Flow Control, Reliable Transmission

[Ref: book by William Stallings]

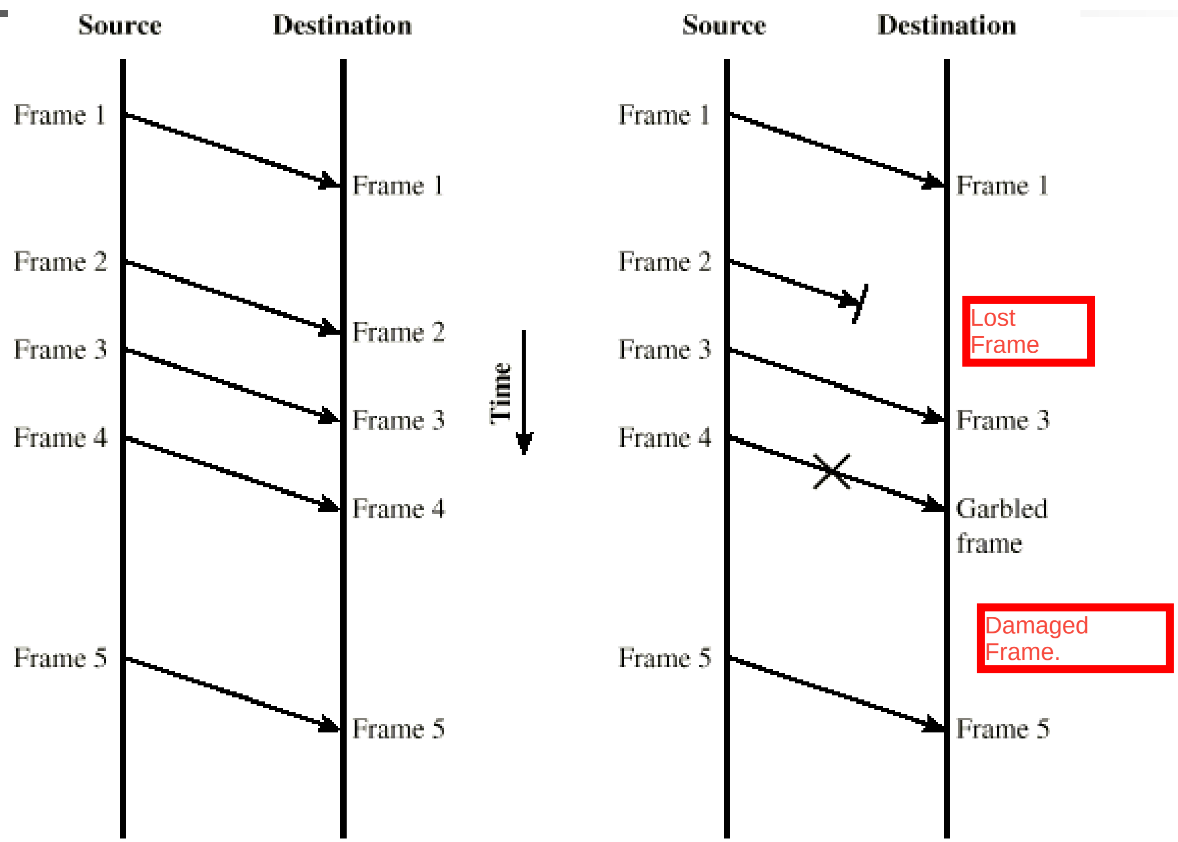
Flow Control

- Flow control is a technique used to ensure that a sender does not overwhelm the receiver
- Usually, receiver allocates a buffer of some size for frame transfer
- Flow control prevents buffer overflow at the receiver
- Flow control concerns with two end nodes: sender and receiver, SHOULD NOT be confused with congestion control

Parameter a

- a = link propagation time/frame transmission time
- a>1
  - $\Rightarrow$ bit length of the link(D$\times$B product) is larger than frame size
  - $\Rightarrow$ sender completes the transfer of last bit in the frame before the first bit reaches the receiver
  - Link utilization is generally poor
- a<1
  - $\Rightarrow$ bit length of the link(D$\times$B product) is smaller than frame size
  - $\Rightarrow$ before the sender completes the transfer of last bit in the frame the first bit reaches the receiver
  - Link utilization is generally good

Model of Frame Transmission



(a) Error-free transmission

(b) Transmission with losses and errors

Stop and Wait

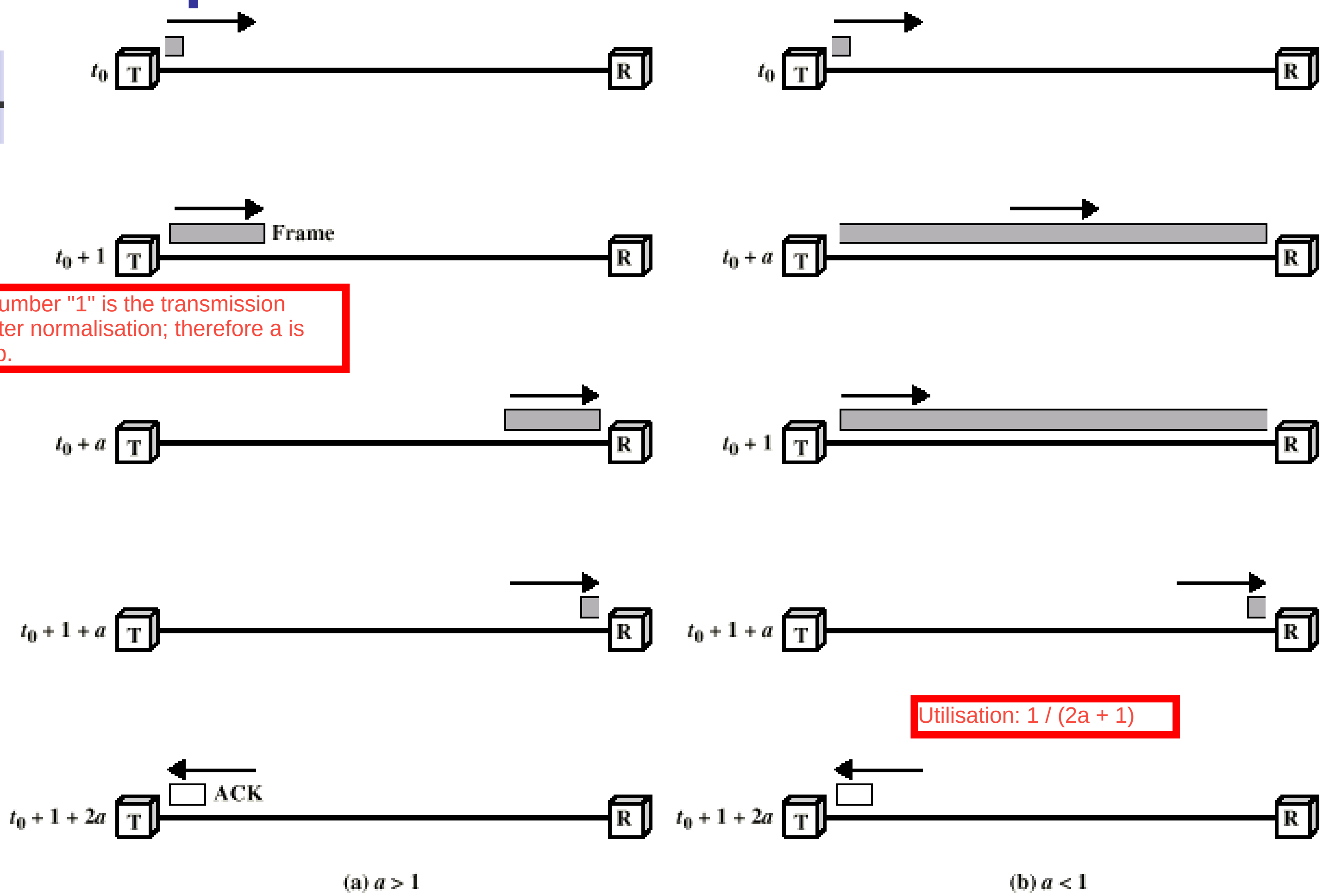
There's a delay of 2T_p in this case

- Source transmits a frame
- Destination receives a frame and replies with an acknowledgement (ACK)
- Source waits for ACK before sending the next frame
- Destination can stop flow by not sending ACK
- Simple implementation

Fragmentation

- Large block of data may be split into small frames for the following reasons
  - Limited buffer size
  - Errors detected sooner (when whole frame received)
  - On error, retransmission frames are small
  - Prevents one station occupying medium for long periods
- Stop and wait becomes inadequate when a large number of frames are sent

Stop and Wait Link Utilization



Here number "1" is the transmission time after normalisation; therefore a is the T_p.

Utilisation: 1 / (2a + 1)

Ref: W. Stallings, 'Data and Computer Communications'

Figure 7.2 Stop-and-Wait Link Utilization (transmission time = 1; propagation time = a)

Sliding Windows Flow Control

- Allow multiple frames to be in transit to improve link utilization
- Receiver has buffer of length W
- Transmitter can send up to W frames without ACK
- Each frame is numbered (called sequence numbers)
- ACK includes the sequence number of next frame expected
- ACK RR n (receiver ready) indicates that the receiver has received frames numbered up through n-1 and is ready to receive frame n onwards
- Sequence number bounded by size of field (k)
  - Frames are numbered modulo 2^k

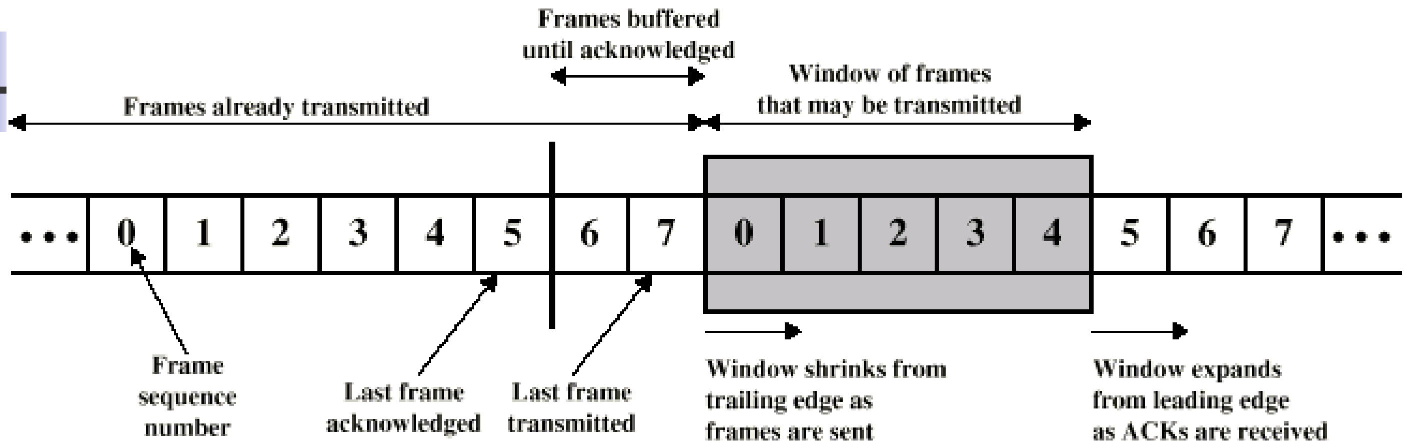
Sliding Window Flow Control (contd.)

- Sender
  - Keeps a window of (max) size W
  - Initially window size is W
  - Window size indicates the number of frames that may be transmitted
  - When a frame is sent, window shrinks by one
  - When an ACK is received, window expands by one
  - Keeps the frames in buffer that are not yet acknowledged (Why?)

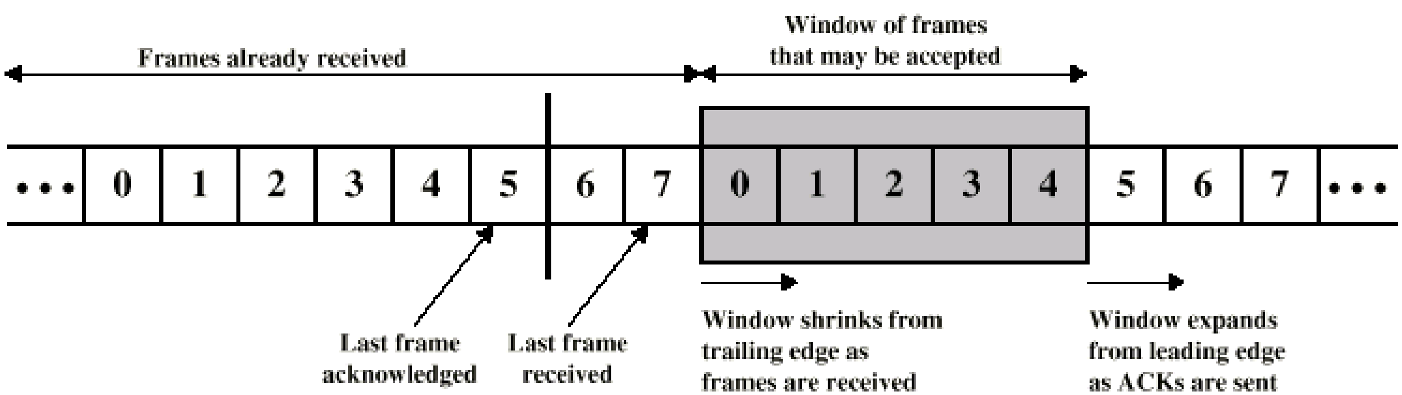
Sliding Window Flow Control (contd.)

- Receiver
  - Keeps a window of (max) size W
  - Initially window size is W
  - Window size indicates the number of frames that may be received
  - When a frame is received, window shrinks by one
  - When an ACK is sent window expands by one
  - Keeps in buffer, the frames received but ACKs have not been sent (Why?)

Sliding Window Illustration

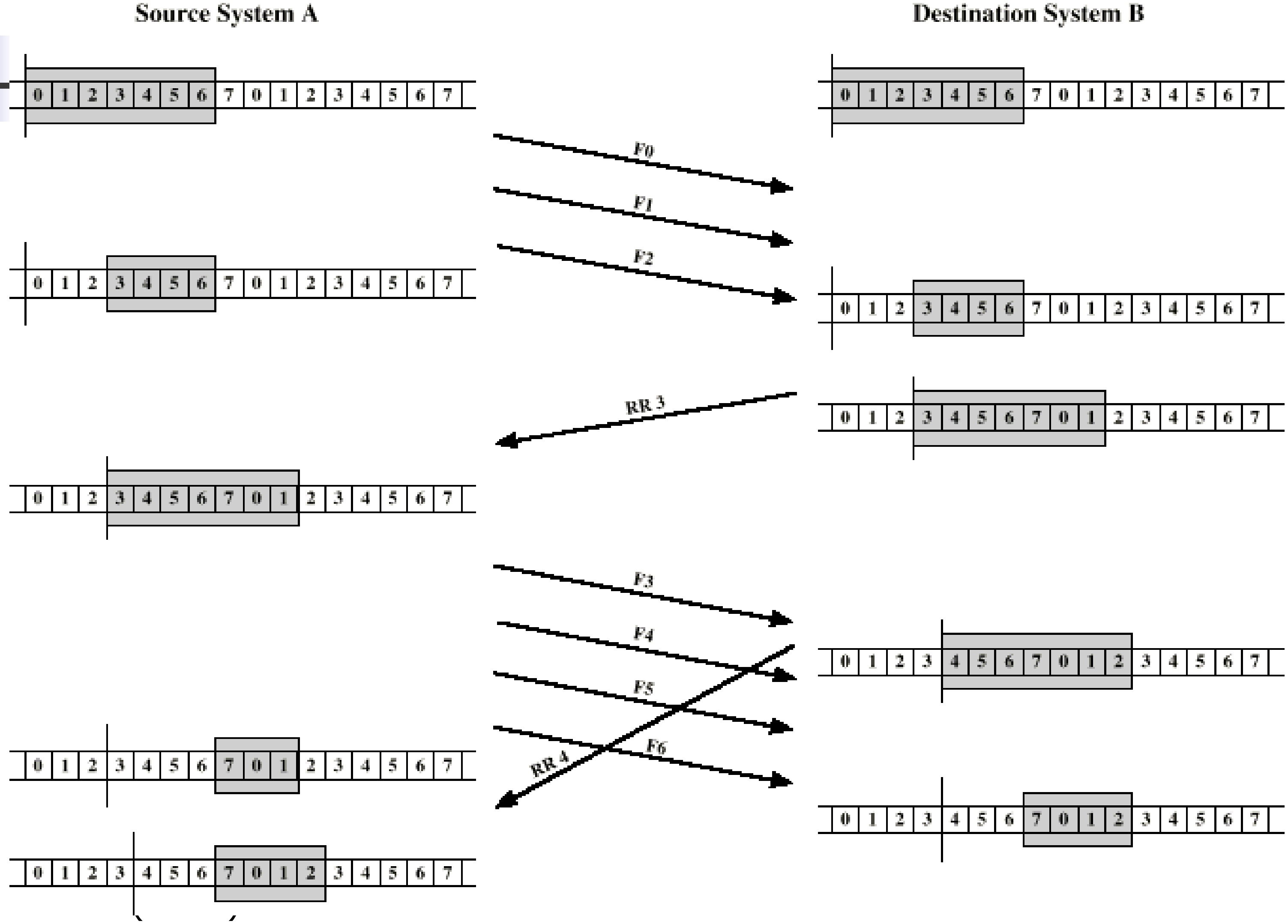


(a) Sender's perspective



(b) Receiver's perspective

Example Sliding Window



Sliding Window Enhancements

- Receiver can acknowledge frames without permitting further transmission (Receive Not Ready)
- Must send a normal acknowledge to resume
- If duplex, use piggybacking
  - Receiver sends ACK as a part of data frame
  - If no data to send, use acknowledgement frame
  - If data but no acknowledgement to send, send last acknowledgement number again

Error Control and Reliable Transmission

- Detection and correction of errors
- Lost frames
  - Noise burst affects the frame to the extent that the frame is not recognizable by the receiver
- Damaged frames
  - Receiver can recognize the frame but some bits are in error
  - If the receiver is not sure about frame sequence number, then damaged frame requires the same treatment as lost frame
- Automatic repeat request (ARQ)
  - Error detection
  - Positive acknowledgment (ACK, RR)
  - Retransmission after timeout
  - Negative acknowledgement and retransmission (NACK, REJ (reject) SREJ (selective reject))

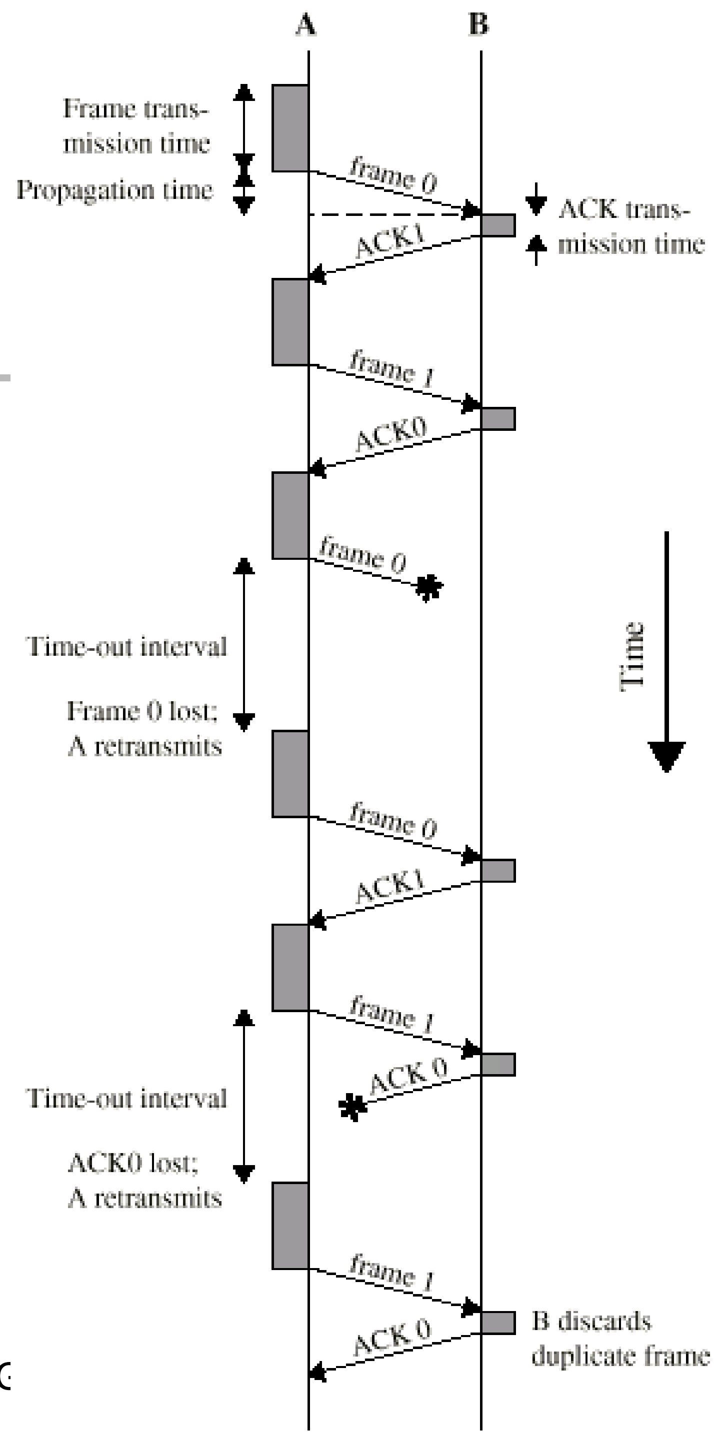
Automatic Repeat Request (ARQ)

- Stop-and-Wait
- Go-Back-N
  - based on sliding window control
  - Max window size is 2^k-1 where k is the seq-no field.
- Selective-Reject (selective retransmission)
  - based on sliding window control
  - Max window size is 2^{k-1} where k is the seq-no field.
- Go-Back-N is widely used when compared to Selective-Reject
- Typical window size
  - 7 for LANs (low speed link, short distance)
  - 127 for WANs (high speed link, long distance), WHY?

Stop and Wait ARQ

- Sender transmits a frame
- When a frame arrives, receiver sends ACK
- Sender waits for ACK before transmitting the next frame
- If received frame damaged/lost, receiver discards it
  - Transmitter uses TIMEOUT mechanism
  - If no ACK within timeout, retransmit
- If ACK damaged/lost, transmitter will not recognize it
  - Transmitter will retransmit
  - Receiver gets two copies of the same frame
  - Alternate between ACK0 and ACK1 to solve the above problem

Stop and Wait ARQ illustration



Stop and Wait - Pros and Cons

- Simple implementation
- Poor link utilization
- Link utilization (U) is defined as the the actual time spent for transmitting the given data frames and the total time the link is engaged until the completion of the transfer of the frames

Go Back N ARQ

- Based on sliding window
- If no error, receiver sends ACK (or RR) as usual with next frame expected
- Use window to control the number of outstanding frames
- If error,
  - Receiver discards that frame and all future frames until error frame received correctly
  - Sender goes back and retransmits that frame and all subsequent frames

Go Back N - Damaged Frame

- Receiver detects error in frame *i*
- Receiver sends REJ *i*
- Sender gets REJ-*i*
- Sender retransmits frame *i* and subsequent frames

Go Back N - Lost Frame (case 1)

- Frame *i* lost
- Sender sends *i+1*
- Receiver gets frame *i+1* out of sequence
- Receiver sends REJ-*i*
- Sender goes back to frame *i* and retransmits frame *i* and subsequent frames

Go Back N - Lost Frame (case 2)

- Frame *i* lost and sender does not send additional frames
- Receiver gets nothing and returns neither ACK nor REJ
- Sender times out and sends RR (command) frame with P (probe) bit set to 1
- Receiver interprets this RR as command which it acknowledges with the number of the next frame it expects (RR *i*)
- Sender then retransmits frame *i* and subsequent frames

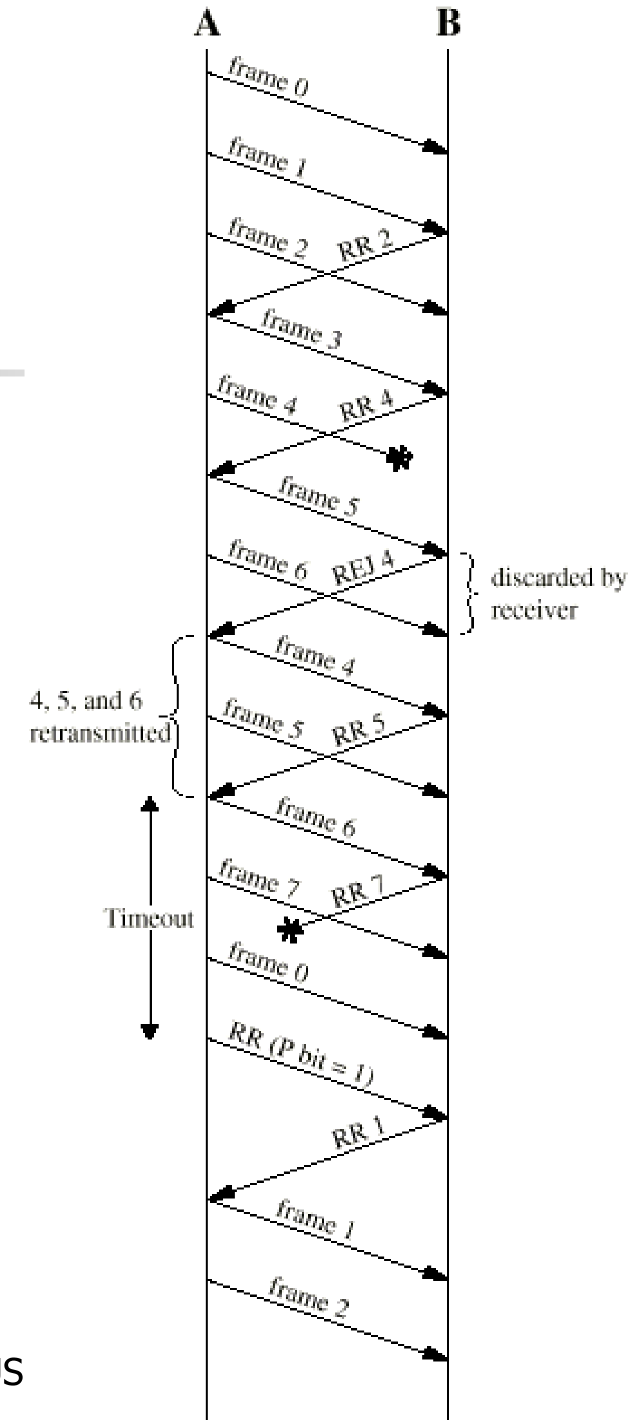
Go Back N - Damaged Acknowledgement

- Receiver gets frame i and sends RR ($i+1$) which is lost
- Acknowledgements are cumulative, so next acknowledgement ($i+n$, $n>1$) may arrive before sender times out on frame i (case 1)
- If sender times out, it sends RR command frame with P bit set as before (case 2)
  - This can be repeated a MAX number of times before a reset procedure is initiated
- Damaged REJ – similar to LOST frame (case 2)

Go Back N Pros and Cons

- Better link utilization than stop-and-wait
- less complex implementation (compared to selective reject ARQ)
- Good choice when errors are rare
- Retransmission of error-free frames reduces link utilization

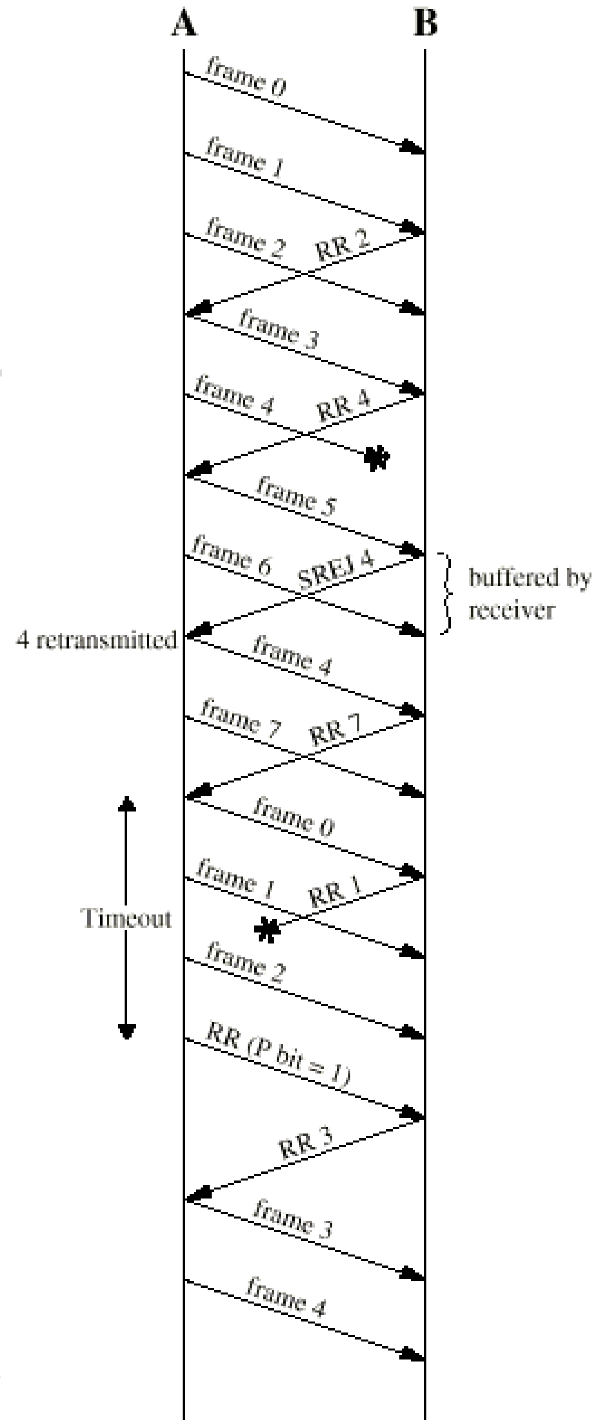
Go Back N Illustration



Selective Reject ARQ

- Also called selective retransmission
- Only rejected frames are retransmitted
- Subsequent frames are accepted by the receiver and buffered
- Need to arrange frames in order before delivering to the higher layer
- Minimizes retransmission, better link utilization than stop-and-wait and Go-back-N
- Unlike Go-back-N, Receiver must maintain large enough buffer
- More complex implementation

Selective-Reject Illustration



Performance Study

- The following assumptions and notation are made
- Frame transmission time T_f is normalized to 1
- Link propagation time T_p is therefore, a
- Total time that the link is engaged for one frame transmission denoted by T_t
- Transmission time of ACK frame is negligible
- Frame error probability denoted by P_f
- Errors in ACK frames can be ignored
- Errors in retransmitted frames other than the frame initially in error can be ignored(in case of Go-back-N)

Performance of Stop-and-Wait

- $P_f = 0$
  - One frame is transmitted for every T_f+2T_p time
  - $T_f = 1$; $T_t = 1+2a$
  - Link utilization $U = T_f / T_t = 1 / (1+2a)$
- $Pf > 0$
  - Let N_r be the expected number of times a frame is transmitted
  - N_r can be shown to be equal to $1/(1-P_f)$ (How?)
  - $U = T_f /(N_r \times T_t) = (1-P_f) / (1+2a)$

Performance of Stop-and-Wait (no assumption of normalized time)

- $P_f = 0$
  - One frame is transmitted for every T_f+2T_p time
  - $T_t = T_f+2T_p$
  - Link utilization $U = T_f / T_t = 1 / (1+2a)$
- $Pf > 0$
  - Let N_r be the expected number of times a frame is transmitted
  - N_r can be shown to be equal to $1/(1-P_f)$ (How?)
  - $U = T_f /(N_r \times T_t) = (1-P_f) / (1+2a)$

Sliding Window Protocol
Error-free Communication

- ACK frame is received by the sender after $1 + 2a$ from the time at which frame transmission starts
- Window size $W \geq 1 + 2a$
  - Sender receives ACK frame before the window is exhausted; it can send frames continuously; Therefore, $U = 1$
- Window size $W < 1 + 2a$
  - Sender sends W frames and waits until $2a + 1$ to receive an ACK before sending additional frames; Therefore, $U = W/(1 + 2a)$

Sliding Window Protocol-Error-free Communication

(no assumption of normalized time)

- ACK frame is received by the sender after $T_f + 2T_p$ from the time at which frame transmission starts
- Window size $WT_f \geq T_f + 2T_p$ ($W \geq 1 + 2a$)
  - Sender receives ACK frame before the window is exhausted; it can send frames continuously; Therefore, $U = 1$
- Window size $WT_f < T_f + 2T_p$ ($W < 1 + 2a$)
  - Sender sends W frames and waits until $T_f + 2T_p$ to receive an ACK before sending additional frames; Therefore, $U = WT_f / (T_f + 2T_p) = W/(1 + 2a)$

Sliding Window Protocol ARQ

- Selective Reject
  - $U = (1-P_f)$, $W \geq 1 + 2a$
  - $U = [W(1-P_f)] / (1 + 2a)$, $W < 1 + 2a$

- Go back N
  - $U = (1- P_f) / (1 + 2aP_f)$, $W \geq 1 + 2a$
  - $U = [W(1-P_f)] / [(1 + 2a)(1-P_f+WP_f)]$, $W < 1 + 2a$

- For proof, refer "Data and Computer Communications" by William Stallings and/or other reference books