Residential Broadband: Technologies for High-Speed Access To Homes

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- 56 kbps Modems, ISDN
- ADSL, VDSL
- HFC, FTTC, FTTH
- Cable Modems
- Cable Modem Standards: DOCSIS, 802.14, ...
Potential Applications

- Video on demand (VOD)
- Near video on demand (NVOD) - staggered starts
- Distance learning, Teleconferencing, Home shopping
- Telecommuting
- Meter reading
- Security

Existing cable TV has the media but no switching
Existing phone service has switching but not enough bandwidth
Residential Access Networks (RANs)

- Central Office
- Twisted pair
- ADSL
- VDSL
- Fiber
- Optical
- Coax
- HFC
- FTTC
- FTTH
- Opto-Electric
- 10-50 homes
- 100-500 homes
- Headend

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RANs (Cont)

- DSL: Digital Subscriber Line (ISDN)
- ADSL: Asymmetric DSL
- VDSL: Very high data rate DSL
- HFC: Hybrid Fiber Coax
- FTTC: Fiber to the curb
- FTTH: Fiber to the home
Why Modems are Low Speed?

- Telephone line bandwidth = 3.3 kHz
- V.34 Modem = 28.8 kbps ⇒ 10 bits/Hz
- Better coding techniques. DSP techniques.
- Cat 3 UTP can carry higher bandwidth
- Phone companies put 3.3 kHz filters at central office ⇒ Allows FDM
56 kbps Modems

- Past:
  ![Past Diagram]

- Current:
  ![Current Diagram]

- ISP’s have direct digital link (T1 or T3)
- Only one D/A/D conversion \(\Rightarrow\) Higher speed possible
Digital Subscriber Line = ISDN

64×2 + 16 + overhead
= 160 kbps up to 18,000 ft

DSL requires two modems (both ends of line)

Symmetric rates ⇒ transmission and reception on same wire ⇒ Echo cancellation

Use 0 to 80 kHz ⇒ Can't use POTS simultaneously
DSL Technologies

- DSL: Digital Subscriber Line (ISDN)
- HDSL: High data rate DSL (T1/E1 on 2 pairs)
- SDSL: Single line DSL (T1/E1)
- ADSL: Asymmetric DSL
- RADSL: Rate-adaptive ADSL
- VDSL: Very high data rate DSL
- VADSL: Very high data rate Asymmetric DSL = VDSL
- BDSL: Another name for VDSL
- VDSLLe: European version of VDSL
HDSL

- Initially T1/E1 over copper used AMI coding ⇒ Repeaters every 3000 - 6000 ft
- Uses 1.5 MHz for 1.5 Mbps ⇒ Wasteful of bandwidth ⇒ Interference ⇒ Can't put more than 1 circuit in a 50 pair cable
- HDSL transmits T1/E1 over two pairs using 80 to 240 kHz ⇒ repeaters at 12,000 ft
- Used in PBX interconnection, cellular antenna stations, interexchange POPs
- SDSL = Single pair version of HDSL. T1/E1 simultaneously. Up to 10000 ft.
ADSL

- Asymmetric Digital Subscriber Line
- Asymmetric $\implies$ upstream $\ll$ Downstream
- Symmetric $\implies$ Significant decrease in rate
- 6 Mbps downstream, 640 kbps upstream
- Using existing twisted pair lines
- No interference with phone service (0-3 kHz) $\implies$ Your phone isn't busy while netsurfing
- Up to 7500 m
- ANSI T1.413 Standard
- Quickest alternative for Telcos
Why Asymmetric?

- Unshielded twisted pair $\implies$ Crosstalk
- Downstream signals are all same amplitude $\implies$ Not affected
- Upstream signals start at different distances $\implies$ Different amplitudes $\implies$ Weak signals are highly affected
- Solutions:
  1. Use asymmetric rates
  2. Use lower frequencies for upstream (Cross talk increases with frequencies)
Very High-Speed Digital Subscriber Lines

Also called VADSL, BDSL, VHDSL

ANSI T1E1.4 standardized the name VDSL and ETSI also adopted it

VDSL to denote European version

For use in FTTC systems

Downstream Rates: 51.84 - 55.2 Mbps (300 m), 25.92 - 27.6 Mbps (1000 m), 12.96 - 13.8 Mbps (1500 m)
VDSL (Cont)

- Upstream Rates: 1.6-2.3 Mbps, 19.2 Mbps, Same as downstream
- Admits passive network termination
  ⇒ Can connect multiple VDSL modems like extension phones
  (ADSL requires active termination)
- Unlike ADSL, VDSL uses ATM to avoid packet handling and channelization
- Orkit Communications (Israel) demoed VDSL modems at Supercomm'96
CATV Distribution Systems

- Amplifiers at extension and branch points
  - These amplifiers require periodic retuning
  - Some of these amplifiers are one-way
Hybrid Fiber-Coax

- Replace supertrunk with fiber
- Electro-optical conversion at headend
- Opto-electrical conversion at fiber node
- Amplifiers are removed.
  Allows two-way, More bandwidth, less noise
Cable Modems

- Modulate RF frequencies into cable.
- Cost $395 to $995
- If cable is still one-way, upstream path through POTS
- $30 to $40 per month flat service charge
- 45 Mbps downstream, 1.5 Mbps upstream
- MAC protocol required to share upstream bandwidth
- Sharing $\implies$ Security issues
- Servers at headend to avoid Internet bottleneck
- @home Plans to create high-speed backbone across US
DOCSIS

- Data over Cable Service Interface Specification
- Developed by Multimedia Cable Network System Partners (MCNS): TCI, Time Warner, ...
- Cablelabs helped manage changes
- Rapidly develop standards (Faster than IEEE)
- Intellectual Property Agreement among partners
- V1.1 in March 1999 added QoS (802.1p), multicast, fragmentation. Required for packet voice.
- V1.2 will add higher speed upstream
DOCSIS: Key Features

- Switched Ethernet service ⇒ One large LAN
- Downstream packets use 188-byte MPEG2 transport stream frames
  ⇒ Compatible with digital video standards
  ⇒ Allows mixing data and video in the same channel
- Upstream is slotted. Head-end allocates minislots.
- Packets can be optionally encrypted using DES for privacy

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Link Security</th>
<th>DOCSIS MAC</th>
<th>DOCSIS PHY</th>
<th>10Base-T</th>
</tr>
</thead>
<tbody>
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</table>

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IEEE 802.14

- ATM and Ethernet interfaces
- Different MAC and PHY than DOCSIS
- Addresses: Permanent (48-bit) and 14-bit local id
# IEEE 802.14 Protocol Stack

<table>
<thead>
<tr>
<th>Layer</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>802.2</td>
<td></td>
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</tr>
<tr>
<td>802.1</td>
<td></td>
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<tr>
<td>AAL</td>
<td></td>
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<tr>
<td>ATM</td>
<td></td>
<td></td>
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<tr>
<td>802.14Access</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHY</td>
<td></td>
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</tr>
</tbody>
</table>

- **All ATM**
- \(\sqrt{\text{ATM Friendly}}\)

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Other Standards

- OpenCable Project:
  - DOCSIS-like effort for set-top boxes
  - Initiated by cable industry
  - Managed by Cablelabs
  - Builds on the DOCSIS for new interactive services
  - Ref: [www.opencable.com](http://www.opencable.com)

- PacketCable Project:
  - DOCSIS-like effort for packet voice
  - Initiated by cable industry. Managed by Cablelabs.
  - POTS over HFC
  - Ref: [www.packetcable.com](http://www.packetcable.com)
Other Standards (Cont)

- DAVIC/DVB:
  - Digital Audio Video Council/Digital Video Broadcasters
  - European set-top box designers
  - ATM cell based transport
  - Ref: [www.davic.org](http://www.davic.org)


- SCTE (Society of Cable Telecommunications Engineers), [www.scte.org](http://www.scte.org)
Fiber to the Curb (FTTC)

- Coax and twisted pair for the last 100-300 m
- Coax is used for analog video, TP is used for POTS
- Baseband ⇒ No frequency multiplexing
- Passive optical network ⇒ signal is optically broadcast to several curbs ⇒ Time division multiplexing
- Up to 50 Mbps downstream, Up to 20 Mbps upstream
- Co-exist with POTS or ISDN on the same cable pair
- Twisted pair ⇒ EMI ⇒ withstand legal 400W radio transmissions at 10 m
Fiber to the Home (FTTH)

- Fully optical ⇒ No EMI
- Initially passive optical network ⇒ Time division multiplexing
- Upstream shared using a MAC
- 155 Mbps bi-directional
- Need new fiber installation
## Comparison of RANs

<table>
<thead>
<tr>
<th>Technology</th>
<th>Typical Downstream Rate</th>
<th>Typical Upstream Rate</th>
<th>Max Distance</th>
<th>Homes Per Opt. Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFC</td>
<td>45 Mbps Shared</td>
<td>1.5 Mbps Shared</td>
<td>N/A</td>
<td>500</td>
</tr>
<tr>
<td>FTTC</td>
<td>25-50 Mbps</td>
<td>25-50 Mbps</td>
<td>100 m</td>
<td>10-50</td>
</tr>
<tr>
<td>FTTH</td>
<td>155 Mbps</td>
<td>155 Mbps</td>
<td>N/A</td>
<td>10-200</td>
</tr>
<tr>
<td>ADSL</td>
<td>6 Mbps</td>
<td>640 kbps</td>
<td>4,000 m</td>
<td>1,000</td>
</tr>
<tr>
<td>VDSL</td>
<td>13-50 Mbps</td>
<td>1.6-5 Mbps</td>
<td>2,000 m</td>
<td>100</td>
</tr>
</tbody>
</table>
# ADSL Vs Cable Modems

<table>
<thead>
<tr>
<th>ADSL</th>
<th>Cable Modems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phone company</td>
<td>Cable company</td>
</tr>
<tr>
<td>Switching experience but low bandwidth ckts</td>
<td>No switching but high bandwidth infrastructure</td>
</tr>
<tr>
<td>Point-to-point ( \Rightarrow ) Data privacy</td>
<td>Broadcast. Sharing ( \Rightarrow ) More cost effective</td>
</tr>
<tr>
<td>Currently 1.5 to 8 Mbps</td>
<td>10 to 30 Mbps</td>
</tr>
<tr>
<td>Perf = fn(location)</td>
<td>Independent of location</td>
</tr>
<tr>
<td>Phone everywhere</td>
<td>Cable only in suburbs (not in office parks)</td>
</tr>
<tr>
<td>Existing customers ( \Rightarrow ) ISDN and T1 obsolete</td>
<td>New Revenue</td>
</tr>
</tbody>
</table>
Satellites for Data

- DirecPC from Hughes
- One-way high-speed connection
Wireless Local Loop

- Fixed, high, directional antennas $\Rightarrow$ Lower loss, no handoff
Summary

- High Speed Access to Home: ADSL, VDSL, HFC, FTTC, FTTH
- 6 to 155 Mbps downstream, 1.5 Mbps upstream
- Both cable and telecommunication companies are trying to get there with minimal modification to their infrastructure
RBB: Key References

- For a detailed list of references, see [http://www.cse.ohio-state.edu/~jain/refs/rbb.refs.htm](http://www.cse.ohio-state.edu/~jain/refs/rbb.refs.htm)
- Cable Data Networks, [http://www.cse.ohio-state.edu/~jain/cis788-97/cable_modems/index.htm](http://www.cse.ohio-state.edu/~jain/cis788-97/cable_modems/index.htm)
- Digital Subscriber Lines and Cable Modems, [http://www.cse.ohio-state.edu/~jain/cis788-97/rbb/index.htm](http://www.cse.ohio-state.edu/~jain/cis788-97/rbb/index.htm)
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- ANSI T1.413, ADSL Metallic Interface
- Cable Labs, http://www.cablemodem.com
- Cable Modem FAQ, http://www.cox.com/modemfaq.html