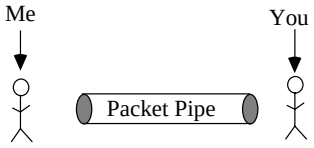
Lecture 5a - *A*utomatic *R*epeat Re*q*uest (BG 2.4)



Consider DLC & Frame Transmission
(Transport Layer can also use ARQ)

- Issue 1:
  - I send a packet
  - Packet may be:
    - -- *lost* (how do I know this?)
    - -- *corrupted* (you can ask me to resend it, but what if your request is corrupted or lost?)
    - -- *duplicated*, due to retransmission of an earlier, corrupted packet (how do I know this?)
  - Thus the DLC *protocol* must have rules to detect & recover from losses/corruption.
  - (Detecting corruption is via CRC in trailer - subject of another lecture)

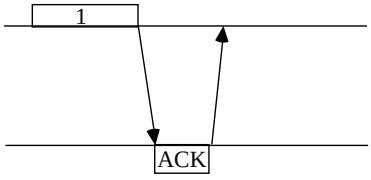
- Second Issue: Efficiency

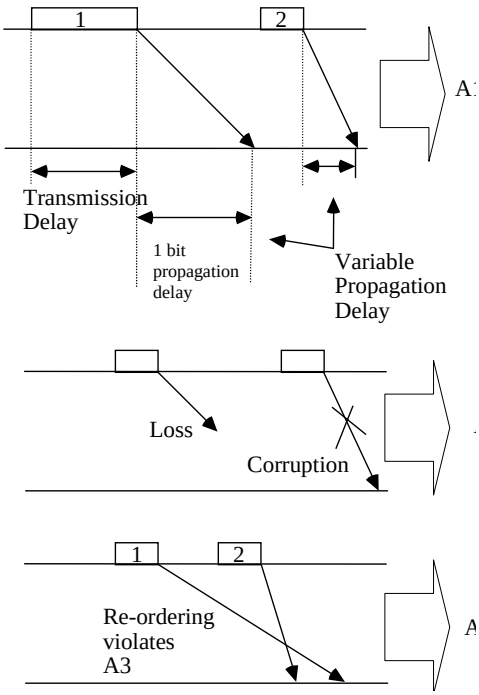
What fraction of pipe capacity is consumed by

- Retransmission?
- "Artificial Delay"? (sender waits for an ACK)
- Overhead (non-data bits sent by protocol)

- Assumptions in constructing an ARQ protocol:
  - -- A1: Each frame undergoes a *variable* propagation delay
  - -- A2: Frame may be lost or corrupted
  - -- A3: Frames always arrive in order sent

Picture with negligible bit delay



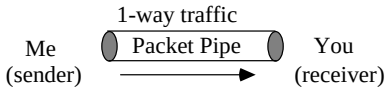


Look at notation used in Figure 2.17 in the text.

- ARQ Protocols
  - Stop and Wait (BG 2.4.1)
  - Sliding window a.k.a. go back-*n* (BG 2.4.2)
  - Selective Repeat (BG 2.4.3)

- BG 2.4.1: Stop and Wait

  - Consider 1 - Way traffic:



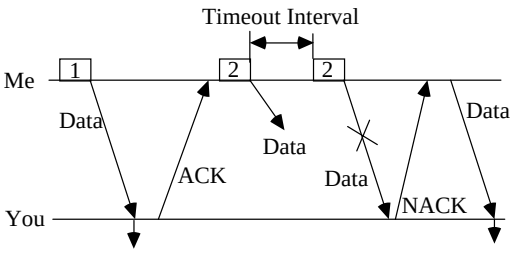
  - 3 Packet Types (header bits identify type)
    -- Data
    -- ACK
    -- NACK (sometimes used)

Stop and Wait (without sequence numbers):

- I do:
  1. Accept packet from layer 3 (possibly waiting for packet to arrive)
  2. Transmit frame containing packet
  3. Start a timer
  4. Wait for event
  5. If ((event == timer pop) or (event==NACK))
     then { resend packet and goto 4 }
     else if (event == receive error free ACK)
     then { goto 1}
     else if (event == receive corrupted ACK)
     then { noop }

- You do:
  1. Wait for frame from link
  2. If (uncorrupted DATA frame is received)
     then {
     send ACK
     release packet to layer
     }
     else {send NACK}

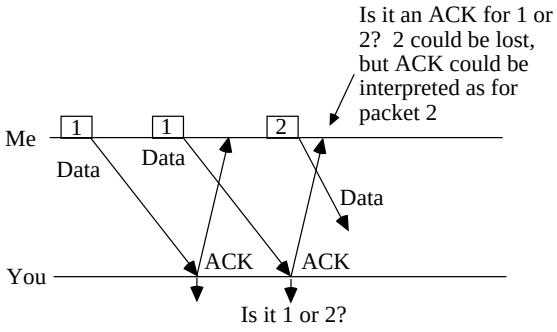
Illustration of Time-Out



- Note on timeout value:
  -- Too short -> lots of unnecessary resends
  -- Too much artificial waiting reduces pipe capacity
  -- We set timeout to be a small (e.g., close to 1) multiple of the round trip delay (RTD)

- For a cross country hop, when ARQ is used at transport layer, estimating RTD is a big problem. Research in early 1990's successfully addressed this

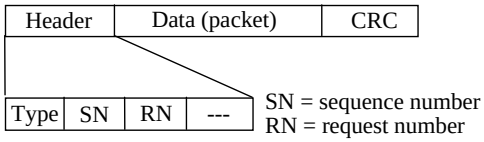
Problem with above algorithm:



- Solution: Each packet (Data, ACK, NACK) has two *sequence numbers*:

  -- SN = id of packet currently being sent
  -- RN = id of next packet expected

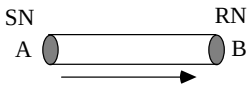
  Each end point maintains SN, RN, too.



Q. Why does each packet contain ***both*** SN and RN?
A. Two way communication piggybacks ACKS/NACKS on opposite direction traffic

Note:
Receiver typically delays ACK/NACK a bit in hopes that returning data arrives from local transport to piggyback ACK

- Algorithm (initially SN = RN = 0):

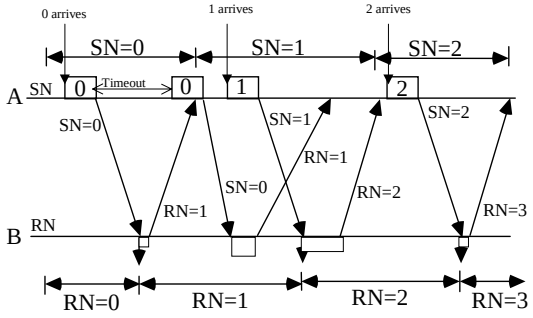


A - to - B (no NACKS in this algorithm)

- Node A does:
  1) SN = 0
  2) Wait for & accept packet from layer 3
  3) A) Transmit (SNth) packet in frame with sequence number SN;
     B) start timer
  4) Wait for event:
  if (event == timer pop)
  then goto 3
  else if (event == receive error free frame w/ RN > SN)
  then { SN = SN+1;
  goto step 2}

- Node B does:
  1) RN = 0
  2) Wait for frame from link
  if (frame is uncorrupted & SN = RN)
  then { RN = RN + 1;
  release packet to layer 3}
  3) At arbitrary times, but within bounded delay after last receipt of error free frame from A: transmit a frame to A containing request # = RN (could be ACK or return direction Data)
  4) Goto step 2 (repeat steps 2, 3, 4 forever)

A -> B Example



Correctness of Stop and Wait (general comments)

- Proof is critical for protocol specs -> zero defects. Spec written once, implemented many times by many companies for many years.
- If spec has bug, 2 company's protocols won't interoperate.
- Must also prove that an implementation matches spec.
- Correctness familiar to:
  -- EE's: hardware verification
  -- CS's: software correctness
- Much research in last 10-15 years on verification methods (by temporal logic, state machines, Petri nets; also on formal specification methods [e.g., LOTUS, ESTELLE])

- Need to prove:
  - *liveness*: continues forever to produce results: transport of packets from A to B continues forever (prove bounded delay); a "there exists a state" property; also, no deadlock
  - *safety*: never produce incorrect result (all packets released by B to its transport in same order sent by A); a "for all states" property
- Key to safety proof:
  - Induction on RN, the packet number released.
  - Liveness: See Fig. 22. Prove $t_1<t_2<t_3$. Requires

- fact that packet is delivered w/o corruption with probability q>0
- Looks at SN, RN as functions of time: SN(t), RN(t)

Alternating Bit Protocol

The proof on pp. 69-71 shows that all sequence numbers can be represented using just 0 & 1, with arithmetic mod 2

(That's because only packets SN and SN-1 can be received in duplicate. Also, if receiver's waiting for RN, it could only get RN or RN-1.)

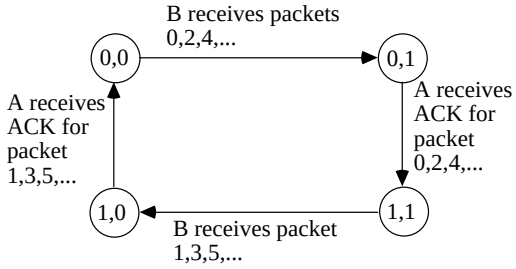
-- The ability to prove a ***bound*** on sequence numbers range is critical to selecting number of bits for SN, RN in frame.

Common protocol representation (for A->B)

Can we use *one picture* to represent the *two algorithms*?

State = (Node A's SN mod 2, Node B's RN mod 2)

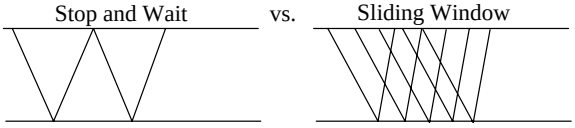
= (packet # being sent, packet # B is awaiting)



Efficiency of Stop-and-wait

In practice, stop & wait rarely used:

For efficiency, you want to keep pipe busy 100% of time in event no errors occur. Long propagation delay reduces efficiency (killer on satellite links -> 2 pkts/sec!).

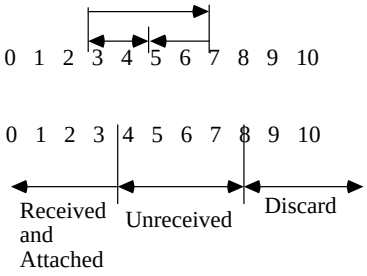


(BG 2.4.2) Go-back N

(BG) 2.4.3 Selective Repeat

- Modification of Go back N:

  -- Receiver buffers packets received out of order
  -- Receive window:



  -- Typically receiver window size = sender size

- BG: "Receiver requests retransmission of any packets missing from received sequence."

- TCP: Same meaning of RN ACK's - send upper half of window (wastefully)