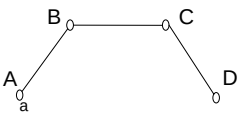
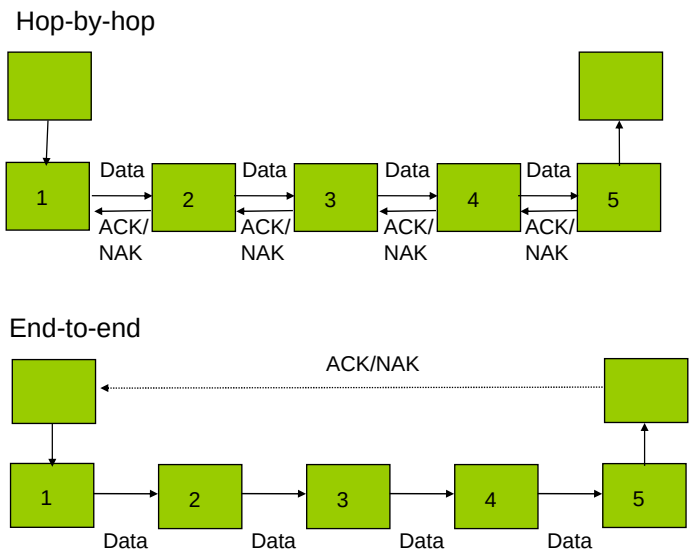
Chap 5 Peer-to-Peer Protocols and Data Link Layer

- Peer-to-peer protocol: involves the interaction of two or more processes (at the same layer) through the exchange of messages → layer n peer process.
  - e.g. a web browser (client) ↔ a web server application layer peer processes

5.1.3 End to End versus Hop by Hop

- Two basic settings of peer-to-peer protocols:
  1) across a single hop
  2) end-to-end across an entire network
- Example: to provide reliable communication (*Fig 5.8*)
  - Two options:
    1. detect/recover from error at every hop
       A↔B B↔C C↔D (e.g. HDLC)
    2. only the end systems detect/recover errors
       A↔ D (e.g. TCP)





5.1.3 End to End versus Hop by Hop

- Hop-by-Hop:
  1. Initiate error recovery more quickly
  2. The processing in each node is more complex and every node in the path must operate correctly
  3. If errors are very likely, hop-by-hop is preferred.
- End-to-End:
  1. Consume less processing resources
  2. Bandwidth is wasted if error happens at the first hop
  3. If errors are infrequent, end-to-end is preferred

5.2 ARQ Protocols and Reliable Data Transfer Service

- ARQ: Automatic Repeat Request.
  - Error detection (e.g. by using CRC)
  - Retransmission (if time-out or NAK)
- Objective: to ensure that packets are delivered error free to the dest. Exactly once without duplicates, in the same order in which, they were transmitted.
  - Three basic types:
    - Stop-and-Wait
    - Go-Back-N
    - Selective Repeat.

5.2.1 Stop-and-Wait ARQ

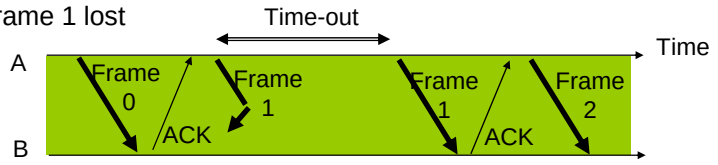
1. The transmitter A sends an information frame to receiver B
2. A stops and waits for an ACK from B
3. If no ACK in some time-out period, A resends the frame, other wise, A sends the next information frame

The need for sequence numbers.

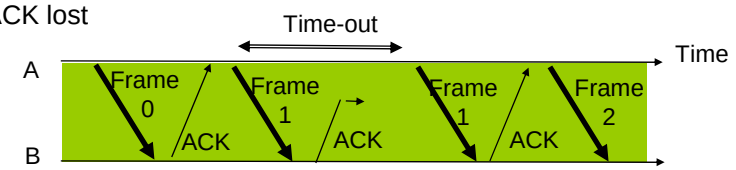
- *Fig 5.10* for an example. (if frames are unnumbered)
  loss of an ACKs can result in the delivery of a duplicate packet
- *Fig 5.11* (if ACKs are unnumbered)
  premature time-outs (or delayed Acks) combined with loss of I-frame an result in gaps in the delivered packet sequence
- Sequence number cannot be arbitrary large (only a finite number of bits available in the frame headers)
- One-bit sequence number is enough for stop-and-wait
  read *pg.295-296* of textbook.

Need for Sequence Numbers

(a) Frame 1 lost



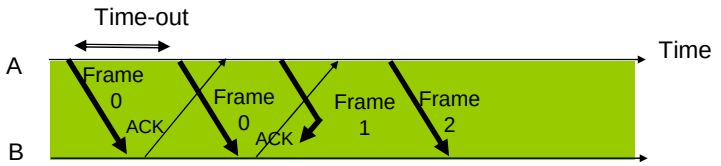
(b) ACK lost



- In cases (a) & (b) the transmitting station A acts the same way
- But in case (b) the receiving station B accepts frame 1 twice
- Question: How is the receiver to know the second frame is also frame 1?
- Answer: ***Add frame sequence number in header***
- S_{last} is sequence number of most recent transmitted frame

Sequence Numbers

(c) Premature Time-out



- The transmitting station A misinterprets duplicate ACKs
- Incorrectly assumes second ACK acknowledges Frame 1
- Question: How is the receiver to know second ACK is for frame 0?
- Answer: ***Add frame sequence number in ACK header***
- R_{next} is sequence number of next frame expected by the receiver
- Implicitly acknowledges receipt of all prior frames

5.2.1 Stop-and-Wait ARQ (continue)

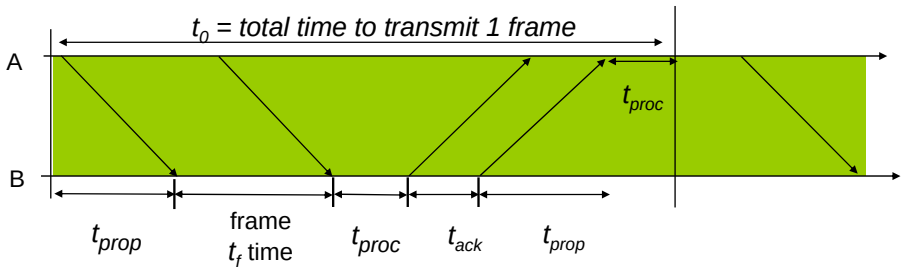
- Performance analysis:
  - In the absence of errors, the time to send a frame and receive an ACK is:

$$t_0 = 2t_{prop} + 2t_{proc} + t_f + t_{ack} = 2t_{prop} + 2t_{proc} + \frac{n_f}{R} + \frac{n_a}{R}$$

where :

t_{prop}:	propagation delay
t_{proc}:	processing time of frame (e.g. to check CRC)
n_f :	number of bits in a information frame
n_a:	number of bits in an ACK
R:	bit rate of the transmission channel.

Stop-and-Wait Model



$$t_0 = 2t_{prop} + 2t_{proc} + t_f + t_{ack}$$

$$= 2t_{prop} + 2t_{proc} + \frac{n_f}{R} + \frac{n_a}{R}$$

bits/info frame

bits/ACK frame

channel transmission rate

5.2.1 Stop-and-Wait ARQ (continue)

– Throughput in the absence of errors:

$$R_{eff}^{0} = \frac{n_f - n_0}{t_0}$$

n_0: number of overhead bits in an I-frame.

– Transmission efficiency:

$$\eta_0 = \frac{R_{eff}^{0}}{R} = \frac{1 - \frac{n_0}{n_f}}{1 + \frac{n_a}{n_f} + \frac{2(t_{prop} + t_{proc})R}{n_f}}$$

5.2.1 Stop-and-Wait ARQ (continue)

– Now consider the effect of errors

- P_f: prob. that a frame transmission has errors and needs to be retransmitted

  on average, we need $\frac{1}{1-p_f}$ transmissions/frame if errors are independent (Number of transmissions/per frame ~ Geometric distribution)

  $\therefore$ To transmit one frame successfully, on average need:

$$t_{sw} = t_0 \bullet \frac{1}{1-p_f} \Rightarrow R_{eff} = \frac{n_f - n_0}{t_{sw}} = R_{eff}^{0}(1-p_f)$$

So $$\eta_{sw} = \eta_0(1-p_f) = \frac{1 - \frac{n_0}{n_f}}{1 + \frac{n_a}{n_f} + \frac{2(t_{prop} + t_{proc})R}{n_f}} \bullet (1-p_f)$$

5.2.1 Stop-and-Wait ARQ (continue)

- Effect of bit error rate
  - *p*: bit error rate (for a single bit)
  - If we assume errors of bits are independent, and no error in ACK.

    $1- p_f=(1-p)^{n_f}$
  - If we also consider errors in ACK

    $1-p_f=(1-p)^{n_f+n_a}$
- Example: $n_f=1250$ bytes with overhead $n_0=25$ *bytes*, $n_{ack}=25$ *bytes*. $R=1Mbps$, Reacting time: $2(t_{prop}+t_{proc})=1ms$.
  Bit error rate $p=10^{-6}, 10^{-5}, 10^{-4}$. Find η_{sw}

  $\eta_{sw}=86.6\%, 70.2\%, 32.2\%$

5.2.2 Go-Back-N

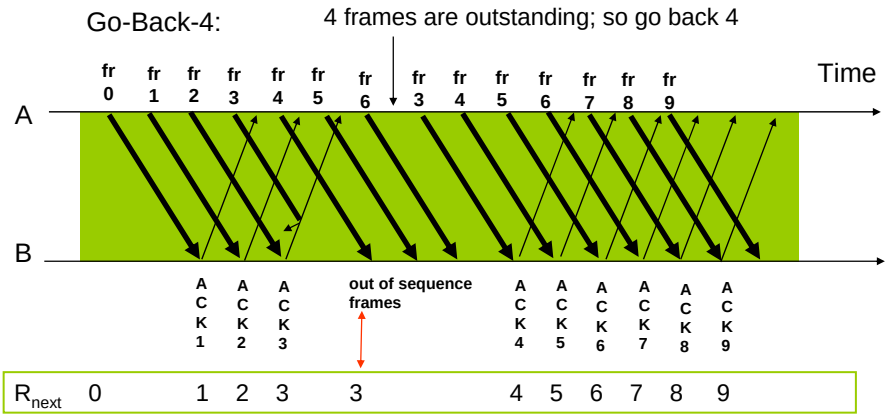
- If $t_{prop}+t_{proc} \gg \frac{n_f}{R}$ then η_{sw}<<1. Stop-and-wait very inefficient
  - Stop-and-wait: can only have 1 frame to be outstanding without ACK
  - Go-Back-N: Improve Stop-and-Wait by not waiting! Keep channel busy by continuing to send frames Allow a window of up to W_s outstanding frames without Ack

    W_s: window size.
  - Alternative: Use timeout

5.2.2 Go-Back-N

1. A sends frame 0, 1, ……, W_s-1 to B continuously
2. If B received frames 0, 1, ……, i-1 successfully and frame i with error. B ACKs each of the frame from 0 to i-1 and ignore frames i, i+1, ……
3. When A receives Ack for frame 0 → A sends frame W_s
   A receives Ack for frame 1 → A sends frame W_s+1
   ……
   A receives Ack for frame i-1 → A sends frame W_s+i-1
   A receives no Ack for frame i → A resends i, i+1, ……, i+W_s-1.
   See Fig 5.15 for an example W_s=4
   When no Ack received, "go back N" frames. N=W_s

Go-Back-N ARQ



- Frame transmission are *pipelined* to keep the channel busy
- Frame with errors and subsequent out-of-sequence frames are ignored
- Transmitter is forced to go back when window of 4 is exhausted

5.2.2 Go-Back-N (continue)

- How to choose W_s
  1. too large, inefficient.
  2. too small, no enough time for Ack to arrive.

     $W_s t_f \geq t_f + t_a + 2(t_{prop} + t_{proc})$

     $$\Rightarrow \quad W_s = \frac{t_f + t_a + 2(t_{prop} + t_{proc})}{t_f}$$

- Alternative: Use a timeout with each frame
  - When timeout expires, resend all outstanding frames

5.2.2 Go-Back-N (continue)

- Performance analysis
  - t_{GBN}: the time that it takes to transmit a frame successfully.
  - p_f: prob. That a frame is received with error
  - If transmitted successfully at the first try

    $t_{GBN} = t_f$
  - If transmitted successfully with i retransmissions

    $t_{GBN} = t_f + i \bullet W_s t_f$
  - Let X be the number of retransmissions, X: a geometric r.v.

    $p_i = P\{X=i\} = p_f^i(1-p_f)$
  - On average:

$$t_{GBN} = \sum_{i=0}^{\infty} p_i (t_f + i \bullet w_s t_f) = t_f + p_f \frac{w_s t_f}{1 - p_f}$$

$$\eta_{GBN} = \frac{\frac{n_f - n_0}{t_{GBN}}}{R} = \frac{1 - \frac{n_0}{n_f}}{1 + (w_s - 1) p_f} \bullet (1 - p_f)$$

Example

n_f=1250 bytes = 10000 bits, n_a=n_o=25 bytes = 200 bits

Compare S&W with GBN efficiency for random bit errors with p = 0, 10^{-6}, 10^{-5}, 10^{-4} and R = 1 Mbps & reaction time=100 ms

Use W_s = 11

Efficiency	0	10^{-6}	10^{-5}	10^{-4}
S&W	8.9%	8.8%	8.0%	3.3%
GBN	98%	88.2%	45.4%	4.9%

- *Go-Back-N significant improvement over Stop-and-Wait*
- *Go-Back-N becomes inefficient as error rate increases*

5.2.3 Selective Repeat

- If an error happens, Go-Back-N retransmit the frame in error and all the subsequent frames
- Selective Repeat:
  1. Only the frame in error is retransmitted
  2. The receiver can accept frames that are out-of-order but error free
- Performance Analysis

$$t_{SR} = \frac{t_f}{1-p_f}$$

$$\eta_{SR} = \frac{\frac{n_f - n_0}{t_{SR}}}{R} = (1-\frac{n_0}{n_f})(1-p_f)$$

  – The performance increases at the cost of significantly greater complexity.

Example

n_f=1250 bytes = 10000 bits, n_a=n_o=25 bytes = 200 bits

Compare S&W, GBN & SR efficiency for random bit errors with p=0, 10^{-6}, 10^{-5}, 10^{-4} and R= 1 Mbps & reaction time=100 ms

Efficiency	0	10^{-6}	10^{-5}	10^{-4}
S&W	8.9%	8.8%	8.0%	3.3%
GBN	98%	88.2%	45.4%	4.9%
SR	98%	97%	89%	36%

- *Selective Repeat outperforms GBN and S&W, but efficiency drops as error rate increases*