15-213

Network technology

November 12, 1998

Topics

- **Overview**
- **Telephone system**
- **Ethernet**
- **ATM**

Course Theme

Abstraction is good, but don't forget reality!

Earlier courses to date emphasize abstraction

- **Abstract data types**
- **Asymptotic analysis**

These abstractions have limits

- **Especially in the presence of bugs**
- **Need to understand underlying implementations**

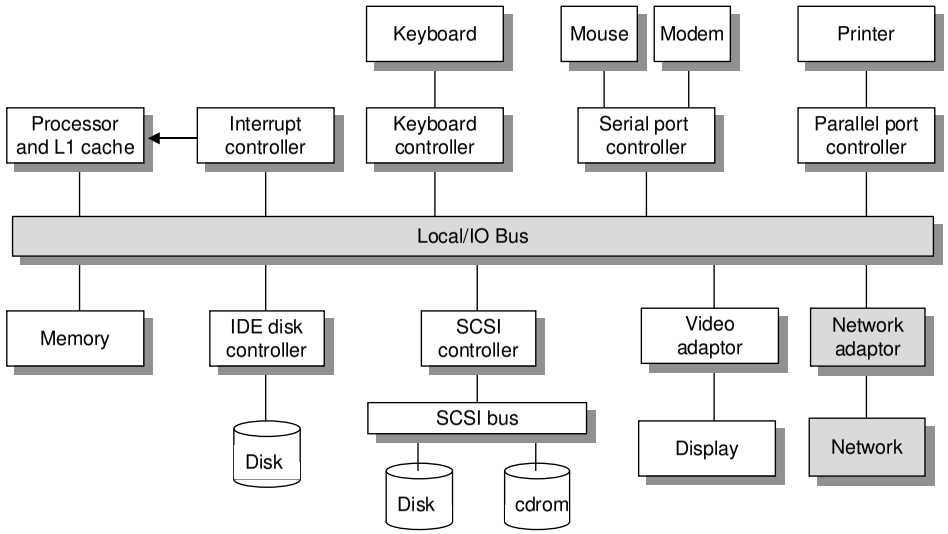
Useful outcomes

- **Become more effective programmers**
  - Able to find and eliminate bugs efficiently
  - Able to tune program performance
- **Prepare for later "systems" classes**
  - Compilers, Operating Systems, Networks, Computer Architecture

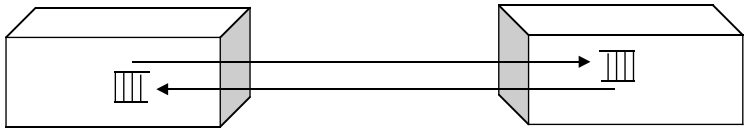
"Harsh Realities" of Computer Science

- **Int's are not integers; float's are not reals**
  - Must understand characteristics of finite numeric representations
- **You've got to know assembly**
  - Basis for understanding what really happens when execute program
- **Memory matters**
  - Memory referencing bugs especially difficult
    - » Violates programming language abstraction
  - Significant performance issues
    - » E.g., cache effects
- **There's more to performance than asymptotic complexity**
  - Constant factors also matter
- **Computers do more than execute programs**
  - Get data in and out
  - Communicate with each other via networks

Computer system



Simple example



Starting Point: Want to send bits between 2 computers

- FIFO queue on each end
- Can send both ways ("full duplex")
- Name for standard group of bits sent: "packet"
- Packet format and rules for communicating them ("protocol")

Simple *request/response* protocol and packet format:

header	payload
0/1	data/address

0: please send the data word at "address"
1: here is the data word you asked for.

Questions about simple example

What if more than 2 computers want to communicate?

- Need computer address field in packet?

How do multiple machines share the interconnect?

- multiple paths? arbitration? congestion control?

What if a packet is garbled in transit?

- Add error detection field in packet?

What if a packet is lost?

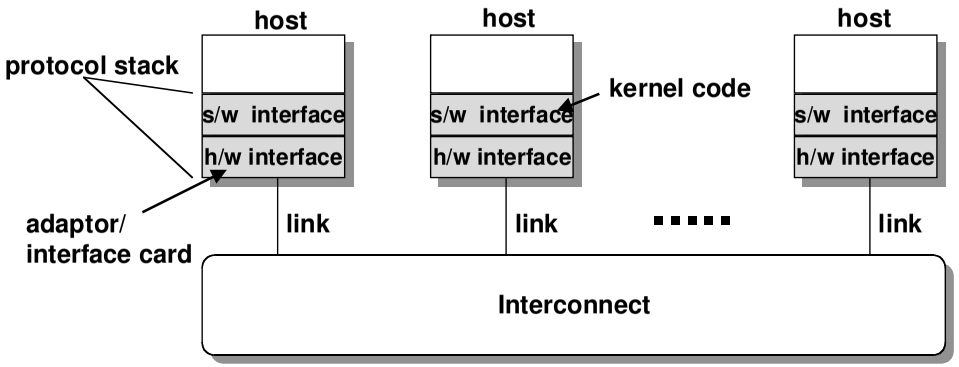
- More elaborate protocols to detect loss?

What if multiple processes/machine?

- one queue per process? separate field in packet to identify process?

Warning: You are entering a buzzword-rich environment!!!

Generic network



Protocols

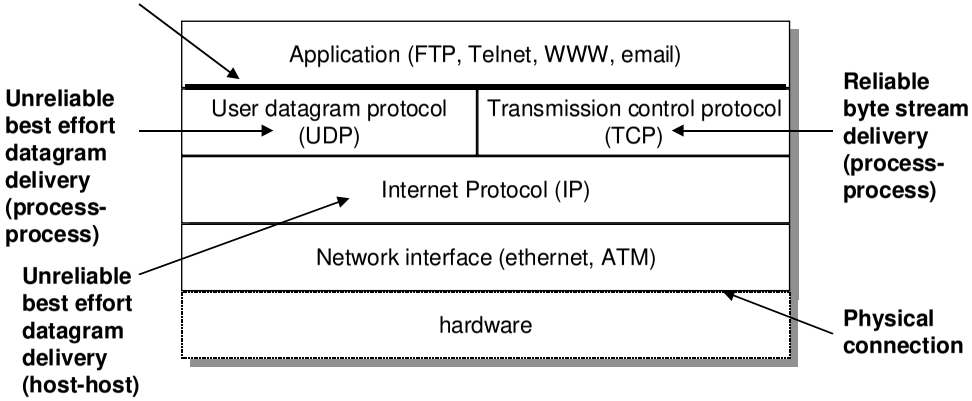
A *protocol* defines the format of packets and the rules for communicating them across the network.

Different protocols provide different levels of service:

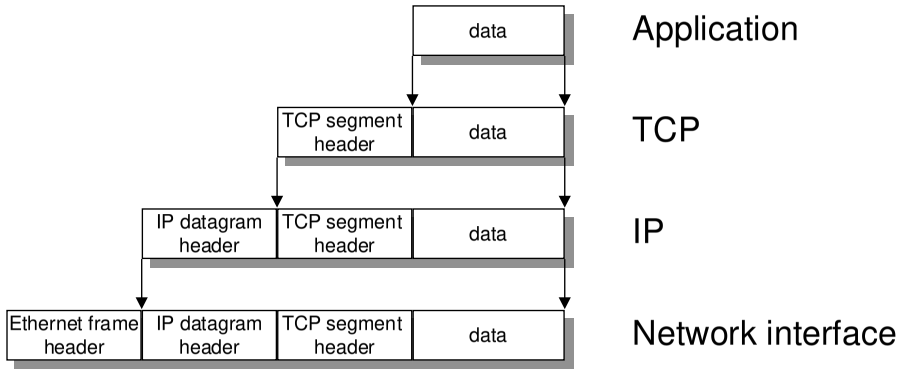
- simple error correction (ethernet)
- uniform name space, unreliable best-effort datagrams (host-host) (IP)
- reliable byte streams (TCP)
- unreliable best-effort datagrams (process-process) (UDP)
- multimedia data retrieval (HTTP)

Protocol layering

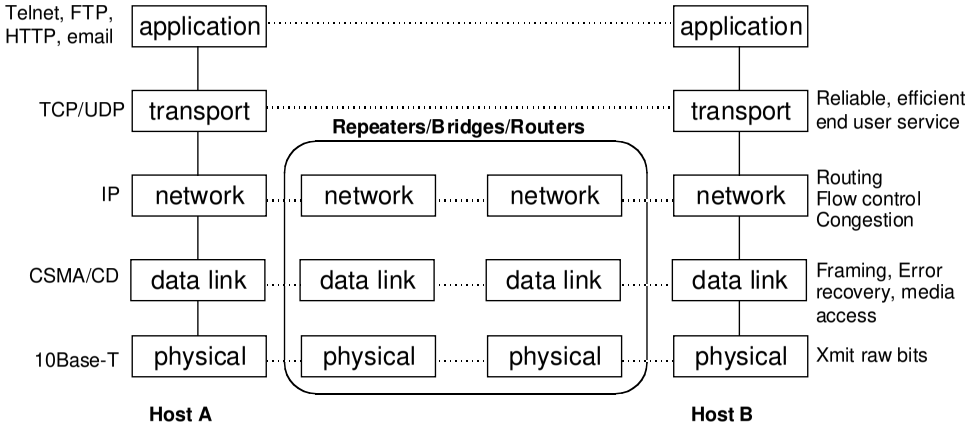
Protocols provide specialized services by building on services provided by other protocols.



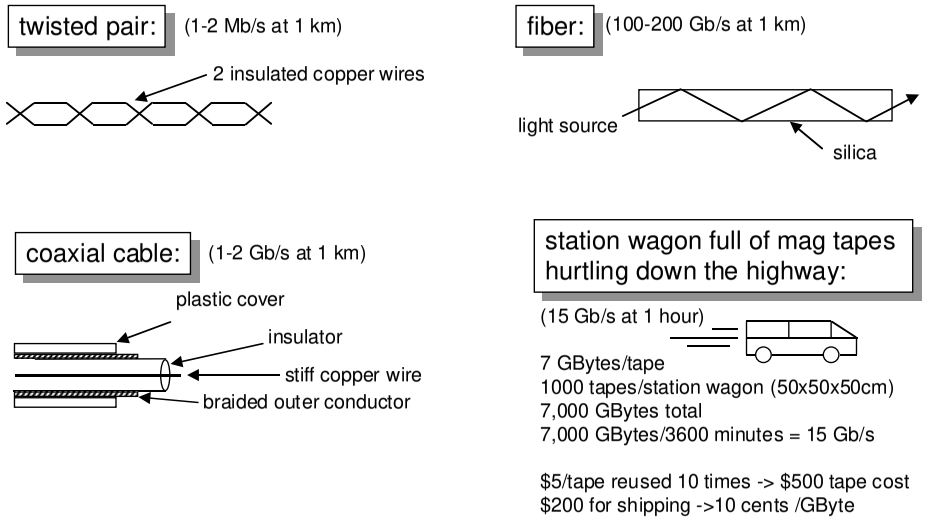
Encapsulation



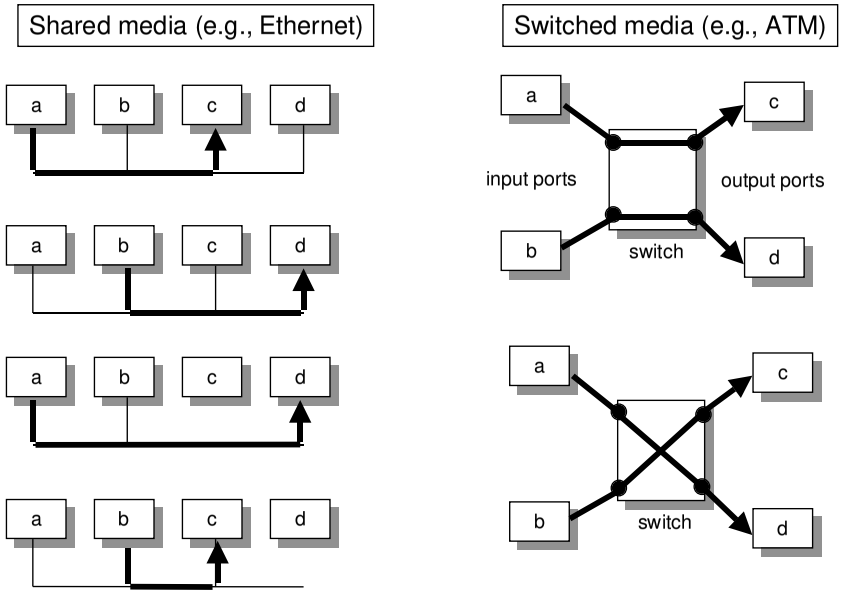
Protocol stacks



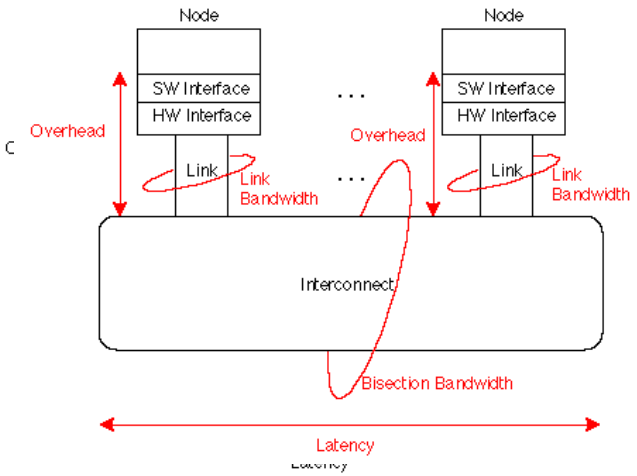
Transmission media



Shared vs switched media



Network performance measures

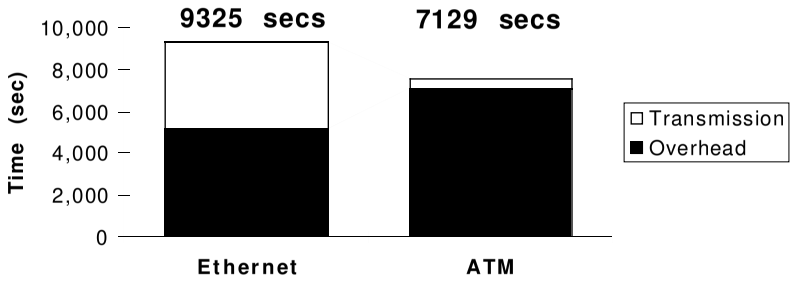


Example performance measures

Interconnect	SAN	LAN	WAN
Example	CM-5	Ethernet	ATM
Bisection BW	N x 5MB/s	1.125 MB/s	N x 10 MB/s
Int./Link BW	20 MB/s	1.125 MB/s	10 MB/s
Latency	5 µsec	15 µsec	50 to 10,000 µs
HW Overhead to/from	0.5/0.5 µs	6/6 µs	6/6 µs
SW Overhead to/from	1.6/12.4 µs	200/241 µs	207/360 µs
		(TCP/IP on LAN/WAN)	

Importance of Overhead (+ Latency)

Ethernet / SS10: **9 Mb/s BW,** **900 µsecs ovhd**
ATM Synoptics: **78 Mb/s BW,** **1,250 µsecs ovhd.**
NFS trace over 1 week: 95% msgs < 200 bytes



- **Link bandwidth is as misleading as MIPS**

Basic network types

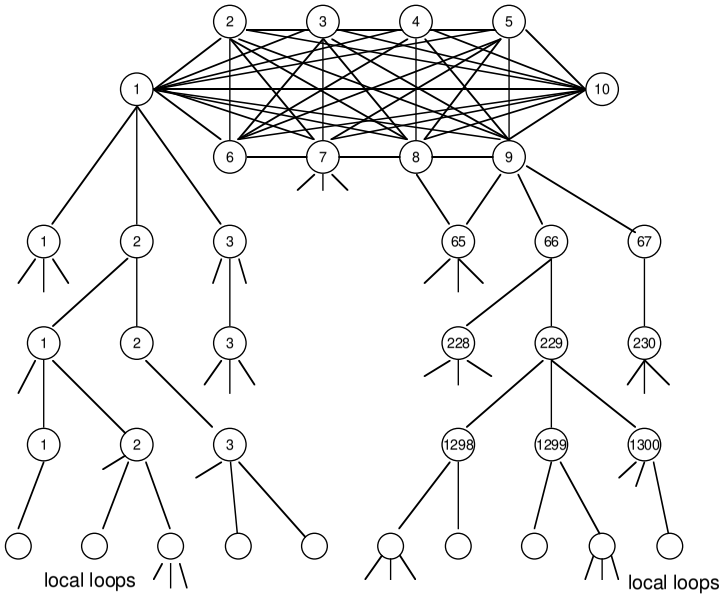
System area network (SAN)
- same room (meters)
- 300 MB/s Cray T3E

Local area network (LAN)
- same bldg or campus (kilometers)
- 10 Mb/sEthernet
- 100 Mb/s Fast Ethernet
- 100 Mb/s FDDI
- 150 Mb/s OC-3 ATM
- 622 Mb/s OC-12 ATM

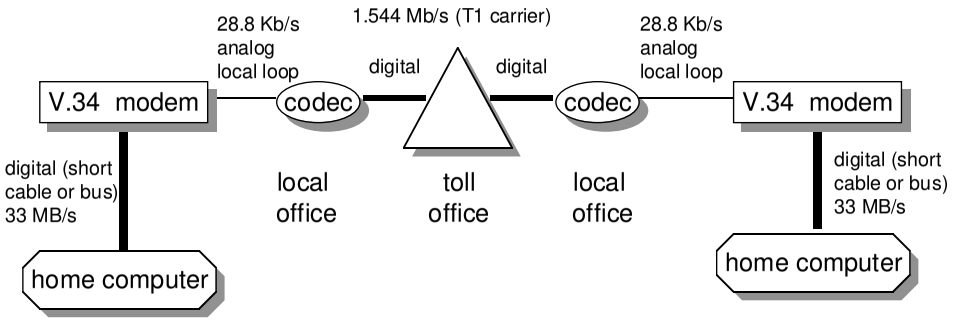
Metropolitan area network (MAN)
- same city (10's of kilometers)
- 800 Mb/s Gigabit Nectar

Wide area network (WAN)
- nationwide or worldwide (1000's of kilometers)
- telephone system
- 1.544 Mb/s T1 carrier
- 44.736 Mb/s T3 carrier

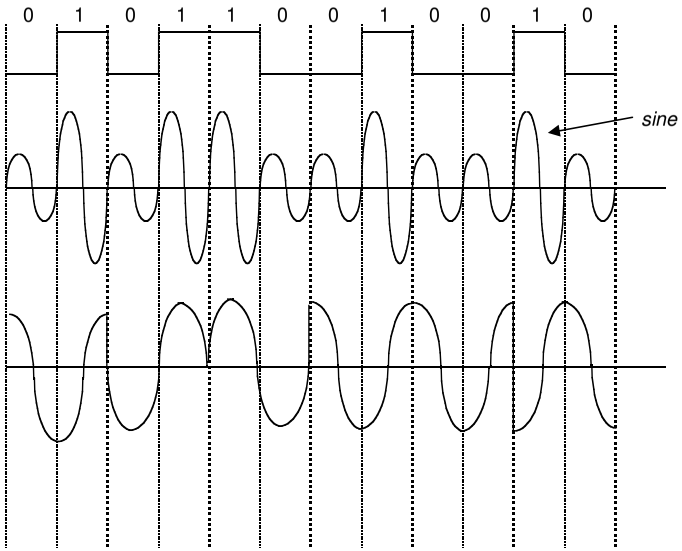
AT&T Telephone Hierarchy



Computer-to-computer calls

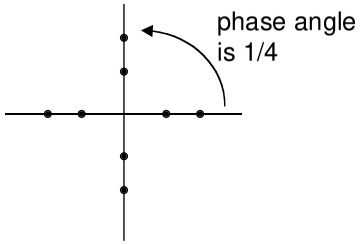


Modulating digital signals

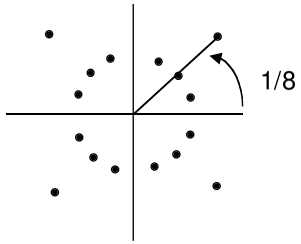


Quadrature amplitude modulation (QAM)

Modern modems use a combination of of amplitude and phase modulation to encode multiple bits per “symbol”, i.e. amplitude/phase pair.



3 bits/symbol QAM modulation
(8 symbols)



4 bits/symbol QAM modulation
(16 symbols)

Conventional Modems

MOdulate: convert from digital to analog
DEModulate: convert from analog to digital

modem standards:

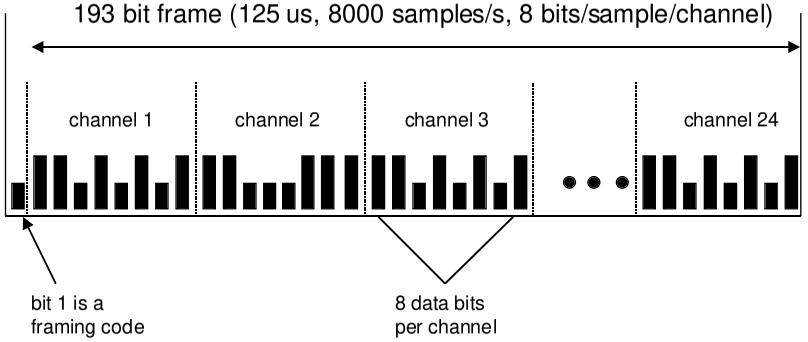
type	symbols/sec	bits/symbol	Kb/s
v.32	2400	4	9.6
v.32.bis	2400	6	14.4
v.34	3200	9	28.8

Theoretical limit for modulated signals is approx 35 Kb/s:

Shannon's law: max bits/s = H log2(1 +S/N), where H is bdwdth and S/N is signal to noise ratio. For phone network, H~3,600 and S/N is 30 dB. Thus max rate is ~35 Kb/s.

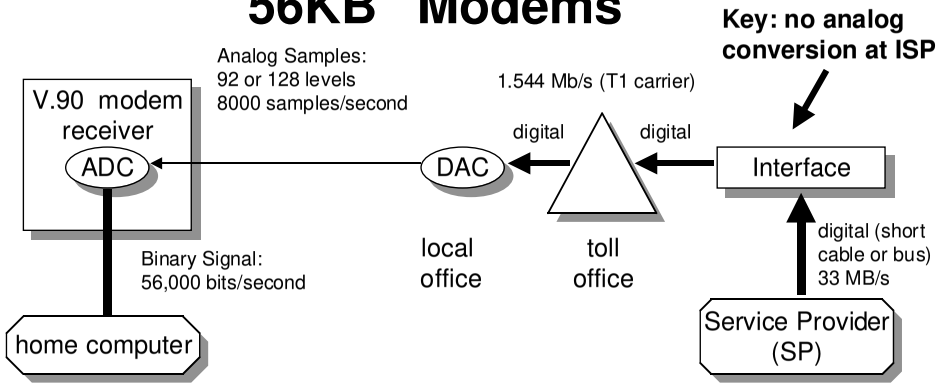
T1 carrier (1.544 Mb/s)

Digital part of phone system based on the T1 carrier:



Each channel has a data rate
of 8000 samples/s * 8 bits/channel = 64 Kb/s

56KB “Modems”



- **Asymmetric: home to SP uses conventional v.34 modem**
- **SP has digital connection into phone system**
  - Channel sending 8000 samples / second, up to 8-bits/sample
- **DAC encodes each sample with 92 or 128 voltage levels**
  - Not enough precision on analog side to handle finer resolution
- **Receiver converts samples back to digital values**
  - Must match frequency & phase of senders DAC
  - Establish using “training” signals from sender

Ethernet

History

- **1976- proposed by Metcalfe and Boggs at Xerox PARC**
- **1978 - standardized by Xerox, Intel, DEC**

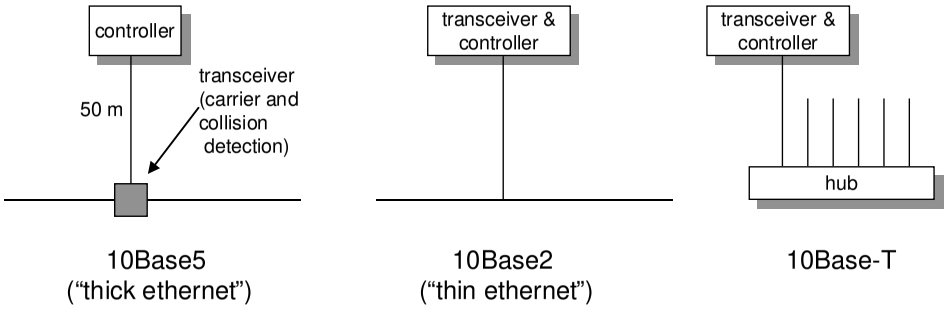
Bandwidth

- **10 Mbits/sec (old) , 100 Mbits/sec (new)**

Key features

- **broadcast over shared bus (the ether)**
  - no centralized bus arbiter
  - each adapter sees all bits
- **each adapter has a unique (for all time!) 48-bit address**
- **variable length frames (packets) (64 - 1518 bytes)**

Ethernet cabling



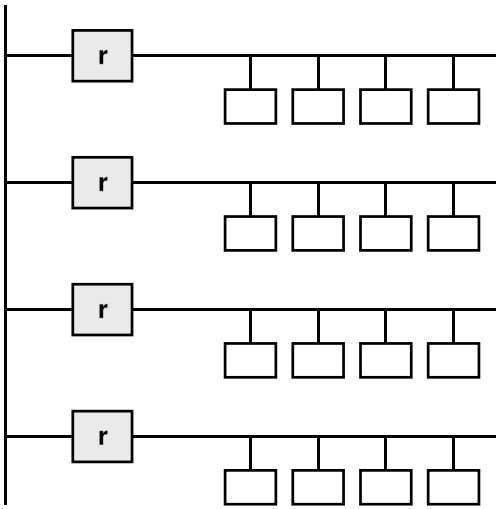
10Base5 ("thick ethernet")

10Base2 ("thin ethernet")

10Base-T

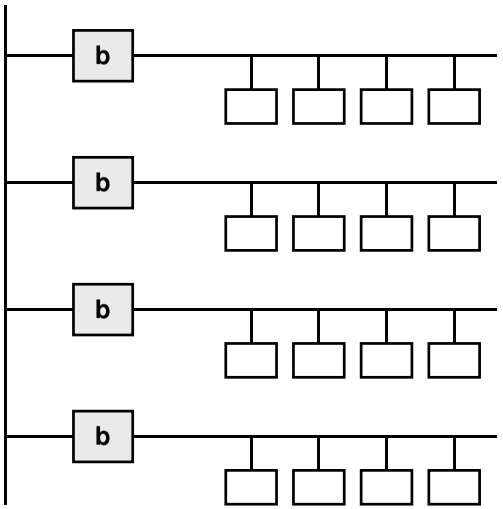
name	cable	max segment	nodes/segment	advantages
10Base5	thick coax	500 m	100	good for backbones
10base2	thin coax	200 m	30	cheapest
10Base-T	twisted pair	100 m	1024	easy maintenance
10Base-F	fiber	2000 m	1024	best between bldgs

Repeaters



Repeaters directly transfer their inputs to their outputs.

Bridges

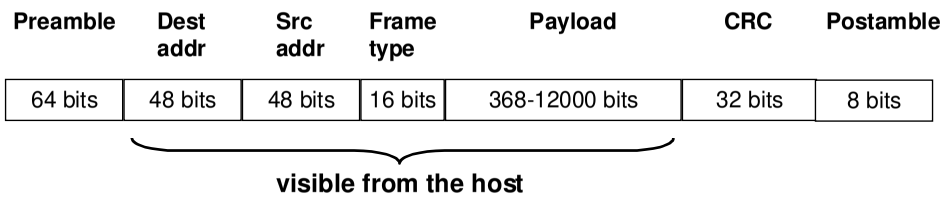


Bridges maintain a cache of hosts on their input segments.

Selectively transfer packets from their inputs to their outputs.

Ethernet packet (frame) format

64 - 1518 bytes



Preamble: 101010101 (synch)

dest and src addr: unique ethernet addresses

payload: data

CRC: cyclic redundancy check (error detection/correction)

Ethernet receiving algorithm

Ethernet adaptor receives all frames.

Accepts:

- **frames addressed to its own address**
- **frames addressed to broadcast address (all 1's).**
- **frames addressed to multicast address (1xxx...), if it has been instructed to listen to that address**
- **all frames, if it has placed in promiscuous mode**

Passes to the host only those packets it accepts.

Ethernet sending algorithm (CSMA/CD)

Problem: how to share one wire without centralized control.

Ethernet solution: Carrier Sense Multiple Access with Collision Detection (CSMA/CD):

1. Adaptor has frame to send and line is idle:

- **then send frame immediately**

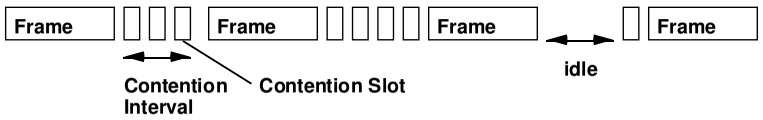
2. When adaptor has frame to send and line is busy:

- **wait for line to become idle, then send frame immediately.**

3. If "collision" (simultaneous sends) occurs during transmission:

- **send at least 1024 bits**
- **send "jam signal" to notify receivers**
- **wait some period of time (binary exponential backoff)**
- **retry**

Binary exponential backoff

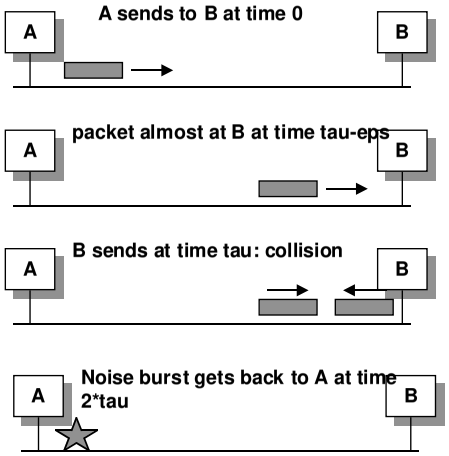


Binary exponential backoff algorithm:

- **after 1st collision, wait 0 or 1 slots, at random.**
- **after 2nd collision, wait 0, 1, 2, 3 slots at random.**
- **etc up to 1023 slots.**
- **after 16 collisions, exception.**

Why the 64 byte minimum packet size?

Assume propogation delay from A to B is tau.



Conclusions: Senders must take more than 2*tau seconds to send their packets.

For ethernet, tau is specified by standard (2500 m cable w/ 4 repeaters) to be 51.2 usecs, which at 10 Mb/s is 512 bit times, or 64 bytes.

Rough estimate: propogation through copper is about 20 cm/ns. With a 2500 m cable, tau is 12.5 us and 2*tau is 25 us.

As speeds increase there are two possibilities:

1. increase packet sizes
2. decrease maximum cable length

Neither is particularly appealing.

Ethernet pros and cons

Pros:

- **simple**
- **robust**
- **cheap ($50/adapter in 1998)**

Cons:

- **no quality of service guarantees**
  - OK for data
  - not OK for real-time bit streams like video or voice
- **fixed bit rate**
  - not keeping up with faster processors
  - workstation can produce data at 10-50 MBytes/sec
- **prone to congestion**
  - processors getting faster
  - bridged Ethernets can help some

Asynchronous transfer mode (ATM)

History

- **1988- proposed by international ATM forum**
- **telecomunications and computer vendors**

Goal:

- **mechanism for integrated transport of bit streams with different performance and reliability requirements (quality of service)**
  - video: 1.5 Mbits/sec, latency and variance sensitive, some bit loss OK
  - voice: 64 Kbits/sec, latency and variance sensitive, some bit loss OK
  - data: high data rates, latency and variance insensitive, bit loss not OK

ATM overview (cont)

Bandwidths

- **OC-1: 51.84 Mbits/sec**
- **OC-3: 155.52 Mbits/sec (current LAN rate)**
- **OC-12: 622.08 Mbits/sec (current LAN rate)**
- **OC-24: 1244.16 (Gigabit network)**

Key features:

- **virtual connections (VC's)**
  - allow bandwidth reservation
- **fixed cell (frame) size of 53 bytes**
  - simplifies high-speed switching
- **small cell size**
  - allows fine-grained allocation of network bandwidth

ATM cell format

53 bytes (fixed)

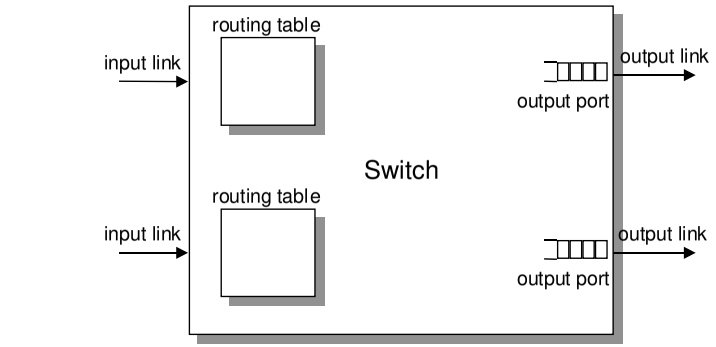
Generic flow ctl	VCI/ VPI	Payload type	Priority	Header checksum	Payload
4 bits	24 bits	2 bits	2 bits	8 bits	48 bytes

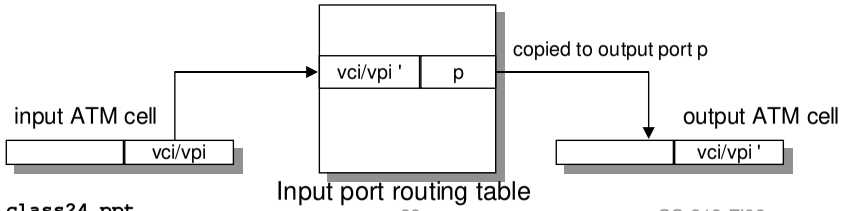
VCI: virtual connection (channel, circuit) identifier

VPI: virtual path identifier

payload: data

ATM cell routing





ATM pros and cons

Pros:

- **bandwidth can be reserved (connections)**
- **scalable aggragate bandwidth (wide range of supported bit rates)**
- **support for network traffic with different quality of service requirements (small, fixed, easily multiplexed cells)**
- **potential for high speed switching (small fixed-size cells)**

Cons:

- **maximum user bandwidth still limited by link bandwidth**
- **connections make broadcast and multicast more difficult**
- **quality of service is still a research issue**