Physical Layer

TCP/IP class

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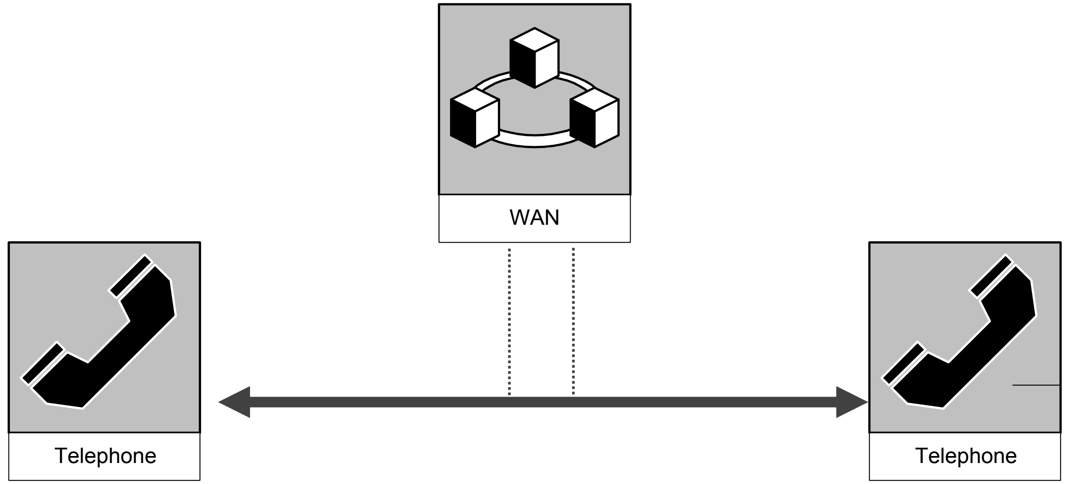
physical layer

- intro - hw concepts
  - topology
  - wan versus lan
  - switches, circuit and packet
- ethernet
- point to point serial
- odds and ends
  - mtu/path mtu/localhost
  - repeaters/bridges/routers

intro/topology/fundamentals

- Two basic ideas:
  - The link layer can **broadcast (multicast)**
  - The link layer is **point to point, can't bcast**
- other topologies built out of these building blocks
- point/point often **Wide Area Network (WAN)**
  - (telcos - equipment is leased)
- broadcast often **Local Area Network (LAN)**
  - (enterprise - equipment is owned)

point to point

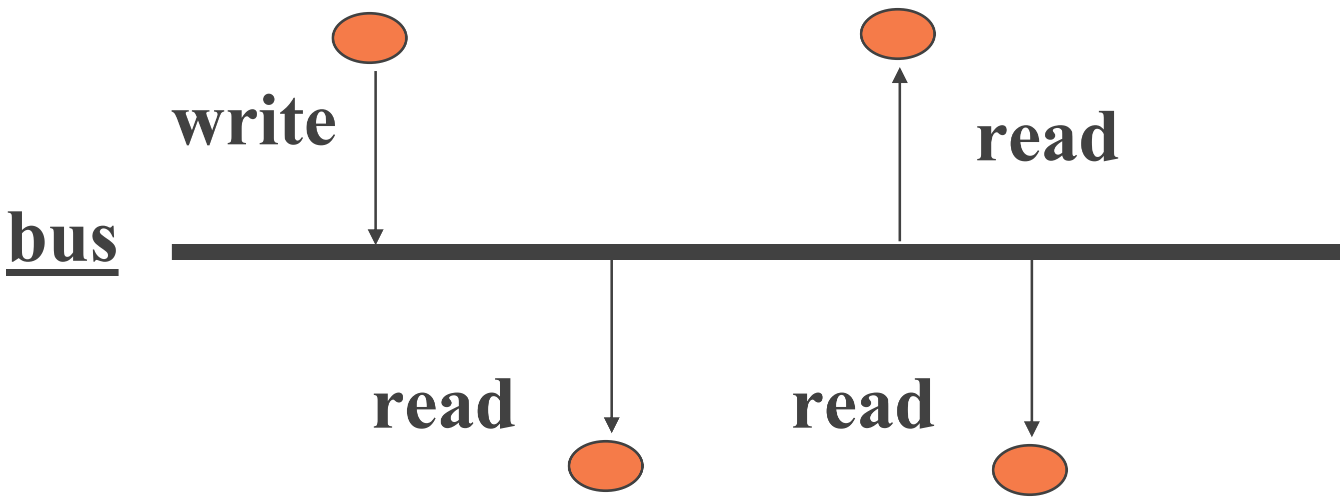


ring, ring! yadda, yadda!
note: telco network in-between (not Internet)

point to point, examples

- modems (POTS/analog)
- ISDN (digital phone)
- RS-232 cable between two computers
- most WAN toplogies (not all)
  - T1/T3, T1 classically 23 64k PCM voice lines
- may have "dynamic connections" and need addresses (phone #s), may not (serial cable)

broadcast



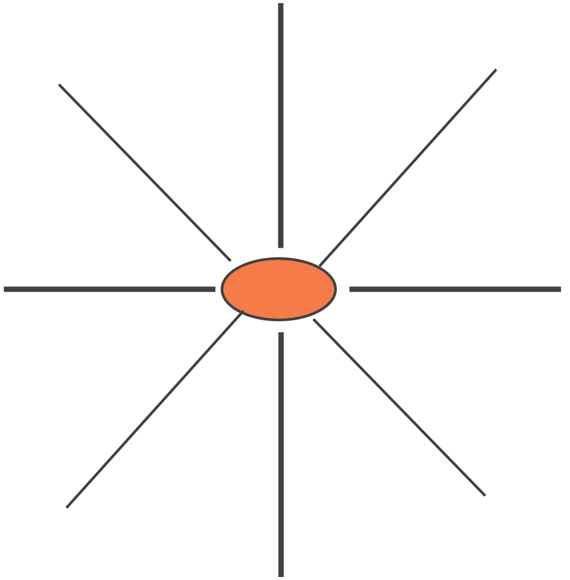
1 write - many reads in parallel

broadcast

- includes one to one
- **broadcast** means 1 to all stations
- **multicast** means 1 to many, includes 1-1, 1-all (broadcast is subset of multicast)
- Examples include ethernet, token-ring, radio
- questions include: can it do CSMA, CD (later) ?
- also notion of **multipoint -** simulation of bcast by 1 to N point to point connections

derived topologies

Star

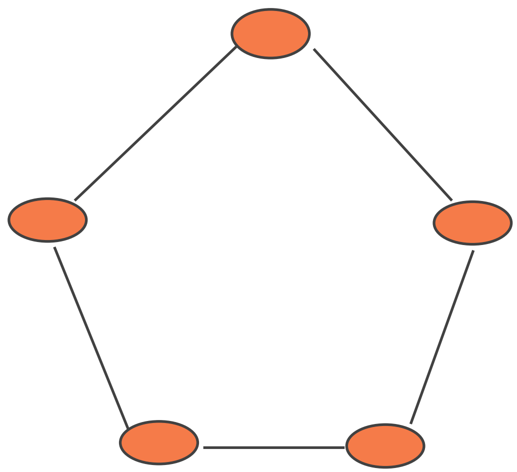


examples:

enet hubs, ATM

derived topologies

Ring

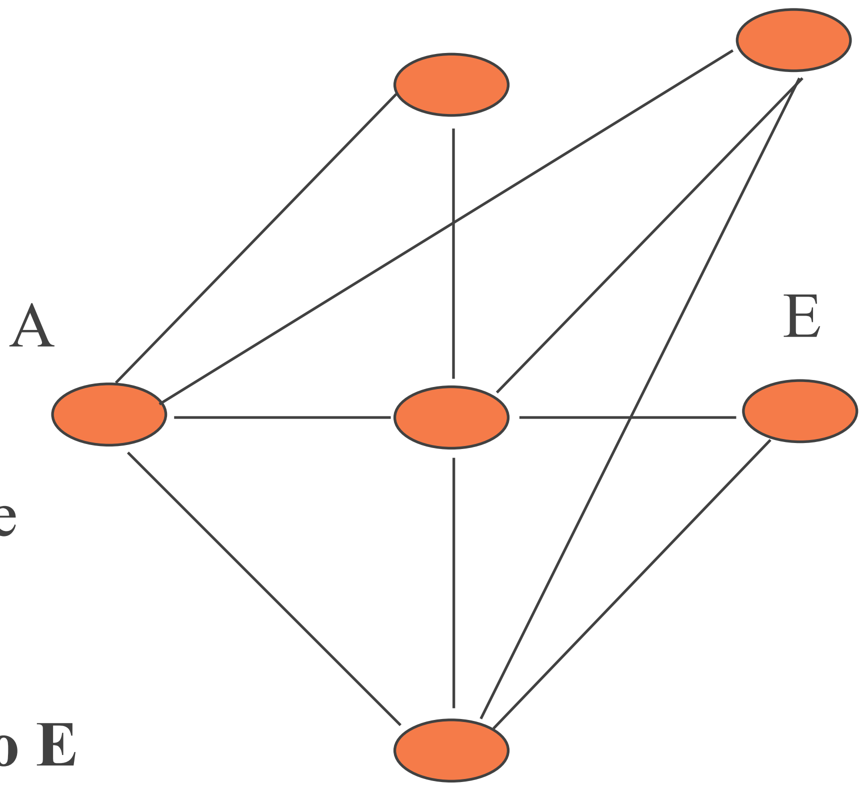


examples:

token ring, fddi

derived topologies

Mesh



examples:

Inet backbone

redundancy, consider A to E

WAN vs LAN

- 3 kinds of network
  - in terms of geography, ownership, speed
  - 1. WAN - wide area, telcos own equipment point to point
  - 2. MAN - metro area, telcos own, but has broadcast (fddi, SMDS, atm?) (shared?)
  - 3. LAN - ethernet, token-ring, local, enterprise-owned

WANS

- telcos own, operate
- Bellcore, US West, GTE, other RBOCs
- Sprint, MCI too
- European PTTs (Post, Telephone, Telegraph) - monopolies
- folks who brought us ISO/OSI and are trying to bring us ATM

WAN vs LAN

- different cultures, people, technologies, lingo (can you say pleisochronous?)
- WAN focus traditionally on **voice**, LAN on **data**
- WAN standardization efforts slow, LAN relatively fast
- somebody who knows both is rare person

WAN characteristics

- focus on voice/low-speed **isochronous** xfer
- customer *rents* equipment and usage from telco
- in past slower than LAN, may change with ATM (maybe not ... 1G enet)
- point to point (connect first, then switch)

WAN examples

- modem over analog phone (POTS)
  - 1200 baud to 28.8k baud (2-3k bps), now 56k?
  - modems can compress, do error correction
- ISDN (some places) - 64k/128k
- leased line/frame relay, 56k to T1 speeds
- STM - synchronous transfer mode
  - T1 - 1.544 megabits per sec, T3 - 44 mbps
- analog/digital cellular wireless (1-2k bps), up to T3 speeds in some cases for pt/pt radio

WAN futures

- cable tv - “upstream” has been problem
- ATM as PVC (permanent virtual circuit)
  – OC3 is 155Mbs
  – OC12 is 622Mbs
  – slower/faster possible too, 1G mbps?
  – short term: ATM is T1/T3 replacement
  – long term: might be LAN technology too
- satellite/radio? TBD

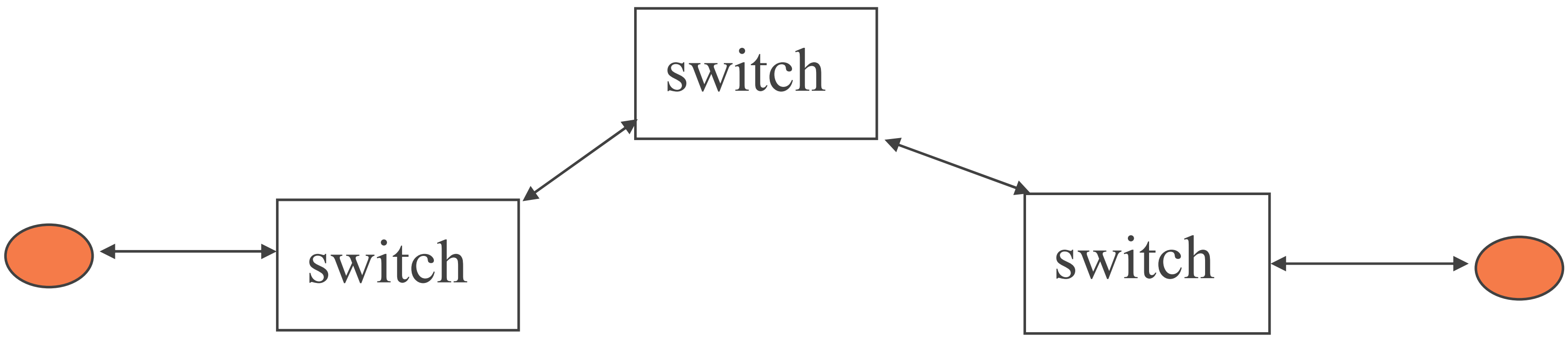
Lan examples (all broadcast)

- Ethernet
  - 10/100 (switched/full-duplex)/1000/10000?
    - many wiring models so far
    - 1000 is man technology too (5..100 or so km)
- Token-ring
  - 16mbps, 100 exists, prognosis not good (see above)
- FDDI, man, ring, 100 mbps
- wireless radio, 1-10 mbps, 802.11 standard
  - Lucent IEEE wavelan 2-? mbps, 400-800 foot cell?

switches, circuit OR packet

- **circuit switch** - telco voice routing
  - point/point “virtual circuit”
  - connect-time sets up path from end to end
  - pros:
    - » endpoints don’t need to worry about load, they have path/circuit capacity reserved
    - » faster than packet-switch (?)
  - cons:
    - » circuit wasted if no data
    - » if switch crashes, must reconnect

circuit switch - diagram



1. connect protocol
   setup path
2. send data
3. disconnect

(not in virtual circuit)

switches contain state: (I(n) , O(n))

packet switch - router

- packet switches used by computers, send data in discrete packets, each packet has addresses
- no connect/disconnect
- each packet is instantaneously routed (output i/f is determined) acc. to table lookup of dest address
  - f(pkt dst, routing table) -> output port
  - routing table may change from pkt to pkt
- pros:
  - good for bursty traffic
  - robust as fate sharing is minimized

packet switches, continued

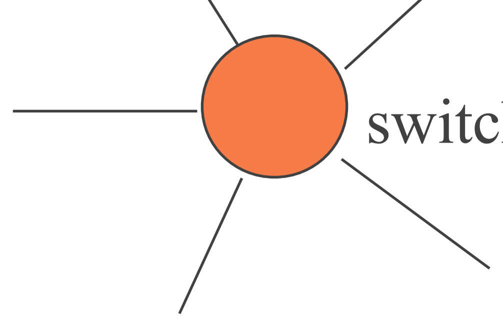
- cons:
  - switches deemed to be faster, since routing table lookup is network layer/sw decision
  - router software can cause warts...
    - “you!. set BGP-4 up on that there router ...!”
  - open problem as to how to do isochronous data xfer

fate-sharing (is a bad thing)

- from very high-level POV
- A-E (end to end) is better than A-B-C-D-E in terms of reliability
- if router C goes down in connection framework, A and E are hosed
- if router C does down in packet switch network, may have delay (reboot) or alternate path **BUT THE CONNECTION STAYS UP! ....**
- fundamental design decision for Internet routing

ethernet switch means what?

- ethernet switch - bridge with fast backplane
  - e.g., 8 ports -> 80mbps (8 * 10mbits)/2
  - **star** topology, still support broadcast but
    - we have features, full-duplex (no collisions)
  - can give each end-node its own 10 mbps to another end-node on switch (point/point)



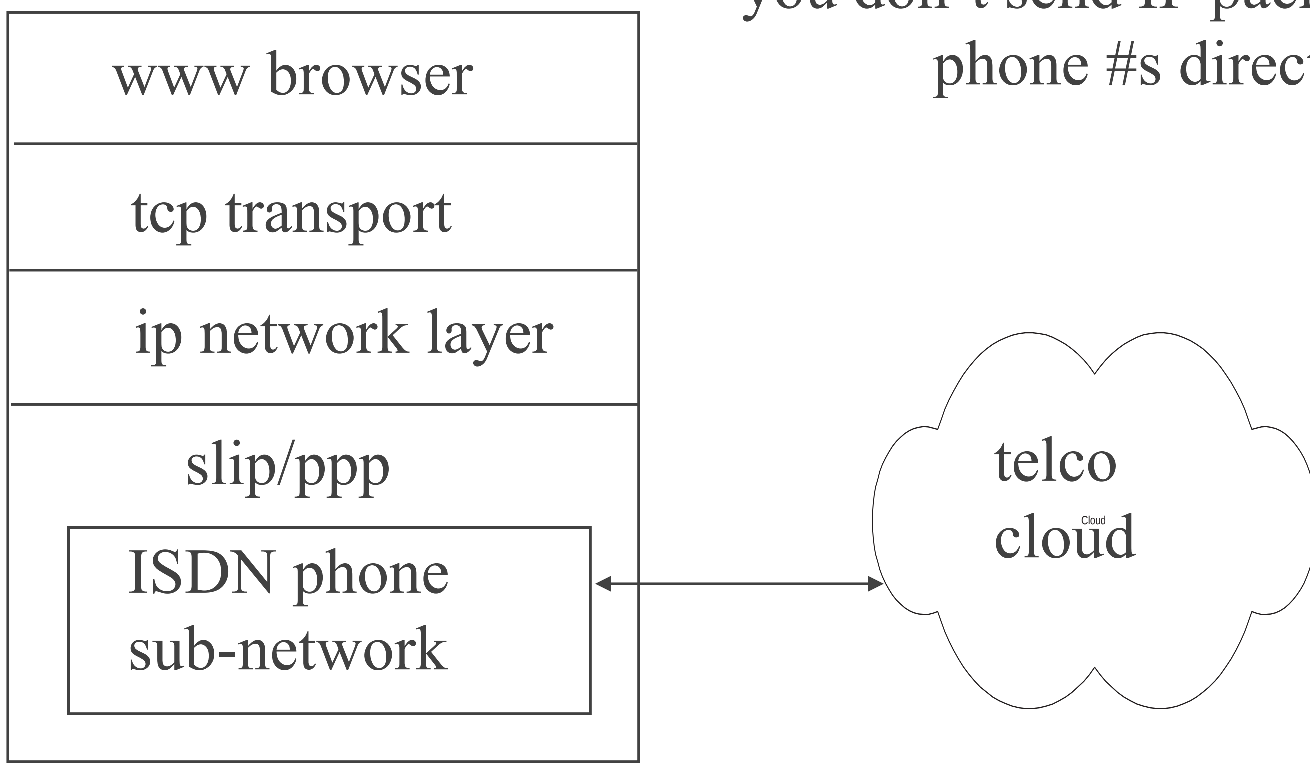
tcp/ip Point of View for WAN

- **sub-net** versus **peer** addressing models
  - sub-net, means we put you in a link-layer box and run on top of you
  - peer - can address all endpoints
  - Internet Protocol (ip) and routers may sit on top of TELCO circuit-switch network (modems/ISDN), examples
    - Inet in WAN, uses T1/T3
    - end user with modem and PPP/SLIP protocols

Telco in a TCP box

your computer at home:

you don't send IP packets to phone #s directly



Ethernet - intro

- invented at Xerox Parc in early 70's
- standardized by Dec/Intel/Xerox (DIX)
- signals on cable called the "ether"
- 80% speed of light
- number of different wire types
- doesn't load as well as token ring, but still cheaper

ethernet wiring types

cable type	alias	connector	length
10BASE5 50ohmRG-11	**thicknet**	**N-type**	**5*500M**
10BASE2 50ohmRG-58	**thinnet**	**BNC**	**185M**
10BASET	**twisted-pair**	**RJ-45**	**?**
100BASE	**fiber/tp**		
1000BASE	**fiber/copper**		

10BASET, popular, cheap, hub-based, need better grade of wire to support 100 mbit ethernet

10BASE2, daisy chain cable, with T connectors + terminators

Enet - properties

- original form: 10 mbps
  - (1.25 mbytes per sec)
- broadcast bus
- distributed access control; i.e., no central "master" saying you may or may not
- hw gets every packet, may not pass it on
- CSMA/CD - carrier sense multiple access with collision detection

enet - rough algorithm

check carrier to see if cable busy **(CSMA)**

if yes

    wait for idle

else

    transmit and listen for collision **(CD)**

    if collision

        backoff randomly and try again N times

    else wait min idle time - give others nodes a chance

      (distributed fairness, time slot == 51.2us for 10mbit)

collision detection/retransmission

- N tries, say 16
- if collision, must send jam signal, random backoff and retransmit
- jam == 512 bits (64 bytes), make sure end nodes hear collision, hence enet min frame is 64 bytes (46 data)
- backoff is "binary exponential algorithm"
- wait 1, 2, 4, 8 time-slots, etc * a random delay, max 1023
- packets can be lost due to collision, especially if network is heavily used
- modern network cards can saturate cable;
- best utilization put at %30 (over elapsed time)

ethernet addressing

- each controller has ***UNIQUE*** (!) ethernet or MAC address, assigned via IEEE in its “brains” (rom, flash memory, whatever)
- 48-bit integer, 6 unsigned char bytes
  - unicast address: **00:00:C0**:01:02:03
- first 3 bytes are manufacturer code
  - Intel: 00:AA:00
  - Sun: 08:00:20
- /standards.ieee.org/db/oui/index.html - IEEE web page for MAC lookup

3 kinds of physical address

- **unicast** - physical address of controller
- **broadcast**: *ff:ff:ff:ff:ff:ff*
- **multicast**: *01:xx:xx:xx:xx:xx*
- IP multicast range: *[01:00:5E:00:00:00..01:00:5E:7f:ff:ff]*
- ip-enet mapping not 1-1, 32 ip addr to 1 enet/ip multicast address

Ethernet frame formats

- what does packet look like on wire?
- at least two formats
  - IEEE 802.3 (Novell/ISO/some UNIX)
  - Ethernet 2.0 (traditional UNIX/Xerox NS)
- 802.3 has 2 sub-layers
  - Logical Link Control - handles demux to net layer
  - Media Access Control - addressing/i/o

IEEE Data Link Layer (2)

LLC - Logical Link Control (IEEE 802.2) - net layer
demux, error handling

MAC (media access control) layer

CSMA/CD IEEE 802.3 (Ethernet)	Token Bus 802.4 (defunct)	Token Ring 802.5	new, 802.6 802.11

MAC - 48 bit IEEE addresses

Ethernet 2.0 frame format

min = 64 bytes, max = 1518

dst	src	type	data	crc
6	6	2	46-1500	4

ip type = 0x800
arp type = 0x806, 18 bytes of padding (0)
rarp type = 0x8035

802.3 frame format

min = 64 bytes, max = 1518

dst	src	len	llc crud	type	data	crc
6	6	2	6	2	38-1492	4

So how can driver tell difference between 802.3 and E 2.0?

and the mystery envelope...

- they don’t overlap. len >= 46 && <= 1500
- ip type == 0x800, 2048 in decimal

headers/trailers

- 8 byte preamble used for synchronization
- CRC is 32 bit “hash code”, if computed crc != packet crc, packet is tossed
- no retries, so-called **“best effort”**
- **what does enet CRC guarantee you ?**
- **what doesn’t it guarantee you?**

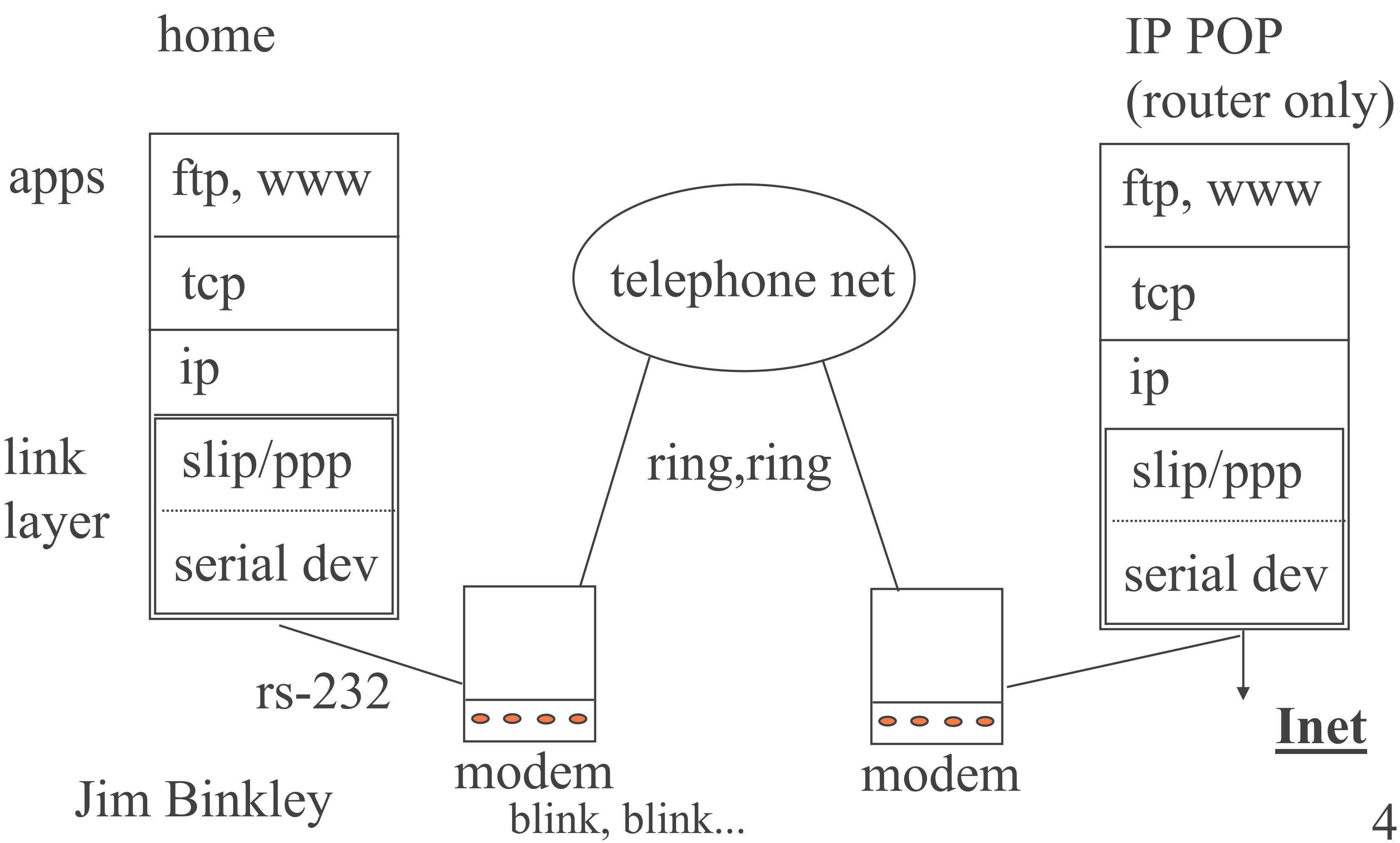
bad things happen to good pkts

- all bit errors are caught by CRC? (no)
  - ethernet crc is better than IP checksum though
- most are caught? (yes)
- that your packet will arrive for sure ? (no)
  - collisions or output i/f may toss as too busy
  - routers are busy and throw packets out (congestion)
  - “noise” causes CRC error, therefore packet is tossed
- if you have 10 routers end to end, CRC is enough to guarantee reliability? (no way)
- where would bad memory hurt a packet?

IP and Modems

- roughly 3 things might be done, focus = #2
  - 1. text-only terminal emulation - dialup
    - » kermit , pcplus (procomm), UNIX telnet session
  - ***2. link-layer full network access (slip/ppp)***
  - 3. application-level tunnel/gateway (linux *term*)
    - » client/server application gateway, client and server communicate directly via rs-232, talk to apps via unix sockets

slip/ppp net diagram



oh, btw

- change the names and previous picture describes Internet backbone too...
- modem -> CSU/DSU (say to T1)
- IP boxes on both sides are routers
- connection might be permanent or dynamic (on demand dialup popular with ISDN)

slip - serial line IP

- the "not a standard standard", RFC 1055
- simple, no protocol header, just one/two byte framing characters around data
- pros
  - extremely simple, common
- cons
  - can't support non-ip net layers (ipx) as no header
  - no CRC, reliability (modern modems - may not matter)
  - can't negotiate anything (ip address, compression)

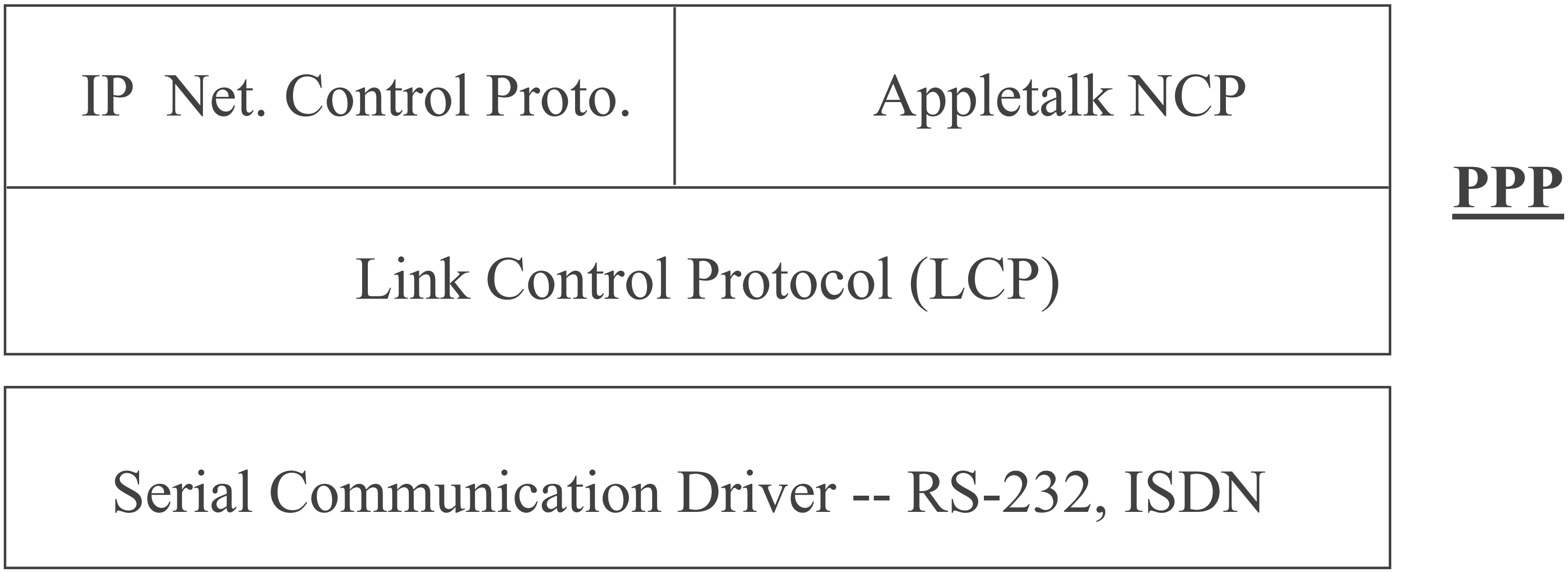
slip protocol (SIC!)

- data 0xc0, 0xc0 is frame char
- need escape char (if 0xc0 is data?)
  - SLIP ESC = 0xdb, on sending
  - if see 0xc0, substitute 0xdb 0xdc
  - if see 0xdb, substitute 0xdb 0xdd
- CSLIP or Van Jacobson Compression
  - **tcp headers only**, not udp, not tcp connection
  - not the data!, not ping (icmp on ip)

ppp - point to point protocol

- architecture at link layer has 2 parts
  - *network control part* (NCP), handles demux to network layer, any network options
    - example, for IP, handle dynamic ip addr exchange
  - *link control part* (LCP), handle link management, reliable (better) communication
- plus *encapsulation (frame) with header for pkt*
  - CRC, multi-protocol, framing as features
  - VJ compression but only for tcp headers

PPP link-layer architecture



Cons: complex to debug (at least compared to slip!)
Pros: IETF protocol used by Novell, Appletalk

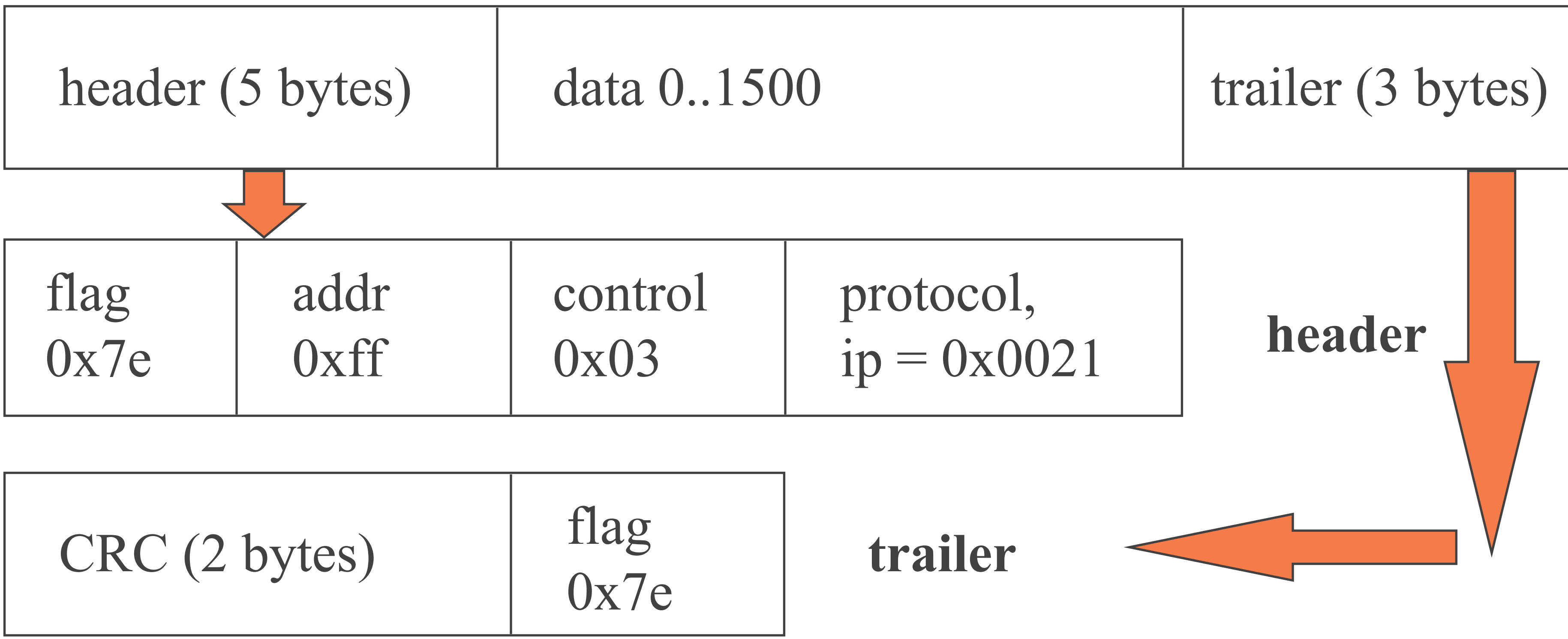
PPP - rfcs

- rfc 1661 - fundamentals including protocol types for LCP part, state machine, etc.
- 1332 - IP/NCP part
  - address negotiation
  - VJ compression
- CHAP (see radius as well)
- and rfcs for new link-layer technology framing and other more clever bits

PPP - a few bullet items

- 16-bit error correction - not as strong as enet
  - possibly duplicated by modem-level protocol?
- multi-protocol; e.g., appletalk/novell/ip
- CHAP - challenge response authentication with shared secret password on both sides as well as PAP which is plaintext password
- client ip address can be dynamically negotiated
- may be used in WAN context as well (ISDN)
- SLIP is mostly extinct

PPP frame format



- LCP prpto, 0xc021, NCP 8021, data x0021

PPP protocol

- protocol roughly consists of:
  - .lcp link establishment and subsequent
    - » close and periodic link status check
  - optional lcp link authentication
  - NCP phase
    - » e.g., IP address negotiation and/or VJ compression
  - final lcp shutdown
- LCP has a number of packet types, configure, terminate, error, echo, etc.

loopback driver

- special IP address, 127.0.0.1
- everything you write to it, comes back up stack
- “localhost” (DNS) -> 127.0.0.1
- % telnet localhost | 127.0.0.1
- a few controllers can’t read own transmissions, so loopback is useful there too (in addition to preventing unnecessary net traffic)

MTU - max transfer unit

- limit on size of frame transmitted at link layer
- on UNIX: *% netstat -in (or ifconfig -a?!)*
- enet II: 1500, 802.3: 1492
- slip: 1004 (ftp/thruput), 296 (telnet/share)
- usoft ppp: 1500
- ATM: around 8-9k, fddi: 4352
- if ip has bigger packet, it **fragments** the pkt

PATH - MTU (avoid fragmentation)

- transport layer determines best link-layer MTU from end to end, RFC 1191 Deering/Mogul
- older and lamentable TCP algorithm:

  if dst on same subnet

  send at MTU size (or 1024!)

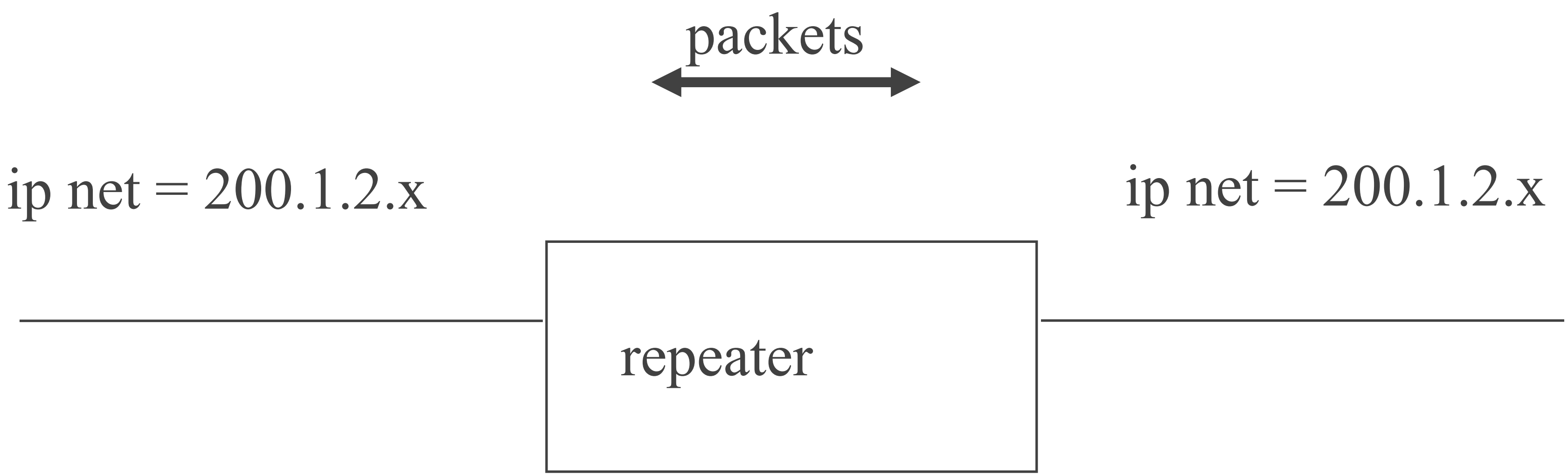
  else

  send at router MSS: 576
- PATH MTU exists in most hosts, but easier for routers to do. host must keep tcp/ip state
  - routers simply send ICMP error message with needed next-link MTU back to source end system, pkts marked Dont Fragment

repeaters/bridges/routers

- **repeaters (hubs)** - function at physical layer (l1)
  - active hw device, strengthen signal
  - simply tie wires together, still same net
  - may have sw brains, managed means speaks SNMP
  - may not forward collisions (or it may)
- **bridges(switches)** - function at device layer (l2)
  - adaptive/learning bridges isolate same-side traffic
  - must flood broadcasts
- **routers** - operate at network layer (l3)

repeater



physical layer only

bridge (or switch? or hub?)

- has **sw** that acts on link layer MAC addresses
- may filter (security) based on MAC address
- network isolation (don't forward garbage)
- may be adaptive learner (efficient)
- may have spanning tree (redundant)
- may be "switch" (parallel) and speak VLAN
- typically same media (enet) on all ports
  - although cross media bridges exist

traditional bridge operation

- i/fs are in promiscuous mode - read all pkts
- collisions aren't forwarded THEREFORE
- network isolation which repeaters can't do (hubs do this)
- learn which packets belong to which side
- bridges as "switches" are rage now
  - fast bus, 10 10mbps enet -> 100 mbit bus
  - support "multimedia", one node per wire
- bridges have **spanning tree algorithm** with own link-layer protocols, form tree to prevent loops - allows redundancy

bridge learning mode

- look at input's src MAC address
- if broadcast or multicast, must forward
- if address not in lookup table, store as (address, i/o port, timestamp)
- if address on "new" port, change entry
- if address on "old" port, update timestamp

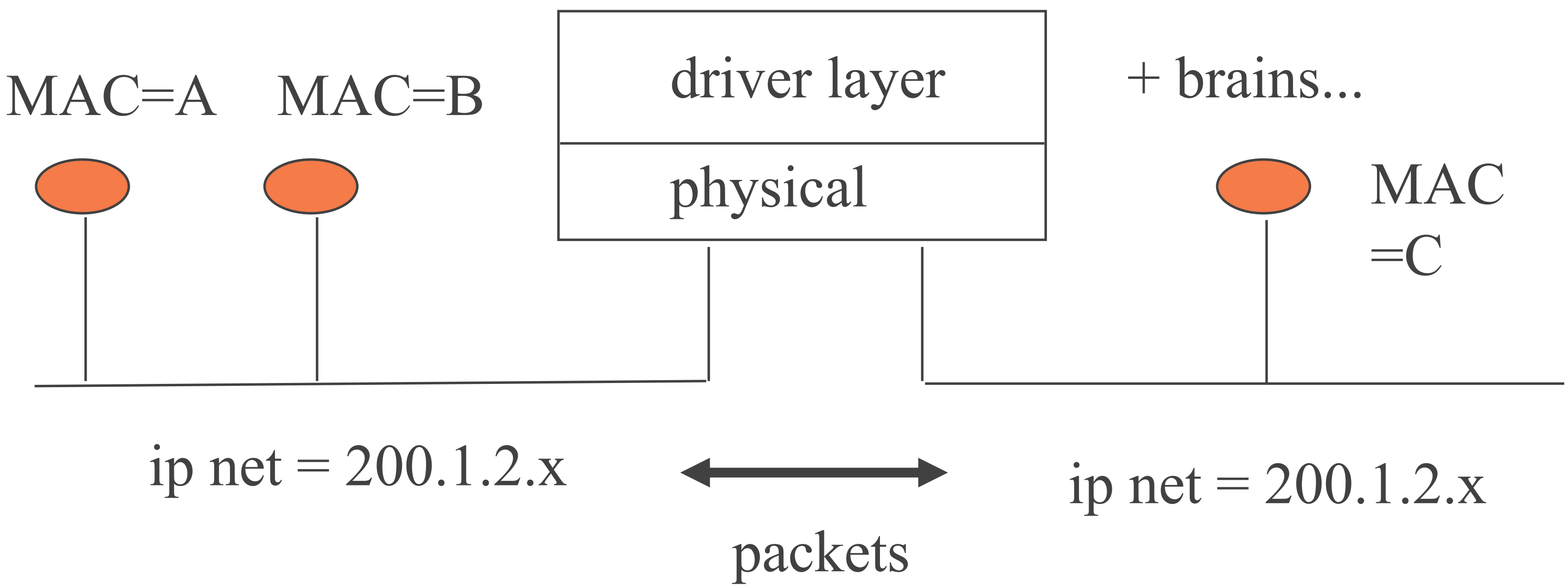
bridge forwarding algorithm

- if dst address broadcast/multicast
  forward
- if address in database
  - if input port same as listed port, don’t forward
  - else forward out other port
- else
  - forward (and store!)

bridge (adaptive/learning)

src A to dst B learns to not forward
src A to dst C must always forward

link layer



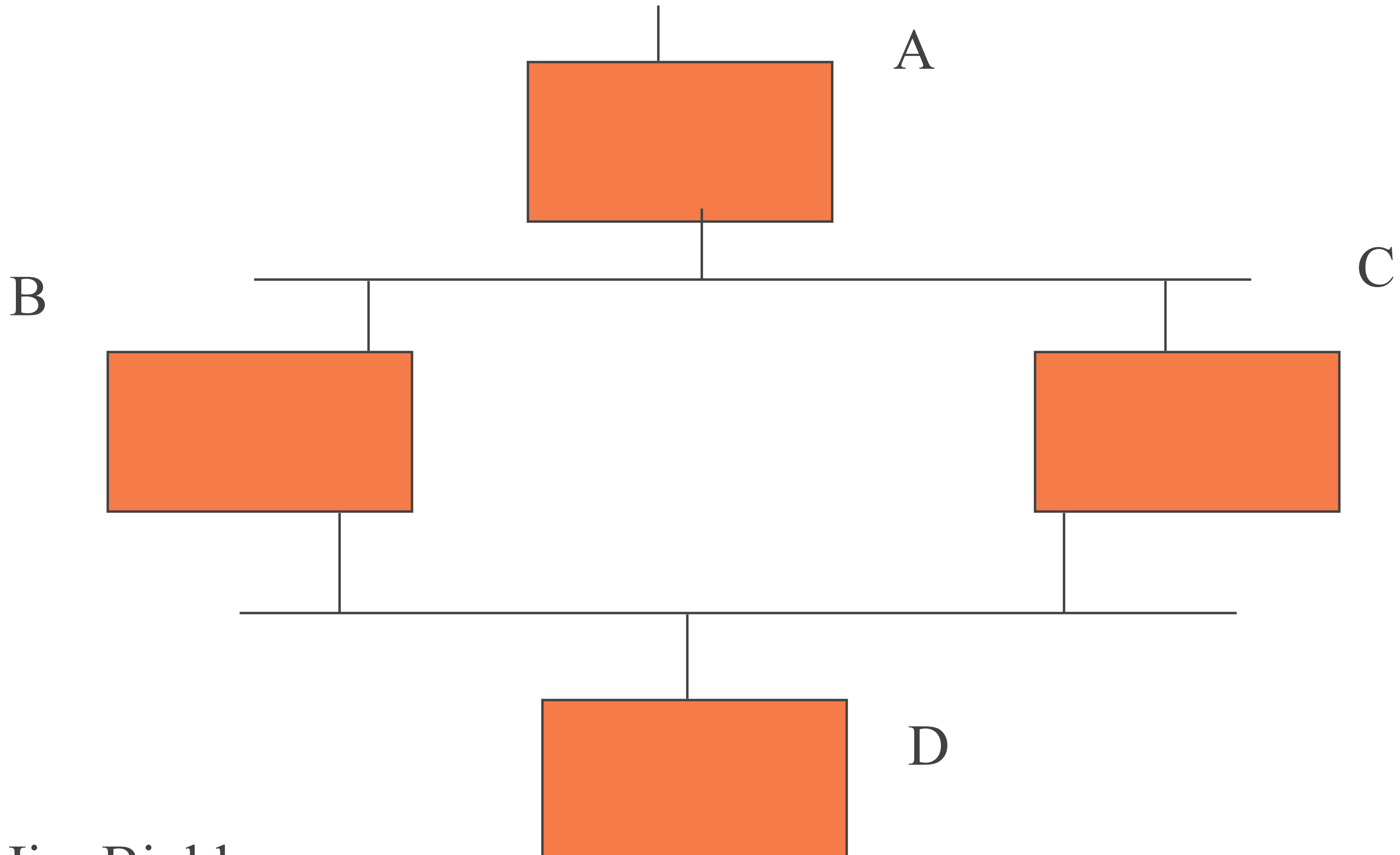
what's wrong?

assume 2 bridges hook 2 ethernet segments together.   no problem, right?

spanning-tree

- see Stallings, Local and Metropolitan Area Networks, for more info
- IEEE 802 standard (802.1D)
- bridge protocol at link layer
- bridges form rooted tree
- leave “cycles” out; i.e., port may be left out of spanning tree and not work (blocked state)
- done with simple link-layer flooding

4 bridges, what happens?



trad. bridge function summary

- adaptive learning - unicast isolation as long as MAC src location can be learned
- same **broadcast domain** on both sides - forward multicast/broadcast
- store and forward, therefore collision detection (modern switches may not do this as must store to calculate crc)
- spanning tree - prevent link loops

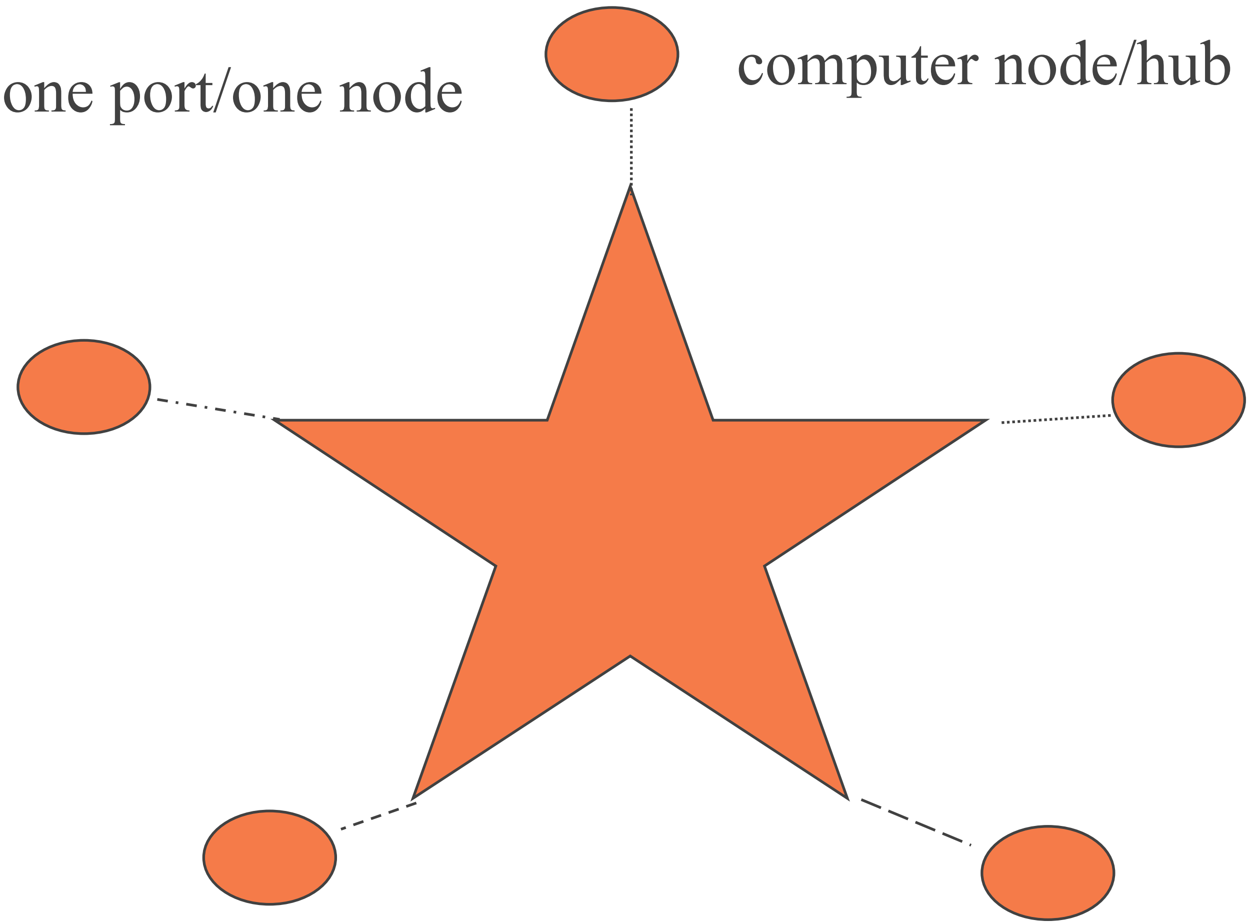
enet switch vs “bridge” or hub

- in a switch, packets forwarded from port A to port B are forwarded in parallel
- in a hub, not so
- switch means fewer collisions if one node per wire as unicast can’t collide (full-duplex means no collisions)
- switch might use **“store/forward”** (traditional bridge) or **“cut through”** (switches will be bridges too)
- cut through means pkt only examined up to dst MAC address
- hubs are often repeaters anyway (e.g., 10BASE-T), but do collision detection (bridge function)

bridge as switch

ideal: one port/one node

computer node/hub



10/100mbit enet: bridge backplane N * 10/100

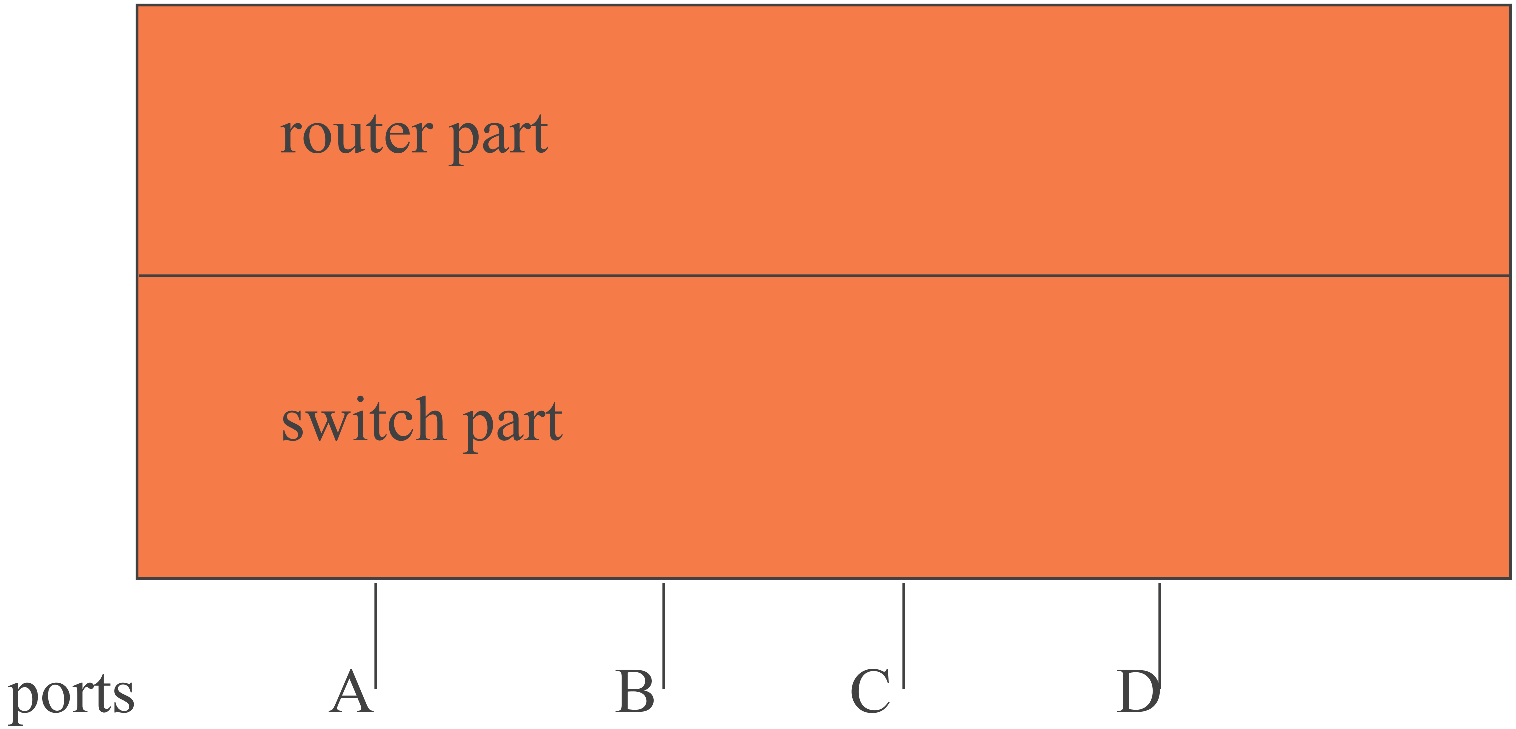
bridge/switch considerations

- **broadcast domain** - “segment” over which broadcasts are forwarded and heard
- **collision domain** - “segment” over which collisions can occur
- have to ask ourselves what these mean in terms of switches/bridges/hubs/repeaters?
- switch setup for cut thru cannot detect collisions (need to look at entire packet)

level 3/4 - switching/VLAN

- beware the marketroids - some think this is oxymoron (level 7 switching ...)
- VLAN means we have ability in switch to logically group segments
- VLAN X on port Y/Z, means Y/Z have shared broadcast domain.
  - logical ethernet segment, not necessarily physical
- on router/switch, thus if pkt crosses from VLAN Y to X, then only is routed

VLAN picture - combined router/switch



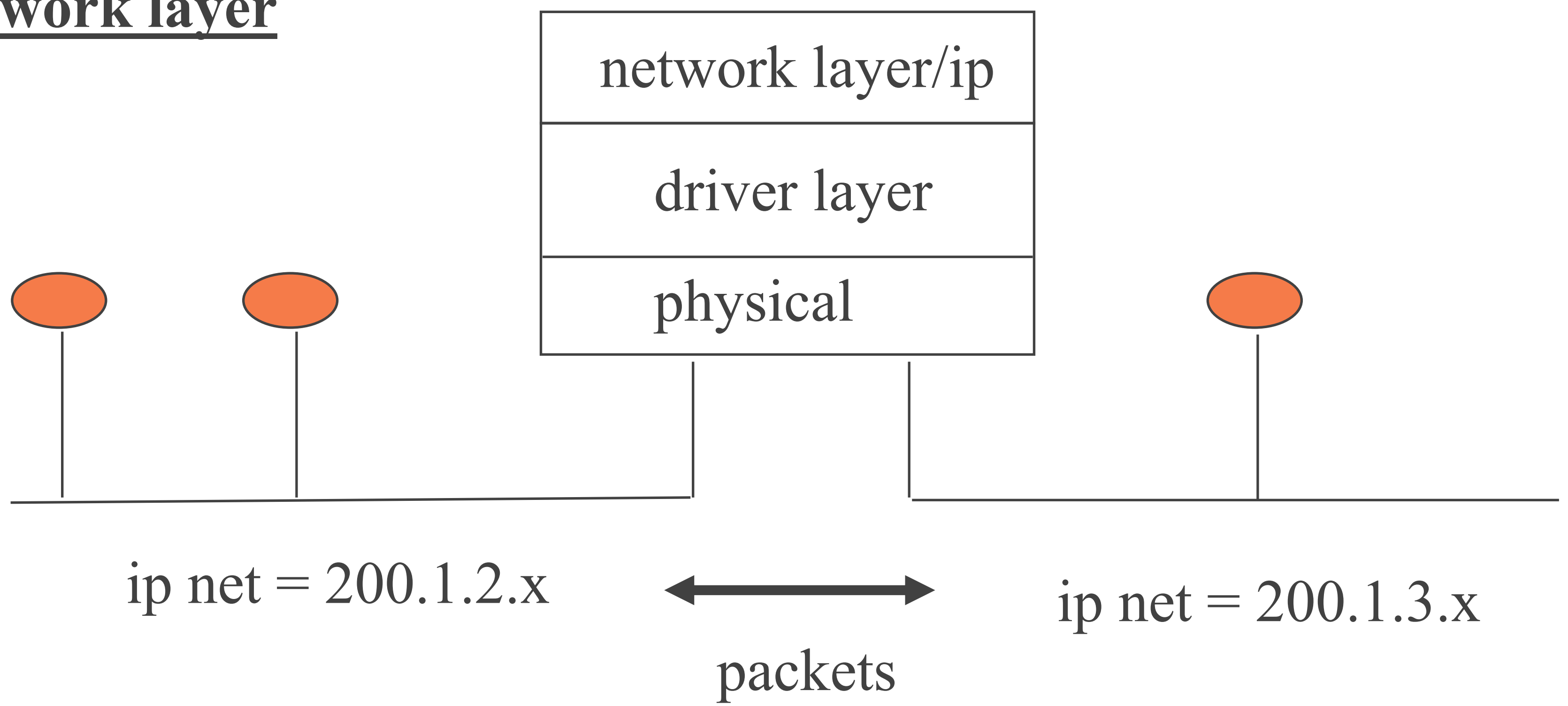
vlan X = ports A/D, pkts to B routed

vlans and switches and subnets

- assume IP subnet 1 to 1 with vlan
- logical vlan connectivity MAY exist (under negotiation in IEEE)
- means -- intra and inter switch vlans
- port i, j on switch I, and port X on switch Y all in same vlan V
- cisco tag switching is one proprietary example

router

network layer



how does router affect collision/bcast domain?

- broadcasts are NOT usually forwarded
  - exceptions exist: e.g., DHCP/BOOTP request
- multicast the SAME, (barring multicast routing)
- collision domain limited as well
- routers may be viewed as absolute sanity firewalls for ethernet segment disasters
  - broadcast meltdown ...

“typical” network topology