Panel 1

The Nyquist Theorem

≈ 1924 by Nyquist

Theorem: Assume a signal is filtered through a low-pass filter of H Hz, and the signal consists of V discrete levels. Then

max data rate = $2 \cdot H \log_2(V)$ bps (bits per sec)

Ex: 3 KHz filter, binary signals

$\Rightarrow$ $2 \cdot 3000 \cdot \log_2(2) = 6000$ bps

Use 16 levels $\Rightarrow$ $2 \cdot 3000 \log_2(16) = 24\,000$ bps

1

Panel 2

Nyquist-Shannon Theorem

Nyquist assume perfect channel, i.e. no noise

Nyquist-Shannon Theorem For a channel with bandwidth H and signal-to-noise ratio S/N

$\Rightarrow$ max. data rate = $H \log_2(1 + S/N)$

Eng. measure S/N in dB

$dB = 10 \log_{10}(S/N)$ $\Rightarrow$ $S/N = 10$ $\Rightarrow$ 10 dB

100

$S/N = 100$ $\Rightarrow$ 20 dB

2

Panel 3

Nyquist-Shannon : max bits/sec = $H \log_2 (1 + S/N)$

Typical analog voice-grade telephone system has
3000 Hz bandwidth and signal-to-noise ration of 30 dB

$\Rightarrow$ $30\ dB = 10 \log_{10} (S/N)$

$\Rightarrow$ $S/N = 1000$

$\Rightarrow$ max rate $= 3000 \log_2 (1001) = 3000 \cdot 10 = 30000$ bps. ($1001 \approx 1024$)

regardless of anything!

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Panel 4

Transmission Media

Magnetic Tape:

8 mm tape ~ 7 GB data
standard box = 1000 tapes
} 7000 GB

Ship in 24 Hours via UPS

$\Rightarrow$ $7000 \cdot 8\ Gb / 24 \cdot 60 \cdot 60 \approx 648$ Gbps

Compares well to 1 Gbps Ethernet!

Cost: 1000 tapes = \$5000, 10× reusable

$\Rightarrow$ \$500 + \$200 shipping = \$700

$\Rightarrow$ 200/7000 GB = 10 cents per GB

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Panel 5

Twisted Pair:

Tapes have high bandwidth but poor delay characteristics

Twisted pair = 2 copper wires twisted ← reduce interference

2 parallel wires = an antenna

2 twisted wire = no antenna

Cat 3, Cat 5 cabling used by Telephone and LAN

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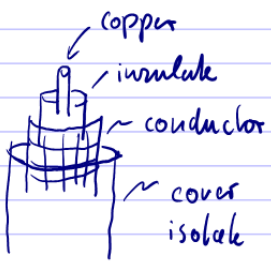
Panel 6

Coaxial Cable



Baseband coax (50 ohm)

Broadband coax (75 ohm)

Broadband coax is used by TV cable system

up to 450 MHz ~ 100 Km

TV channel uses 6 MHz (analog)

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Panel 7

Fiber Optics Cable

≈ 1000 km of fiber installed every day in US
(100 km bundle with 10 strands = 1000 km!)

≈ 1970 computers (CDC) 1 instruct. per 100 usec

≈ 1990 computer (Cray) 1 instr. per 1 usec

⇒ Factor 10 improvement per decade!

Data Comm.: 1970: 56 kbps (ARPANET)

1990: 1 GB

⇒ factor > 100 improvement per decade

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Panel 8

More on Fiber

CPU performance reaches physical limit

Current fiber has bandwidth > 50 000 Gbps

Bottleneck (!Gb): optical/electric converters

Thus: Computers are slow, network rules

Avoid computational overhead

⇒ waste bandwidth

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