10 Mbps</td>
<td>10 Mbps</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>~ 90 Mbps</strong></td>
<td><strong>~30 Mbps</strong></td>
</tr>
</tbody>
</table>

100 Mbps no longer looks like a luxury
Growth of broadband deployments
What is fuelling this growth?
The current access network
   ➢ DSL deployments 1 – ADSL
   ➢ DSL deployments 2 – VDSL
   ➢ Overview of future fibre deployment options
UK copper access network

- Built for telephony up to 80 years ago
- 29 m copper pairs
- 5600 exchange buildings
- 1.5 m DP poles
In addition to Copper

- **Cable** – Widely deployed, particularly in US and Canada. Primarily for TV broadcast services.
- **Fibre** – Very low penetration due to present cost issues, some residential FTTH in EU but mainly commercial office/campus networks
- **Satellite** – Seen as last resort option for remote CPs, very expensive
- **3G cellular wireless** – Some services becoming available
- **Wireless** – WiMax etc. – Promising but still early stages
Narrowband - Dialup

- Dialup – dominant until late 1990’s
  - Transmitting directly over the voice channel
  - 64 kbps digital PSTN network with ~3 kHz analogue bandwidth
  - Transition from 2.4 Kbps, 4.8 Kbps (1987/8)
  - Mid 1990s V.34 standard QAM based – Shannon limited to ~33 kbps
  - Mid/late 1990s V.90 standard PCM based – relied on the digital PSTN exchange, could theoretically therefore reach the 64 kbps (although standard limited to 56 kbps)
  - Useful for basic email/internet access typified by slow data transfer and ability to use either telephone OR data
Digital Subscriber Line

- Introduced as a ubiquitous broadband upgrade path for reuse of existing copper network
- Earliest DSL standards date back to 1970’s but really took off in early 1990’s with advent of powerful DSP processors
- Simultaneous voice and data over same link
- Makes full use of available frequency spectrum
- Growth of broadband deployments
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Digital Subscriber Line Family

- IDSL – similar rates to IDSN to 144 kbps symmetrical
- HDSL – First introduced commercially (1992)
  - 1.5 Mbps symmetric over 2 pairs
- SHDSL – to 2.3 Mbps Symmetric over single line
- ADSL – Rate adaptive to 15 kft
  - to 8 Mbps DS, 640 kbps US over single line
  - Aimed at Internet, data, low equipment cost
- VDSL
  - Asymmetric to 52 Mbps DS
  - Symmetric to 26 Mbps
  - Rate adaptive, relatively short reach (1-3 kft)
  - VDSL2/VDSL+ etc. Exceed 100 Mbps
DSL LAN wiring configuration

- Potential of DSL for home networking or SME LAN interface
ADSL - Impairments

- Noise
  - Switches, lighting, power lines, AM broadcasting, Ham radio

- Crosstalk
  - NEXT – reflected back to adjacent receiver
  - FEXT – Cross coupling between adjacent wires in binder, attenuated by the line
  - NEXT dominates FEXT where it occurs although reduced for example by non-overlapping DS/US frequency bands

- Bridged taps
  - Tap cable not in the direct CPE-CO path, can result in echoes and attenuation glitches

- Attenuation…
Network was built for voice traffic
- Primary limitation to transmission distance
- Leads to reduced SNR at far end
- 1km (3.3kft) of 24AWG Cat-3 cable
Survey average loop length

% Cumulative

Distance (km)

Source: IEEE
Discrete Multi-tone Modulation

- One of the main modulation formats employed in DSL
  - Although some early adopter VDSL based on CAP/QAM format
- Attempts to make best use of poor quality transmission channel
- Transmitting multiple tones each carrying narrowband QAM signal
- Handshaking between modems sets out water-filling or bit-loading condition for each of the tones depending on link quality at tone frequency
ADSL - DMT modulation

- **Voice band (baseband)** for first 4kHz
- **POTS splitter** to separate voice and data signals
- **ADSL** = 256 carriers, spaced ~4 kHz apart within 1.1 MHz analogue bandwidth
- 26 - 138 kHz for US, 138 kHz - 1.1 MHz for DS
- Each carrier supports QAM signal at a level determined by water-filling
- Tones bit loading may be reduced or increased in line with SNR at that frequency
- Total data transmission is the sum of contributions from all tones
Example of link loss and bit-loading characteristics for typical clean 9 kft (2.7 km) link.

In this example, the ADSL modems established a link with data rate of 7008 kbps DS.
Example of link loss and bit-loading characteristics for 9 kft (2.7 km)

Here, the link attenuation is slightly degraded by the presence of a bridged tap after 300 ft

Here a data rate of 5888 kbps DS was achieved
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VDSL

- Very high data rate DSL
  - The next evolutionary step from ADSL
  - VDSL supports up to 52 Mbps DS
  - Reach limited to typically <1 km
  - VDSL2/VDSL2+ now achieving 150 Mbps over 300 m
  - Requires a change of network architecture to accommodate shorter reaches
VDSL bandplans

- VDSL supports several Bandplan standards
- DS always lower frequency range – so it is the least affected by link attenuation
- China – simple split between DS and US
- 997/998 multiple US/DS bands interleaved to maintain even ratio as link deteriorates
- 997 more symmetrical in nature than 998
xDSS capabilities - ADSL to VDSL

Based on lab measurements so optimistic
Fibre extend reach due to low attenuation, crosstalk impairments
Street node contains DSLAM, higher layer transmission protocol between ONU and OLT
This configuration called the RDSLAM (remote)
ONU options

- RAM – Remote Access Multiplexer
- Low profile version of the RDSLAM designed to fit into cabinet, avoiding the need for additional cabinet
- Smaller size and lower cost – can be squeezed into existing cabinet space
- May be externally powered
- Up to 48 subscribers per unit
ONU options

- SAI-based DSLAM – (service area interface)
- Deep fibre penetration (FTTcurb) required
- Due to remote nature must be rigorously industrially hardened
- Line powered – potentially from the CO
- Can be placed virtually anywhere and may be used to extend to the fringes of a DSL network
- Picture shows 24-port ADSL DSLAM
ONU options

- Fibre-optic DSL extender (virtual DSLAM)
- Extends existing CO DSLAM signal to remote cross-connect cabinets
- Multiplexes DSL signal over GigE interface (for example)
- Facilitates delivery of DSL to remote outreaches
- May reach 25 km from the CO (more typical of US networks)
VDSL over Fibre to the Curb architecture
- SAI-based ONU
- Retains DSLAMs at the CO
- Low cost, low power interfacing hardware at the Cab/Curb
- Designed for remote power feed
- Sub-carrier multiplexing for hardware efficient provision to multiple premises
Sub carrier multiplexing

- Each CPE VDSL signal assigned own frequency at the OLT/ONU
- Each frequency converted signal then Sub-carrier multiplexed onto single directly modulated laser
- Typical low cost laser modulation bandwidth of 1 GHz allows for up to 40 12 MHz band VDSL signals without sideband removal
- Penalties
  - Intermodulation distortion
  - Nonlinear distortion of laser – corrected through passive predistortion circuit or signal processing
Hardware setup

CP

CPE modem
100BASE-T

106m UTP

100BASE-T

ONU

DFB-LD

HPF

LO

Directional Coupler

Photodiode

Upstream

Downstream

Optical fibre

OLT/CO

DFB-LD

HPF

LO

Directional Coupler

Photodiode

DSLAM

Internet
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Optical architecture considerations

- Passive Optical Networks – General wavelength assignment
- 1490nm DS traffic
- 1310nm US traffic
- 1550nm Broadcast Video
- Range limited to <20km so dispersion and loss characteristics of fibre are not important in wavelength choice
Basic PON structure showing both FTTP and FTTC architectures

- FTTC in this case shown with final VDSL drop
WDM PON overlay

- Next level showing C-band WDM overlay
- WDM wavelengths could increase bandwidth provision for some users (businesses etc.)
WDM ring network - Protection

- Again WDM overlay but using ring for protection
WDM ring network

- WDM ring now incorporating a distribution ring tributary – potentially increasing sharing of available bandwidth on this wavelength
Summary

- Access bandwidth availability increasing
- Increasing bandwidth requirements in services
- Copper telephony network heavily dominates current infrastructure
- DSL best current technology for using existing network capabilities
  - reach limitations will demand rethink of this infrastructure if bandwidth provision is to increase
- Finally, some fibre penetration scenarios briefly discussed
  - Speculating on the potential role of WDM and ring architectures
Thank you for your attention.
Acknowledgements

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  - P. Vetter, J. Wellen, A. Koonen, K. Dieter-Langer, K. Habel and others 😊
- Information on DSL deployment options and scenarios for the future are available on www.dslforum.org
- Information on PON deployment options and trends available on www.ponforum.org