Next Generation of High Speed Modems

High Speed Modems.
Traditional Modems

• Assume both ends have Analog connection
• Analog signals are converted to Digital and back again.
• Limits transmission speed to 33.6 Kbps. This is Shannon’s Law
  – Signal to Noise Ratio (38-39dB best case)
  – Analog to Digital Only
• Over the past decades, telephone companies have been replacing Analog networks with Digital circuits
How does your V.34 Modem Work?

• Analog signal sent from home modem
• In the PSTN the signal is digitized (Not converted in POTS)
• The digitized signal is converted back to analog at the receivers local loop
• The Analog signal arrives at the receiver’s modem.
V.34 Modems

How a V.34 Connection Works
High Speed Modems

- View the PSTN as a *Digital* network
- One modem MUST have a *Digital Connection*.
- Downstream data is *digitally* encoded instead of being modulated on the PSTN.
- Digital data is received by the client’s modem. No ADC conversion is necessary!
How does it work...

Home Modem DSP

Analog Loop

Codec

Digital Loop

u-law Codec

2 Wire Twisted Pair

Corporate Digital Network

T1 Connection

Delay

PSTN

64 Kbps PCM

Work Modem DSP
PCM Signaling

• Mu-law codec has 256 non-uniform quantization levels
• Work modem generates quantization points on analog line with 8 bit PCM to the mu-law codec.
• PSTN is sampling at 8Khz & generating volt levels on local loop at 8000 times/sec
• Home modem must be able to determine which quantization point was sent by the Work modem at 8000 times/sec
How is data sent?

• Assume Work Modem can send only 2 different PCM sample values
• The two voltage levels generated on the Analog line would represent binary 0 or 1
• These samples would be sent at 8000 times/sec
• If the Home modem can interpret the two voltages at 8000 times/sec, a data rate of 8Kbps would be achieved.
Modem determines if Voltage is quantization 0, 1

Voltage
2 Possible Values
Representing Binary 0, 1

u-law Codec

PCM
2 Possible Quantization Values
0, 1
Achieving Higher Data Rates

Possible Values/Voltages

Conveyor delivers 8000 boxes/sec

1 Box * 8000 boxes/Sec
(8 Bits) * 8000 boxes/Sec
64Kbps
Increasing Data Rates

<table>
<thead>
<tr>
<th>Number of Voltage Levels (PCM Signals)</th>
<th>Bits Per Level</th>
<th>Line Rate (bps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
<td>8000</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>16000</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>24000</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td>32000</td>
</tr>
<tr>
<td>32</td>
<td>5</td>
<td>40000</td>
</tr>
<tr>
<td>64</td>
<td>6</td>
<td>48000</td>
</tr>
<tr>
<td>128</td>
<td>7</td>
<td>56000</td>
</tr>
<tr>
<td>256</td>
<td>8</td>
<td>64000</td>
</tr>
</tbody>
</table>

** V.42 Comp. Increases speeds to 230.4 Kbps

Modems8

Copyright 1998, Prof. John T. Gorgone
Who is building them?

- 3 Manufacturers - Lucent, Rockwell, and US Robotics
- Lucent and Rockwell are compatible.
- At this point, USR only works with USR
- All companies looking toward ITU for international standard.
Summary

• 56Kbps only work if one modem has direct digital connection.
• If any analog conversion is done, defaults to V.34
• Asymmetric, 33.6 upstream 56Kbps down
• 56Kbps is best case based on “clean” lines.
Broadband Modems

• Never has there been such a leap in technology
  – Microprocessors 2x every 18 months
  – Analog Modems 10x faster over 20 years
• 2 orders of magnitude over analog
• 1/100 cost of a T1 line
• 1 - 5 Mbps a month for under $40
Users of Broadband Technology

- **RBOCs**
  - 600 Million phone lines
  - Betting on ADSL
  - Capable of 9 Mbps over existing copper wire

- **Cable Companies**
  - Cable Modems
  - Available to 90% of the homes
  - 30 Mbps achievable
How do they work?

• Convert Digital data into RF Signals
• Much wider spectral bandwidth
  – 6 MHz for Cable Modems using NTSC
  – vs. 3.3 kHz on POTS
• Speeds would overwhelm serial port. Instead, 10-BaseT is used to the computer.
• Computer sends ethernet packets to modem
• Some modems modulate ethernet packets to network. Others convert to ATM cells.
Inside the Modem

Inside a Broadband Modem

**Downstream path**
- Receives signal from network.
- Stores packets for burst control.
- Tunes input to 6-MHz channel between 54 and 750 MHz into digital bit stream.
- Converted modulated signal.
- Sends packets to computer.

**Upstream path**
- Sends signal to network.
- Tunes output from 5 to 42 MHz.

- RF tuner*
- Demodulator and A/D converter
- Network protocol layer
- Ethernet controller
- To PC

- RAM buffer
- Modulator and D/A converter
- Tunable RF modulator*

*Cable modems only.
**ADSL modems only.
***Some modems convert Ethernet packets into ATM cells or other formats.
ADSL

- Frequency-Division Multiplexing (FDM)
- Splits off a 4 kHz band for POTS
- Divides the higher frequencies into an upstream and downstream path
- Another ADSL standard uses DMT to allocate 255 separate 4 kHz channels and send data one each using Quadrature Amplitude Modulation (QAM). Good at avoiding crosstalk.
3-QAM Example

<table>
<thead>
<tr>
<th>Bit Values</th>
<th>Amplitude</th>
<th>Phase Shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>1</td>
<td>None</td>
</tr>
<tr>
<td>001</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>010</td>
<td>1</td>
<td>1/4</td>
</tr>
<tr>
<td>011</td>
<td>2</td>
<td>1/4</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>1/2</td>
</tr>
<tr>
<td>101</td>
<td>2</td>
<td>1/2</td>
</tr>
<tr>
<td>110</td>
<td>1</td>
<td>3/4</td>
</tr>
<tr>
<td>111</td>
<td>2</td>
<td>3/4</td>
</tr>
</tbody>
</table>
3-QAM Wave
ADSL - The Need for Speed

- Max electrical resistance is 1,500 ohms = 15,000 ft using 26 gauge wire OR 18,000 ft with 24 gauge wire.

### Speed as a function of Local Loop Distance

<table>
<thead>
<tr>
<th>Distance (ft)</th>
<th>Downstream Line Rate (bps)</th>
<th>Upstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>18,000</td>
<td>1.544 Mbps</td>
<td></td>
</tr>
<tr>
<td>16,000</td>
<td>2.048 Mbps</td>
<td></td>
</tr>
<tr>
<td>12,000</td>
<td>6.312 Mbps</td>
<td></td>
</tr>
<tr>
<td>9,000</td>
<td>8.448 Mbps</td>
<td>640 Kbps</td>
</tr>
</tbody>
</table>

! ** Assumes a clean connection
Problems for ADSL

• Loading Coils - Filter everything > 4kHz
• Overlong Loops
• Crosstalk (Cross Coupled Interference)
• Not sure just how much of the existing wire is compatible
• One vendor claims that 75 - 95% of the homes in US can be reached
• Asymmetric
Cable Network (HFC)

A Hybrid Fiber-Coaxial Network

Most modern cable systems already have fiber-optic backbones that terminate in fiber-coaxial neighborhood nodes. Each fiber node bridges to a coaxial feeder line that has 500 to 2000 cable drops (user sites). All users on a node share about 30 Mbps of downstream bandwidth and 512 Kbps to 10 Mbps of upstream bandwidth per channel, depending on the cable modem.

Some cablecos will use servers at their head-ends to cache heavily used resources on the internet.

Internet

Fiber-optic backbone

Fiber node

Coaxial feeder line

As demand increases, cablecos can add more channels and subdivide their fiber nodes.

Fiber node

Coaxial feeder line

Telephone network

Optional 28.8-Kbps return path via POTS

Most cable users don’t yet have access to a bidirectional cable network. An interim solution is to use a regular modem to send data upstream to the head-end.

Satellite uplink

Some cablecos are connecting their head-ends together on fiber rings to form regional networks.
What can HFC do for you?

• Plain Old Telephones Service (POTS)
• 23 to 37 analog TV channels
• 188 digital TV channels
• 272 to 464 digital point cast channels (Viewer on Demand Channels)
• High speed two way digital link
Cable Modem

- Utilizes spectrum from 54 - 750 MHz. About 116 NTSC channels.
- Reserves 1, 6 MHz channel allowing around 30 Mbps
- Most cable modems use 64 or 256 QAM
- Upstream uses 5- 42 Mhz
  - Below lowest cable channel
  - Very vulnerable to noise!
- QPSK or DWMT upstream to help with noise problem. Yields 512 Kbps to 4 Mbps
Cable Modem Access Control

• How do you control access (MAC)
  – TDM or SDM
    • Everyone gets a turn to transmit
  – Polling
    • You, then you, then you
  – CSMA
    • Anyone out there? Ok, then I’ll speak

• Most likely the control will be done from the headend.
Cable Problems

- 30 Mbps is shared aggregate
- Not originally designed for 2-way data
- Assume whole world is IP (no pt - pt)
- Estimates are that 5 - 40% of infrastructure is ready.
- Security issues since neighborhood is a LAN.
“Bandwidth Bandits”

The Bandits of Bandwidth

Most of the potential downstream bandwidth available to broadband modems is siphoned off by the limitations of Ethernet, miscellaneous bottlenecks inside your computer, and—with cable modems—other users in your neighborhood.

Theoretical broadband speeds = Bottlenecks = Real-world speeds

Cable = 30 Mbps
Cable networks deliver about 30 Mbps per channel. It is shared by everyone on the same channel. Overhead from communications protocols and forward error correction claims another 10 percent of this total.

Bottleneck 10 Mbps
Most broadband modems connect to computers through a 10Base-T Ethernet port.

Bottleneck 3 Mbps
The network interface card, Ethernet protocol stack, CPU, OS, and peripheral bus further reduce throughput.

ADSL = 9 Mbps
ADSL is slower than cable, but bandwidth isn’t shared by anyone else.

But even a measly 1.5 Mbps is more than 50 times faster than a 28.8-Kbps analog modem, 12 times faster than Basic Rate ISDN, and equal to a digital T1 line that costs thousands of dollars per month.
Infrastructure Issues

• Problems for the ISP
  – Most ISPs have T1 (1.5 Mbps) links to the Internet
  – Broadband Modems will jam the on-ramps to the internet (cache servers will help)

• Problems for the Telcos
  – Circuit allocation based on 6 minute phone call
  – Average Modem lasts 60 minutes