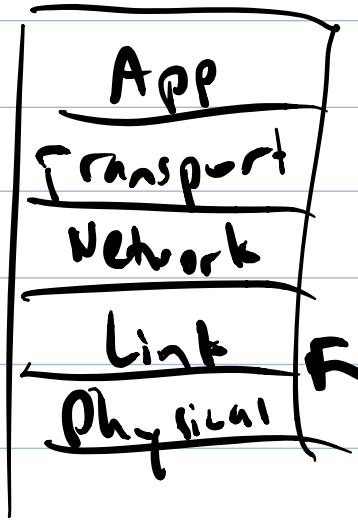
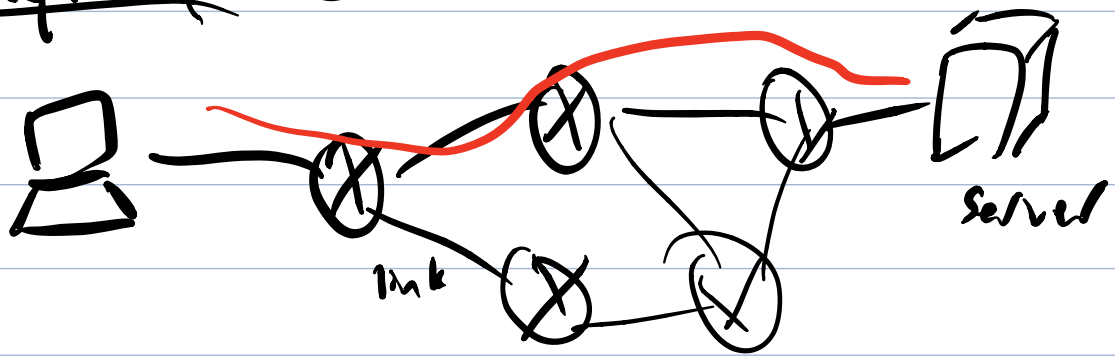


instance of app ↔ instance of app

process ↔ process

host ↔ host

hop ↔ hop



ARP: address resolution protocol IP → MAC

host and routers: nodes

channels connecting adj. nodes: links (wired, wireless, LANs)

layer-2 packet: frame (encapsulates datagram)

data-link layer is responsible for txing datagram from one node to a physically adj. node

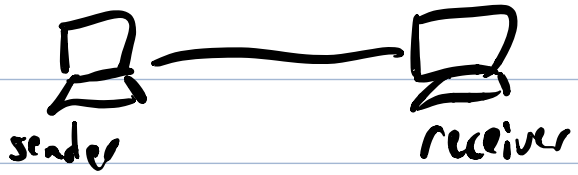
Network [Datagram] ↓

Link [HL | Datagram | TL] frame

- offers framing, link access
- reliable delivery between adj. nodes

Reliable data transfer means to deliver packets in order without errors

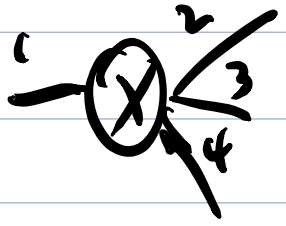
- **flow control**



↳ ensures that sender will not overwhelm the receiver buffers (implemented w/ feedback)

- error detection
  - ↳ errors caused by signal attenuation & interference
  - ↳ receiver detect presence of errors
    - ↳ signals sender for retransmit or drop frame
- error correction
  - ↳ receiver identifies and corrects bit errors without resorting to re-tx
- half-duplex and full-duplex
  - ↳ half-duplex: a node can either tx or rx
  - ↳ full-duplex: a node can tx and rx at the same time

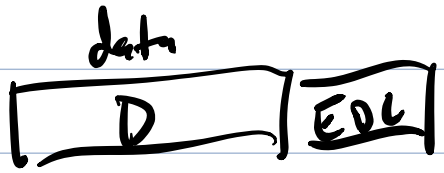
link layer implemented mostly in NIC.

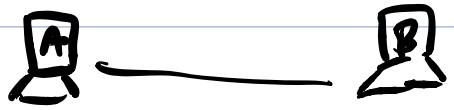


each intf has an NIC
in a router

EDC - error detection & correction bits

Error Detection





parity checking → detect single bit errors

odd parity
- add 1 bit to data s.t. # of 1s is odd
  1011 → 10110

even parity
- add a parity bit to make # 1s even

2D parity check
↳ assume e.g. odd parity
D = 1010 1100 1011

00100

1011	0
1100	1
1010	1
0010	0

1010 1100 1011 0 → to rx

1	0	1	1	0
1	1	0	0	1
1	0	1	0	1
0	0	1	0	0

error

error
↳ flip to 1

Cyclic redundancy checking (CRC)

- more powerful, detect multiple bit flips

Sender receiver

Agree generator G: 1001 G: 1001

data D

CRC R

$\frac{D||R}{G} \bmod 2 = 0$

D||R ⟶

CRC calculated s.t. $\frac{D||R}{G} \bmod 2 = 0$ (no remainder)

Assume G has r+1 bits.

Then size of CRC (R) will be r bits

⇒ Max # errors that we can detect is r

frame D'||R'

$\frac{D'||R'}{G} \bmod 2 = r$

0: No error detected

1: errors

e.g. data = 10111 0 sender side, compute CRC

G = 1001

CRC size r = 3 ⟶ r+1 = 4 = size of R ⟶ 10111 0000

LSL r bits left

D ≪ 2^r

$R = \frac{D \cdot 2^r}{G} \bmod 2$

division mod 2:

- subtraction is XOR w/o a borrow
- result of a division mod 2 is the leading bit of the dividend

$$R = \text{rem}\left(\frac{D \cdot 2^r}{G}\right) = \boxed{011}$$

Sender transmits frame $D \| R$

$\boxed{1011100 11}$