P5: Broadband Access
When do we Get 100 Mbps?

Chair: J. Cioffi  (Stanford U.)
ICC 2004 –Paris
June 22, 2004
cioffi@stanford.edu

SPEAKERS
Tony Werner, CTO – Liberty Cable
Ted Rappaport, Professor, U of Texas (Austin)
Oleh Sniezko, CTO Aurora Networks
Paul Spruyt, DSL technology strategy, Alcatel
Access Products, Antwerp, Belgium
Access Networks

- Internet
- PSTN
- MAN Ring
- CO
- OLTs
- RN
- FTTC, FTTH
- FTTB
- DSL
- Wireless Access
- ONU
- DSLAM
- Power Co?
- Satellite
Winners?

• All of them
  – Tremendous telecom opportunity in next decade
• Demanded data rates never go down
  – 6.4 Billion people on Earth
  – 1.38 Billion Cellphone subscribers
  – 750 Million PCs in operation
  – 700 Million Internet Users (12% of world)
  – 100 Million Broadband Users (1.7% of world)
  – 5.7 Billion people have yet to use Internet (!)

• Applications
  – Video, data, voice/audio (as always)
Worldwide Broadband Subscribers by Technology

Source: RHK Inc. (www.rhk.com)

Also – T. Rappaport, C. Na, J. Chen, H. Nam, and S. Lemo
FCC TAC presentation, April 2004
Panel Broadband Evolution

Millions of Paying Customers

- recently, DSL has come to deploy more new adds than cable after lagging cable net adds for several years.
DSL Percentage penetration

Paying customers per 100 people (source is DSL Prime, 5/17/04) – YE03

- China now has the largest number of DSL subscribers in the world
## Countries with Highest Raw # of Internet Users

<table>
<thead>
<tr>
<th>#</th>
<th>Country or Region</th>
<th>Internet Users Latest Data</th>
<th>Population (2004 Est.)</th>
<th>Internet Penetration</th>
<th>Source of Latest Data</th>
<th>% of World Usage / Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>United States</td>
<td>199,096,845</td>
<td>294,540,100</td>
<td>67.6 %</td>
<td>Nielsen//NR Jan/04</td>
<td>26.7 %</td>
</tr>
<tr>
<td>2</td>
<td>China</td>
<td>79,500,000</td>
<td>1,327,976,227</td>
<td>6.0 %</td>
<td>CNNIC Dec/03</td>
<td>10.7 %</td>
</tr>
<tr>
<td>3</td>
<td>Japan</td>
<td>62,374,142</td>
<td>127,944,200</td>
<td>48.8 %</td>
<td>Nielsen//NR Feb/04</td>
<td>8.4 %</td>
</tr>
<tr>
<td>4</td>
<td>Germany</td>
<td>45,315,037</td>
<td>82,633,200</td>
<td>54.8 %</td>
<td>Nielsen//NR Jan/04</td>
<td>6.1 %</td>
</tr>
<tr>
<td>5</td>
<td>United Kingdom</td>
<td>35,089,470</td>
<td>59,157,400</td>
<td>59.3 %</td>
<td>Nielsen//NR Jan/04</td>
<td>4.7 %</td>
</tr>
<tr>
<td>6</td>
<td>South Korea</td>
<td>29,220,000</td>
<td>47,135,500</td>
<td>62.0 %</td>
<td>KRNIC Dec/03</td>
<td>3.9 %</td>
</tr>
<tr>
<td>7</td>
<td>France</td>
<td>22,233,907</td>
<td>59,494,800</td>
<td>37.4 %</td>
<td>Nielsen//NR Jan/04</td>
<td>3.0 %</td>
</tr>
<tr>
<td>8</td>
<td>Brazil</td>
<td>20,551,168</td>
<td>183,199,600</td>
<td>11.2 %</td>
<td>Nielsen//NR Jan/04</td>
<td>2.8 %</td>
</tr>
<tr>
<td>9</td>
<td>Italy</td>
<td>19,900,000</td>
<td>56,153,700</td>
<td>35.4 %</td>
<td>ITU Dec/02</td>
<td>2.7 %</td>
</tr>
<tr>
<td>10</td>
<td>Canada</td>
<td>16,841,811</td>
<td>32,026,600</td>
<td>52.6 %</td>
<td>Nielsen//NR May/02</td>
<td>2.3 %</td>
</tr>
<tr>
<td></td>
<td><strong>TOP TEN COUNTRIES</strong></td>
<td><strong>530,122,380</strong></td>
<td><strong>2,270,261,327</strong></td>
<td><strong>23.4 %</strong></td>
<td><strong>IWS - Apr.6/04</strong></td>
<td><strong>71.1 %</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Rest of the World</strong></td>
<td><strong>215,230,718</strong></td>
<td><strong>4,183,049,740</strong></td>
<td><strong>5.1 %</strong></td>
<td><strong>IWS - Mar.19/04</strong></td>
<td><strong>28.9 %</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Totals</strong></td>
<td><strong>745,353,098</strong></td>
<td><strong>6,453,311,067</strong></td>
<td><strong>11.5 %</strong></td>
<td><strong>IWS - Apr.6/04</strong></td>
<td><strong>100.0 %</strong></td>
</tr>
</tbody>
</table>

Source: InternetWorldStats.com

Also – T. Rappaport, C.Na, J. Chen, H. Nam, and S. Lemo
FCC TAC presentation, April 2004
Where is it?  (DSL – May 2004)

Source: DSL Prime, 6-20-04  -- Total = 73,426 Million Paying Customers
Real Question Then?

• When do we get 100 Mbps?
  – Symmetric
  – Yes, it’s feasible in DSL (and fiber)
    • See Thursday tutorial

• ANSWERS
  – To follow
    • Cable, Wireless, Fiber, DSL
      – Audience should cover power-line and satellite!
        » We could only have 4 panelists
  – (Cioffi’s prediction – 2010: 250 Million will have 100 Mbps to/from the internet, not just within premises or local network)
Broadband Access: 
*When do we get 100 Mbps?*

Tony Werner
June 22, 2004
Agenda

- What is 100 Mbps?
- How is Bandwidth Used
- What is Available Today
- Technologies & Architectures
- Summary
What is 100 Mbps?

- Best Efforts, Guaranteed, QOS, Burst, Asynchronous, Isochronous, Synchronous
- Phy Layer Speed, or net of all overhead
- Symmetry
- Traffic Shaped
How is Bandwidth Used

- A moving target
  - Illegal music decreasing
  - Legal music increasing
- P2P can account for significant % of Traffic
  - 40% - 80%
  - Small % of customers can also account for high % of traffic

Source: Jupiter Research, Screen Digest, Pew Research, RedSheriff, Nielsen Netratings, Internal measurement
Trends in Video Coding

- HD ATSC specification
- SD MPEG-2
- HD MPEG-4 AVC H.264
- Starts to Become Internet Friendly
- HDTV
- Multiple Sets
Storage Technology Impact on Video Services

- One hour of 2 Mbps video requires 1GB of storage.
- A 640 GB HD will store:
  - 320 movies of 2 hours
  - 26 full days of TV programs
  - 460 full days of CD quality music
- In 2010-2011 a 10 TB HD will cost <$1K.

Assume a person watches TV for 2 hours a day during 75 years:
A $6K PC with 3x20 TB HD will store a lifetime of video!
What is Available Today

- Varies Significantly by Market
  - US Typically 3Mbps Cable Modem, 1Mbps DSL
- Japan
  - Competing on speed and aggressive marketing
    - Handing out free modems at train stations

<table>
<thead>
<tr>
<th>ADSL</th>
<th>Advertised Tiers (Mbps)</th>
<th>Price*</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSL</td>
<td>8,12,26</td>
<td>$32.50 - $45.00</td>
</tr>
<tr>
<td>Cable Modem</td>
<td>8,10,30</td>
<td>$37.00 - $51.00</td>
</tr>
<tr>
<td>FTTH</td>
<td>100</td>
<td>$44.50 - $70.00</td>
</tr>
</tbody>
</table>
Japan 30 Mbps Tier Speeds

Busy Hour Average Speeds

Source: Internal Test Scripts
Technologies & Architectures

Primary Ring

Primary Hub

FN

FN

Analog TV

Digital TV

DOCSIS

5 50 500 750 1G
Technologies & Architectures **Cable Modem**

**Demand**
- Take Rate
- Applications
- User Behavior

- More RF Channels
- Higher RF Efficiency
- Split Nodes
- Push Fiber Deeper

**Bandwidth per Home Passed**

**Time**
Technologies & Architectures **Cable Modem**

*Multi or Wide Band DOCSIS is fastest way for Cable to Achieve 100 Mbps*

- EDOCSIS 2.0: 50 Mbps DS, 120 Mbps US
- MBDOCSIS: 1 Gbps DS, 120 Mbps US

“Multi-Band” DOCSIS

LIBERTY
When Does Cable Provide 100 Mbps

• If 5 to 10 Mbps Serves Data Needs and Excess is Required for Video, then
  – Cable Delivers today - Typically 1 Gbps of broadcast MPEG2 and >100 Mbps of switched MPEG2

• If 100 Mbps is Required for other Applications, then
  – Multi-Band DOCSIS
    • Proprietary implementations available today
    • Standards based, 2006
Summary

• Several Technologies Will Serve the Broadband World
• Cable Architecture Has Fast Evolution Model to Provide High Bit Rates
• Needs Unclear… Other Than Video
  – Cable Already can and does provide digital and Switched MPEG Video
  – Telcos Need Bundle
Appendix Material
Technologies & Architectures

**DSL**
- Initial Capacity From First 2 KA Satellites is 11 Gbps

**CM**
- Boeing building *Anik F2*
- Loral building *WildBlue-1*

**Satellite**
- Spot beams provide 4-8x the capacity per dollar (vs. CONUS Ku beam)

**BPL**
- Geosynchronous orbit covers continental U.S. with 1 satellite

**FTTP**
- Low cost “bent pipe” satellite
Technologies & Architectures

Net data rate of 2-6 Mbps 50+ Mbps next generation

DSL
CM
Satellite
BPL
FTTP
802.16
Broadband Access: When do we get to 100 Mbps

Prof. Theodore S. Rappaport

Wireless Networking and Communications Group
The University of Texas at Austin
wireless@mail.utexas.edu
ICC ’04 Paris
June 22, 2004
What is driving bandwidth?

- Memory costs are rapidly decreasing
- Semiconductor Roadmap
- PAN, UWB, Mobile Internet early adoption
- Worldwide Demand for Broadband fueled by survival or expansion of democracy. 85% of the world’s inhabitants have yet to log-on!
- Spectrum Allocations for Broadband Wireless
## ITRS Technology Nodes and Chip Capabilities

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Microprocessor Speeds (MHz)</strong></td>
<td>1,684</td>
<td>5,173</td>
<td>11,511</td>
<td>28,751</td>
</tr>
<tr>
<td><strong>Gate Length (nm)</strong></td>
<td>65</td>
<td>32</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td><strong>DRAM Cost/bit (micro-cents)</strong></td>
<td>7.7</td>
<td>1.9</td>
<td>.34</td>
<td>.042</td>
</tr>
<tr>
<td><strong>DRAM memory size</strong></td>
<td>512M</td>
<td>2G</td>
<td>8G</td>
<td>64G</td>
</tr>
</tbody>
</table>

Gate Width - Lithography

EUVL: Extreme Ultraviolet Lithography


C. 2004 T. S. Rappaport  
June 22, 2004
Korea Broadband Market

- Broadband is Fully Deployed
  - 90% of households
  - Dialup has become "horse and carriage"
  - Broadband is social infrastructure like telephone or automobile or television

- Building Next Generation Broadband
  - VDSL(40 Mbps) vs FTTH(100 Mbps~)
  - LAN(~FTTH) deployment at 15%

- Mobile and Wireless
  - Mobile Internet is taking off
  - Major deployment of wireless LAN
Spectrum Policy Worldwide

- Global Digital divide must be bridged by Wireless Broadband
- India, UK, Korea has 10-12 GHz spectrum (approx. 100 MHz blocks)
- Most countries have 2.2 GHz, 3.5 – 3.7 GHz (approx. 50 MHz blocks). US just now considering 3.65-3.7 GHz band at high power w/shared FSS
- UWB, WiFi, WiMax to proliferate worldwide
- LMDS at 28 – 38 GHz (500 MHz blocks) but frequencies too high for semi roadmap
HIPERLINK/802.15/802.16/802.20

- Hiperlink will provide short-range very high-speed interconnection of HIPERLANs and HIPERACCESS, e.g. up to 155 Mbit/s over distances up to 150 m.
- 802.15.3.a (UWB) Shipping in 2005 – Wireless USB (100 - 480 Mbps in homes)
- Standardization underway includes MiMo, Mesh Networking, WiFi, WiMax
EU Spectrum Guidelines for Fixed Wireless

- Radio frequency spectrum is managed on a national basis within EU
- EU provides guidelines to member countries
- Spectrum available for fixed wireless:
  - 3.4 – 3.6 GHz
  - 10.15 – 10.3 GHz
  - 10.5 – 10.65 GHz
  - 24.5 – 26.5 GHz
  - 27.5 – 29.5 GHz

ETSI TR 102 137 V1.1.1 (2002-11) - Electromagnetic compatibility and Radio spectrum Matters (ERM); Use of Radio Frequency Spectrum by Equipment meeting ETSI Standards
# BWA Spectrum in India

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.535 – 2.655</td>
<td>LMDS and MMDS may be coordinated on a case-by-case basis</td>
</tr>
<tr>
<td>2.7 – 2.9</td>
<td>MMDS may be considered on case-by-case basis up to a maximum of 77 MHz</td>
</tr>
<tr>
<td>3.3 – 3.4</td>
<td>LMDS and MMDS may be considered on a case-by-case basis</td>
</tr>
<tr>
<td>10.15 – 10.65</td>
<td>LMDS may be considered on a case-by-case basis</td>
</tr>
<tr>
<td>24.5 – 26.5</td>
<td>LMDS and MMDS may be considered on a case-by-case basis</td>
</tr>
<tr>
<td>27.5 – 29.5</td>
<td>LMDS and MMDS may be considered on a case-by-case basis</td>
</tr>
</tbody>
</table>
China: Government Initiatives for 3.5 GHz in China

- Aug. 2000: The Chinese State Radio Regulatory Commission (SRRC) allocated two blocks of 31.5 MHz each: 3399.5 - 3431 MHz and 3499.5 - 3531 MHz
- 2001: standard YD/T1158-2001 enacted
- 2002: standard YD/T1197-2002 enacted
China: Bid Winners (the First Round)

- China Communications and China Mobile both won all 5 cities.
- China Satcom, PTIC, China Siajiang, and Xiamen (Amoy Jing Qiao) won the bids for one city each.
- All six license-winners are Chinese companies.
China: Bid Winners (the Second Round)

- China Communications: 25 cities
- China Unicom: 23 cities
- China Netcom: 17 cities
- China Mobile: 10 cities
- China Telecom: 9 cities
- China Railcom: 5 cities
- China Satcom: 3 cities
- Icitic and Xiamen (Amoy Jin Qiao): 1 city each
- All nine license-winners are Chinese companies
China: 32 Cities of the Second Tender
China: the 3\textsuperscript{rd} tender for 3.5 GHz

- Licenses in 27 provinces and autonomous regions (330 cities). Each region has three blocks of 10.5 MHz each, each of which is assigned to a licensee.
  - China Telecom: 15 regions
  - China Netcom: 19 regions
  - China Mobile: 15 regions
  - China Unicom: 14 regions
  - China Railcom: 16 regions

- China’s 3.5 GHz network will soon become very popular – world model!
## Mobile Internet Technologies Considered in Japan – 2005 rollout

<table>
<thead>
<tr>
<th></th>
<th>Flarion</th>
<th>ArrayComm</th>
<th>Navini</th>
<th>Broadstorm</th>
<th>ETRI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operating frequency</strong></td>
<td>700MHz, 2.3GHz</td>
<td>1.9, 2.3 GHz</td>
<td>2.3 ~ 2.5 GHz</td>
<td>700 ~ 3.5 GHz</td>
<td>2.3GHz</td>
</tr>
<tr>
<td><strong>Duplex</strong></td>
<td>FDD</td>
<td>TDD</td>
<td>TD</td>
<td>TDD</td>
<td>TDD</td>
</tr>
<tr>
<td><strong>Multiple access</strong></td>
<td>Fast-Hopping OFDMA</td>
<td>TDMA/SDMA</td>
<td>SCDMA</td>
<td>OFDMA+ MC-CDMA</td>
<td>OFDM/TDMA</td>
</tr>
<tr>
<td><strong>Frequency efficiency</strong></td>
<td>2.56bps/Hz (3.2Mbps/1.25 MHz)</td>
<td>4bps/Hz (1Mbps/625KHz)</td>
<td>3 ~ 7bps/Hz</td>
<td>3.2 bps/Hz(5 MHZ)</td>
<td>3.4bps/Hz (34Mbps/10Mbps)</td>
</tr>
<tr>
<td><strong>Modulation</strong></td>
<td>BPSK, QPSK, 16QAM</td>
<td>BPSK, QPSK, 8PSK 16QAM, 24QAM</td>
<td>QPSK, 8PSK 16QAM, 64QAM</td>
<td>QPSK, 8PSK 16QAM, 64QAM</td>
<td>BPSK, QPSK 16QAM, 64QAM</td>
</tr>
<tr>
<td><strong>Antenna</strong></td>
<td>Multi-Tx Antenna</td>
<td>Adaptive Antenna array</td>
<td>smart antenna</td>
<td>None</td>
<td>Two Antenna, later MIMO</td>
</tr>
<tr>
<td><strong>Channel coding</strong></td>
<td>Vector LDPC</td>
<td>RS</td>
<td>RS</td>
<td>Convolutional Code</td>
<td>Turbo Code</td>
</tr>
<tr>
<td><strong>ARQ</strong></td>
<td>Flash-ARQ &amp; CRC</td>
<td>ARQ</td>
<td>ARQ</td>
<td>ARQ</td>
<td>H-ARQ</td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td>~ 100Km/h</td>
<td>~ 50Km/h</td>
<td>Almost none</td>
<td>~ 100Km/h</td>
<td>~ 60Km/h</td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td>Flash-OFDM</td>
<td>i-Burst</td>
<td>Ripwave</td>
<td>Broad@ir</td>
<td>HPi</td>
</tr>
</tbody>
</table>
When do we get to 100 Mbps?
Rappaport predicts:

- 100 Mbps in homes NEXT YEAR (2005 -UWB)!
- 100 Mbps in 802.11 a/g NEXT YEAR (2005)!
- 85% of the World still needs the Internet – Broadband wireless to surpass all wired (cable/DSL installations) by 2013
- 10 – 12 GHz is MAGIC SPECTRUM for 100 MBPS WiMAX in 2006/2007. This will populate the world beginning in 2007.
- 100 Million Broadband Users will have 100 Mbps Broadband Wireless to the home by 2009, growing to 1 Billion people in 2014 (Today it doesn’t exist). WiMax early stages of a revolution of broadband delivery. Emerging nations and rural first world countries will be early adopters. Cable and Phone companies will abandon PON, DSL on cable, and begin switchover from fiber/copper to wireless in 2007. Mobility in 2009 will launch broadband explosion.
- Companies and Government R&D offices in Asia and Europe are waking up to the world export opportunity for fixed wireless technologies.
Aurora Networks
A Whole New Light

Broadband Access:
When do we get to 100 Mbps

Oleh J. Sniezko
Aurora Networks, Inc.
ICC ’04 Paris
June 22, 2004
Sales of broadband access will grow slowly.

Most broadband subscribers are happy to have rates up to 1.5 Mbps.

Demand for 1.5 Mbps rates to homes will peak around 2005.

Around that time, demand for 6 Mbps will become real.

Only after 2010, speeds of 24 Mbps will be in demand.

Study of Technology Futures Inc. (group funded by a consortium of carriers)
## Hybrid Fiber Access Alternatives & Services

Hybrid Fiber Access Type | Services | Interfaces |
--- | --- | --- |
Coax | Internet, Phone & VideoPhone, Broadcast A & V, VoD, AoD, IP-VPN, P2P, B2B | FE, MTA, DVB/MPEG, DOCSIS |
xDSL | Internet, Phone & VideoPhone, VoD, AoD, IP-VPN, P2P, B2B | 10 BaseT & RJ-11 analog phone, ISDN, B-ISDN, xDSL |
Wireless | Phone, Internet, IP-VPN, P2P, B2B | Ethernet 802.11 |
Fiber Depth Evolution (Before 2000)

- Cascades >25 RF Amplifiers
- Cascades <10 RF Amplifiers
- Cascades <5 RF Amplifiers
Fiber within 2000 feet (600 m) from the farthest customer
Practically unlimited growth capability
High reliability and low maintenance

Each node has a capability of backhauling 1.6 Gbps (Full Duplex) per wavelength

- Headend sends multiplexed (DWDM, FDM, TDM) signals to the hub
- Hub sends dedicated signals to dedicated nodes
- Node sends the node-bound signals to all subscribers (CPEs)
- Forward bandwidth is shared
- Each user is given a time slot (TDMA) and channels are FDM
- Upstream on the same coax, different frequencies, aggregated into different wavelengths
- Synchronization of the assigned time slots achieved with ranging
Opportunistic Deployment of FTTP

Fiber within 2000 feet (600 m) from the farthest customer
Practically unlimited growth capability
High reliability and low maintenance

Each node has a capability of backhauling 1.6 Gbps (Full Duplex) per wavelength

Hub Ring: DWDM
Hub (Pass Through)

Headend
Hybrid Fiber Coax Access
Bandwidth Capacity

- **Bandwidth/Capacity (coax only, fiber capacity enhanced with CDWM and DWDM)**
  - **Single Card DOCSIS 2.0 (Upstream Capacity > Downstream Capacity)**
    - >50 Mbps in 8 MHz 256-QAM downstream channel
    - >120 Mbps in four 6.4 MHz 64-QAM upstream channels
  - **Forward Channel Pooling and Evolutionary Progress (MBDOCSIS)**
    - >130 Mbps in two 1024-QAM downstream channels, up to 1 Gbps/card
  - **Total Capacity (mid-split 5-100 and 120-860 MHz HFC plant)**
    - 5-6.5 Gbps downstream
    - >360 Mbps
  - **Shared among 50-100 households (50 customers)**
    - Downstream ~100 Mbps/customer
    - Upstream ~7 Mbps
  - 1.6 Gbps and higher per node for SMB services

- **Distance:**
  - 160 km one way over fiber, 320 km loop distance

- **Cost (Hybrid Fiber Coax Access)**
  - Greenfields cost numbers range from $400-$800/household (all inclusive except for CPEs)
  - Brownfields cost numbers range from $200-$500/household (all inclusive except for CPEs) with exception for highly urbanized areas
From Fiber-Deep to FTTH

- Downstream Video: WDM, FDM & TDM
- Upstream: DWDM, TDM
- Pass the Node: Two-Way IP with any FTTH or Hybrid Fiber Technology
- Combines Advantages of PON with Dedicated Fiber Technology

Each node has a capability of backhauling 1.6 Gbps (Full Duplex) per wavelength

Cost
- Incremental cost of placing fiber is $100-$200 per household for greenfields
- OLT and EDFA cost shared (can be postponed until demand increase)
- CPE deployed selectively for high-end customers
Ethernet in the First Mile (EFM) vs. Passive Optical Network (PON)

- **EFM**
  - P2P over copper (EFMC/LRE)
  - P2P over Fiber (EFM-Fiber)
  - P2MP Ethernet over Fiber (EPON)

- **PON**
  - P2MP ATM over Fiber (APON, BPON)
  - P2MP Native (GFP) over Fiber (GPON)
FTTH Access Alternatives

Dedicated fiber
- ATM, SDH, Ethernet, PPP/IP

Active switched
- Fiber drop or hybrid
- IP; RPR; ATM; MPLS, SDH

PON
- WDM, TDM/TDMA, FDM or combination thereof
## PON Varieties

<table>
<thead>
<tr>
<th>PON Type</th>
<th>APON</th>
<th>EPON</th>
<th>GPON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard(s)</td>
<td>ITU-T G.983</td>
<td>IEEE 802.3</td>
<td>ITU-T G.984.1 through 3</td>
</tr>
<tr>
<td>Bandwidth/Capacity</td>
<td>155 or 622 Mbps</td>
<td>1 Gbps</td>
<td>2 or 1 Gbps</td>
</tr>
<tr>
<td>Bandwidth to customer</td>
<td>4.8 or 19.4 Mbps</td>
<td>31.25 Mbps</td>
<td>31.25 or 15.625</td>
</tr>
<tr>
<td>Number of ONT Ports</td>
<td>32</td>
<td>32</td>
<td>64</td>
</tr>
<tr>
<td>Cost Factors</td>
<td>Not easy to upgrade speed</td>
<td>OLT-ONU links not compatible with Ethernet</td>
<td>Small number of vendors</td>
</tr>
</tbody>
</table>

Based on Reference 5.

- **Equipment Cost**
  - Cost numbers range from $1,200-$3,000/customer
  - Forecast: $700-$800/customer range for equipment within the next year (no fiber, no trenching)

- **Driving factors:**
  - Applications (video adds a lot)
  - Deployment Location
OLT sends frames (ATM, Ethernet or other) of data to splitter

- Splitter sends same set of frames to each ONT/ONU
- Forward Bandwidth is shared

- Each user is given a time slot (TDMA)
- Upstream on the same fiber, different wavelength
- Synchronization of the assigned time slots achieved with ranging
FTTH Deployments

- Japan surpassed 1 million subscriber mark in 2004 (announced by Japanese government on March 31, 2004)
  - 46.8 million households total
  - 8.5% growth over January 2004
  - 296% growth over February 2003

- RBOCs (Verizon, SBC, BellSouth) issued RFP
  - Verizon is still promising 1 million homes passed in 2004
    • Mostly deploying FTTC
    • Regulatory problems (RBOCs vs. FCC and FTTH Council)

- Meantime 128 communities in the US (as of May 19, 2004) had customers serviced with FTTH (ILECs, CLECs, Muni, Utilities, Developers)
FTTH Deployment Forecast

Source: Legg Mason, OFS
Summary

- Never enough bandwidth but
  - Demand will grow slowly

- Best-Fit-Technology will lead the deployment rates
  - Best technology will be deployed under subsidies or to take advantage of the regulatory environment

- Short term leaders:
  - Pure copper xDSL
  - Cable modems over traditional HFC and fiber-deep (Hybrid Fiber Access)
  - Wireless

- Long term winners:
  - Hybrid Fiber (coax or copper) with cable modems (sufficient and renewable bandwidth at very low incremental cost) or xDSL
  - Wireless (ubiquitous and tether-less)
  - FTTH deployed selectively (FTTP, FTTB, hybrid fiber) and opportunistically
References

2. Russell Kay, *QuickStudy: WiMax*, December 1, 2003, Computerworld
3. TR 101 031 V02.02.01, Broadband Radio Access Networks (BRAN); High Performance Radio Local Area Network (HIPERLAN) Type 2; Requirements and architectures for wireless broadband access
8. Tim Bechter, Max Nelson, *How Fast will carriers build out fiber?*, July 1, 2003
9. Anupam Banerjee, Marvin Sirbu, *Towards Technologically and Competitively Neutral Fiber to the Home (FTTH) Infrastructure*
DSL
(when) can it offer 100 Mb/s?

Paul Spruyt
DSL Technology Strategy
Alcatel
paul.spruyt@alcatel.be
> DSL is the leading form of broadband access - today and tomorrow
  • DSL growing faster than cable
> DSL growth rate continues at ~ 2.6M lines per month
> 44.8 Mio DSL lines shipped WW in ‘03 versus 23.7 Mio in ‘02
Broadband services drive access networks

**User profiles**
- HDTV user or multiple-TV user
- digital TV user
- broadband PC user (High Speed Internet Access)
- narrowband PC user

**Typical bandwidth consumption**
- 10-20 Mb/s × 400
- 2.5-5 Mb/s × 100
- 0.5-3 Mb/s × 25
- 0.05 Mb/s × 1
DSL: more than only High Speed Internet
Active introduction of new BB services

Belgacom ups the speed of ADSL
Belgacom investeert 522 miljoen euro in VDSL

Línea ADSL + Adaptador de
Red PlayStation 2
Juegue con su PlayStation 2 a
através de la Línea ADSL

FASTWEB TI REGALA
IL CAMPIONATO DI CALCIO
2003 - 2004

EVERQUEST
ONLINE
ADVENTURES

LAUNCH
MUSIC ON YAHOO!

X BOX
LIVE
Zoom into DSL TV ("Digital Copper Television")

> given state of the art of technology, DSL TV can deliver:
  • unlimited number of channels
  • competitive quality and zapping times
  • full interactivity (VOD, Gaming, Karaoke ...)
  • iTV (PVR, televoting, ...)
  • single or multiple simultaneous channels per household

> this can be delivered to:
  • >80% of European households who live within 3.5 km from CO
    – 100% with remote deployment
  • any household with a TV set and a phone line
    – 100% of covered topology
  • in high density urban areas DSL can fill DVB-T's and/or satellite's coverage white spots
Evolution of speed over twisted pair

- **ADSL**
- **HDSL**
- **VDSL**
- **VDSL2**
- **xDSL**
- **ISDN**
- **V.26**
- **V.27**
- **V.29**
- **V.33**
- **V.34**
- **V.90**
- **voice-band modems**

![Graph showing the evolution of speed over twisted pair](image-url)
Spectrum usage

channel capacity [bit/s]

\[ \log_2 \left( 1 + \text{SNR}(f) \right) \, \text{df} \]

C.E. Shannon

PSD

POTS

ISDN

ADSL

VDSL

VDSL2

frequency [MHz]

0.004 0.02 0.08 0.138 1.1 12 17.6 (30)

downstream rate [Mb/s]

100 Mb/s

50 Mb/s

13 Mb/s (ADSL2)

8 Mb/s

5 Mb/s (READSL2)

160 kb/s

56 kb/s

28.8 kb/s

14.4 kb/s

4.8 kb/s

2.4 kb/s

0.16

0.08

0.04

0.02

0.01

voice-band modem

ISDN

ADSL

VDSL

VDSL2

100

10

1

0.1

0.01

0.001

C.E. Shannon

channel capacity [bit/s]

\[ \log_2 \left( 1 + \text{SNR}(f) \right) \, \text{df} \]

frequency [MHz]

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0.08

0.04

0.02

0.01

voice-band modem

ISDN

ADSL

VDSL

VDSL2

100

10

1

0.1

0.01

0.001
VDSL band plans

> all band plans can be supported with single platform
DSL access network topology

- **FTTB**
- **FTTCab**
- **FTTEx**

- compact DSLAM
- MxU ring
- P2P fiber or PON feeder

- ADSL(2plus)
- VDSL

- end-user
- remote terminal
- Central Office

ATM / Ethernet / IP uplink

- VDSL

- DSLAM

**ICC2004 - 100 Mbps over DSL**
End-to-end DSL network
(example: multi-edge model)

> different aggregation models
  • ATM / Ethernet / IP ; single edge / multiple edge
> DSLAM as first (gating) service point in network
  • security cntr (e.g. block L2 user to user communication, broadcast msgs)
  • multicasting (IGMP engine)
  • subscriber management awareness (e.g. DHCP relay option 82)
  • prioritization of traffic (QoS)
DMT line code

- DMT universal line code for ADSL, ADSL2, ADSL2plus, VDSL and VDSL2
- Large number of independent carriers
  - 256 for ADSL, 512 for ADSL2plus, 4K for VDSL
- Offers optimum spectrum use, spectrum compatibility, service flexibility
VDSL2

- under standardization in ITU-T, ETSI TM6, ATIS/T1E1.4
  - standard targeted for 2005
- is “next generation” VDSL
- DMT only
- new band plans under discussion that extend spectrum above 12 MHz
  - should provide ultra-high speeds: order of 100 Mb/s
- new features
  - e.g. ADSL2-like features
- performance increase
  - reach extension
  - bitrate increase (e.g. through Trellis coding)
- facilitate ADSL2/VDSDL2 multi-mode devices
Bonding

> use 2 or more pairs to offer higher speed services over “bonded group” than what is possible over single pair
  • e.g. bond 2 VDSL lines at 50 Mb/s each to offer 100 Mb/s
  • mainly intended to cover “tail” of loop length distribution

> common practice for business access over DSL by means of HDSL
  • also supported with SHDSL

> standards available for bonding over VDSL:
  • T1E1.4/2003-334 for ATM VDSL
  • IEEE 802.3ah for EFM VDSL (Ethernet in First Mile = packet VDSL)

> motivated by available spare copper
  • over dimensioning of copper plant: mainly in distribution section, also (less) in feeder section
  • churn of fixed phone users to wireless
Future evolutions

> vectoring
  • also referred to as
    - MIMO
      (multiple input, multiple output)
    - DSM level 3
      (Dynamic Spectrum Management)
  • based on crosstalk mitigation:
    - cancellation in upstream
    - pre-compensation in downstream

> bonding + vectoring
  • in case of bonding, performance can be boosted further by applying MIMO at both ends
Conclusions

> DSL can offer full triple-play services TODAY
  - single video stream + voice + data over ADSL
  - multiple video streams (+ voice + data) over ADSL2plus or VDSL
  - high interactivity ; virtually unlimited number of channels

> next generation VDSL technology will support ultra-high bitrates
  - VDSL2: order of 100 Mb/s over single twisted pair

> bonding allows to multiple speeds by grouping pairs
  - in combination with vectoring in future to boost speed further
DSL: the ultimate experience
Access Technology Comparison

<table>
<thead>
<tr>
<th></th>
<th>Satellite</th>
<th>Cable</th>
<th>Terrestrial</th>
<th>Telco - DSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reach</td>
<td>nationwide</td>
<td>patchwork</td>
<td>not yet</td>
<td>urban</td>
</tr>
<tr>
<td>Channels</td>
<td>&gt;200</td>
<td>150-250</td>
<td>30-60</td>
<td>&gt;200</td>
</tr>
<tr>
<td>Interactivity</td>
<td>very low</td>
<td>high</td>
<td>very low</td>
<td>very high</td>
</tr>
<tr>
<td>Local Content</td>
<td>no</td>
<td>yes</td>
<td>limited by channel number</td>
<td>yes</td>
</tr>
<tr>
<td>Triple Play</td>
<td>no (limited coverage)</td>
<td>yes</td>
<td>no (limited coverage)</td>
<td>yes</td>
</tr>
</tbody>
</table>

> None of the actors can deliver all
  - except cases like Belgium, where cable is everywhere
  - except cases like Southern Europe, where copper loop lengths are extremely short

> Telco and terrestrial are the "new kids on the block"
  - highest investment to make in digital TV infrastructure (e.g. head-ends)
  - natural fit for cooperation in some countries

> Telco & satellite could collaborate in some markets along same reasoning
Services Will Drive Broadband Adoption

1. Aggressive marketing
2. Flexible pricing & bandwidth management
3. New services over PC
4. Beyond PC
   - TV sets
   - Videophones

Key services

More bandwidth !!!
Strict Quality of Service in the access node is imperative

- dedicated multicast resources
- prioritization of traffic
- strict delay & jitter control
- high availability

VOD = Video On Demand
PVR = Personal Video Recorder
VDSL + vectoring
Symmetrical rate-reach curve

SIMULATION PARAMETERS
- 2 lines
- ETSI type A alien noise
- 0.5 mm (24 AWG) line type
- 3 dB coding gain
- 6 dB noise margin
- zipper band plan up to 28 MHz
- 11.5 dBm total power constraint
- -60 dBm/Hz spectral mask
- 135 Ω source and load impedance
- Xtalk mitigation by means of zero-forcing

100 Mb/s symmetric @ 500 m (100-PASS-TS)
Future evolutions

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    - MIMO (multiple input, multiple output)
    - DSM level 3 (Dynamic Spectrum Management)
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