Wired Broadband Access
How “far” can we go with wires?

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Outline

• The broadband rollout
• DSL
• Home networks
• Power line carrier
• Conclusions
Broadband Access
A true paradigm shift

- Currently over 15M users are receiving broadband access
  - Significantly, the majority of this service is to residences
- The total addressable market is in the vicinity of 150M users
- Megabit per second speeds, always-on, IP based

Overall Broadband Subscribers (In Millions)

- Cable
- DSL
- Other

Yankee Group
December 2002
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Brief Tutorial on DSL Access Technology

ADSL architecture
Brief Tutorial on DSL Access Technology

Frequency of operation

Frequency Division Multiplexing

Signal Power

Low Bit Rate
ADSL Return Channel

High Bit Rate
ADSL Forward Channel

Region Occupied by existing Telephony

Frequency, kHz

500

1000
Brief Tutorial on DSL Access Technology

**ADSL line codes**

DMT was standardized as the line code, competing with CAP, etc.
Brief Tutorial on DSL Access Technology

Crosstalk

Near-End Crosstalk (NEXT)

Far-End Crosstalk (FEXT)
DSL Industry Trends

• New DSLs: faster *and* longer reach
  – Asymmetric
    • ADSL+
    • VDSL – up to 12 MHz
• Jointly Optimize across all lines in a cable
• Dynamic Spectrum management (DSM)
  – Control and minimize crosstalk
• “Bonded” Multi-line DSLs
**ADSL+**

- Double the downstream bandwidth of “regular” ADSL
  - 2.2 MHz instead of 1.1 MHz
  - Maximum 20 to 32 Mbps downstream
  - “Annex J” upstream: up to 3 Mbps (regular ADSL: 1 Mbps)
- ITU-T standard out for ballot January 2003

![Graph showing downstream bit rates vs. 26 gauge loop length for Managed ADSL+, Unmanaged ADSL+, and ADSL.](image_url)
Joint DSL optimization example

**Today**

use worst-case

- CO → Remote
  - 13500’
  - 26 Gauge (worst-case)
  - Binder → New ADSL
  - 24 SDSL (worst-case)
  - 170 kbps Upstream
  - 2.1 Mbps Downstream

**Tomorrow**

detailed knowledge = performance

- CO → Remote
  - 5000’
  - 24 gauge
  - 4000’
  - 24 gauge
  - 4500’
  - 22 gauge
  - New ADSL
  - 2 SDSL + 3 ISDN
  - 868 kbps Upstream
  - 6.3 Mbps Downstream
Dynamic Spectrum Management (DSM)

- Crosstalk is NOT random noise – control and manage it!

\[ XT_{1,2} \quad DSL \#1 \quad XT_{1,3} \]

\[ DSL \#2 \quad XT_{2,3} \quad DSL \#3 \]

- Bit rates **DOUBLE OR TRIPLE**

Different actual pair-to-pair crosstalk coupling functions

Static spectrum management
Bonded DSLs – Multi-line

- Typical: bonded G.shdsl up to about 4.3 Mbps symmetric per pair, up to symmetric DS3 rate using many pairs
  - In a few products now, more by year end 2003
- Crosstalk cancellation, Vectoring, and Coordinated Coding
  - Leverage noise correlations, up to 3 X bit rate with 2X number of lines
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Lower Layer Technologies
HomePNA (http://www.homepna.org/)

- Uses existing phone wiring; plug into RJ11 jacks
- Telephones and ADSL continue to operate normally, over the same wiring
- Adapts lower-layer modulation format to interface to standard Ethernet software drivers
- Version 2.0, with adaptive equalization, operates at 10 Mb/s
Lower Layer Technologies
WiFi (802-11)

- WiFi is an extension of wired Ethernet
- 802.11b runs at 11 Mbps over the unlicensed 2.4 GHz band
  - Began in the business environment (wireless office LANs), but has moved into “Starbucks” and homes
- 802.11a promises 54 Mbps (operates in the 5 GHz band).
- Supported by Windows, Mac OS, Unix, Linux
- Prices coming down
- Walls and microwave oven still a problem
Lower Layer Technologies
IEEE 1394 “Firewire”

- Technology originally developed by Apple and trademarked as Firewire™
- Standardized by 1394a for local device interconnect up to 4 meters
- Japanese consumer giants embedding 1394 into next-generation digital appliances; digital cameras, digital camcorders, digital VCRs
- CableLabs OpenCable standard specifies 1394 as the interface between the cable set-top box and the DTV
- Potential for 1394 as a home network was recognized, and is being developed as 1394b, “long-range Firewire”
- 1394b will operate over 100 meters of UTP-5 cable
Power Line Carrier

- Power Line Carrier has been used commercially for years for low speed (telemetry) applications
- With continuing advances in signal processing, systems operating at up to 10 Mb/s are now commercial for local applications!
- Practically every home and office has a phone; practically every room has a power outlet!
- Integrated scenarios would couple into the power cord; with appropriate plug-n-play features, the simple act of plugging in an appliance, such as a PC or a DVD player, would place it on the local network
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Power line carrier
Basics of the channel

• Transmit power is limited in the U.S. by the Federal Communications Commission (FCC) radio emissions regulations Part 15, for class B (residential) devices
  – Between 450 kHz and 30 MHz about 250 microvolts are allowable
  – Above 30 MHz emissions regulations become even more stringent

• Modulation formats are relatively new and unstandardized
  – Spread spectrum techniques
  – Orthogonal Frequency Division Multiplexing (multitone)

• Little data on noise in the MHz bands
  – A Telcordia noise survey found levels around –100 dBm/Hz (background white noise is around –140 dBm/Hz)
  – However, much variability!

• The channel loss varies widely, depending on topology!
  – Plugging a device in, and turning it on, will change the channel characteristics
Power line carrier
A “nasty” channel

- Noise measurement to 30 MHz in a residence; evening, with TV on, dimmers off
- Noise changes with time of day, and with usage of appliances

- Attenuation measurement to 30 MHz between two power outlets in a room
- Attenuation changes as appliances are plugged in and turned on
Power Line Carrier
An example of modeling

- A typical topology for the 120 VAC power mains in the home

![Diagram of power line carrier topology](image)
Power Line Carrier
An example (Cont.)

- This top graph shows the predicted frequency response of the topology, based on simulation modeling
  - T. Banwell, S. Galli, "A new approach to the modeling of the transfer function of the power line channel", ISPLC 2001, Malmo, Sweden, April 4-6, 2001

- The bottom plot shows actual measured frequency response of the same topology
- See more in upcoming IEEE Communications Magazine special issue on PLC, May 2003
**Power Line Carrier**

**Power grid becomes a broadband last mile network!**

- Utility operators are taking a second look at both telecommunications services and power line carrier technology
  - Although somewhat slow, utility operators have the capital investment base, cash flow, and low debt structure to allow them to enter the communications marketplace in a meaningful way

- Broadband power line carrier technology could allow utilities to reuse their existing distribution infrastructure to provide Internet access and VoIP services

- “Ambient and Consolidated Edison Announce Successful Joint Testing of Power Line Communications Technology,” New York, 7/8/02
  - 1.5 cable miles between 4 premises. Throughput rates from 3.5 to 7 Mbps.
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Some final thoughts

- A wise Bell Labs executive (Nick Osifchin) once said: “Wired throughputs always seem to stay an order of magnitude ahead of wireless throughputs.”
  - E.g., While WiFi reaches for 54 Mbps, Gigabit Ethernet is emerging
- Wireless and terrestrial networks will coexist
- Terrestrial wired networks will leverage in-place wires for several decades, evolving slowly to fiber*
- Keep your eye on PLC applied to the power grid; could be a “sleeper” technology!

Broadband Access
Dave Waring

David L. Waring began his career at Bell Laboratories designing subscriber loop electronics. He moved to Bellcore at its inception in 1984, where he worked on early Metropolitan Area Network field trials and led teams that proposed requirements for HDSL and ADSL. He was project manager of several industry-leading interactive digital video trials. Dave currently leads research into "last mile" broadband local access and customer premises networks. He has also performed recent work on projects relating to critical infrastructure protection (CIP), and he manages a related NIST (National Institute of Standards and Technology) grant program. Dave is a Senior Member of the IEEE.