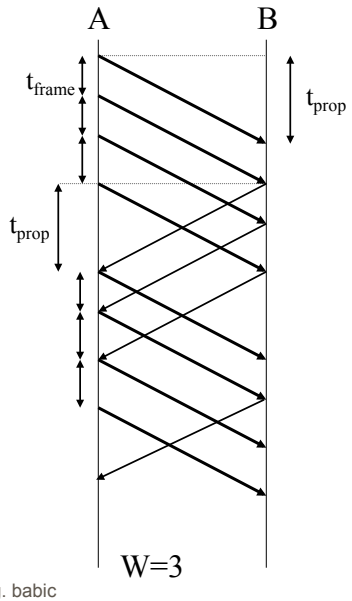
Sliding Window Control: Details (continued)

- If both sides are sending info-frames, use piggybacking, i.e. send acknowledgement in the header of info-frame
  - If no data to send, use acknowledgement frame
  - If data but no acknowledgement to send, send last acknowledgement number again
- It can be shown that for N-bit sequence number field, the largest $W=2^N-1$. For example, if N=3, than $W \leq 7$.
- Note: Stop and wait flow control is a special case of sliding-widow flow control with N=1 and W=1.
- Note: In some protocols, W may change dynamically during a given session of message exchange.

Sliding Window: Link Utilization



$t_{proc} = 0$ assumed

$$U = \frac{W \times t_{frame}}{2 \times t_{prop} + t_{frame}}$$

$$U = \begin{cases} W/(2a+1) & \text{if } W \leq 2a+1 \\ 1 & \text{if } W \geq 2a+1 \end{cases}$$

Sliding Window: Link Utilization (continued)

t_{frame} =1 → a = t_{prop}

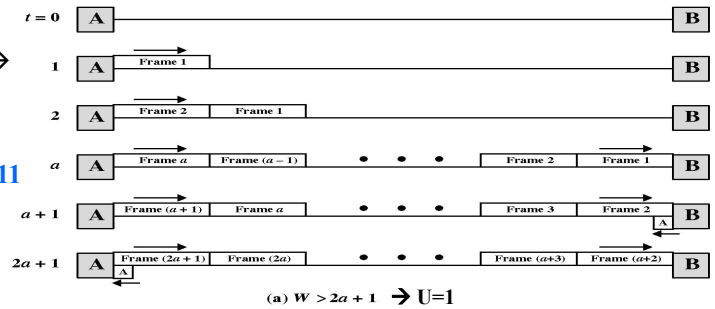


Figure 7.11

(a) $W > 2a + 1$ → U=1

→ U=W/(2a+1)

Error Control

- Error control refers to mechanisms to detect and correct errors that occur in exchanging frames.

  Besides errors introduced by transmission system, it is possible that a complete frame gets lost when receiver buffers are full.

  Receiving DLC should be delivering to the upper layer received frames in the same order in which they are sent and without duplications.
- Error control is based on some of the following mechanisms:
  - error detection (and/or error correction)
  - sequence numbers for info-frames
  - positive acknowledgment
  - retransmission after time-out
  - negative acknowledgment and retransmission
- Error control mechanisms are referred as automatic repeat request – ARQ and we study three ARQs.

Stop and Wait ARQ

- Sender transmits only one unacknowledged info-frame, i.e. W=1
- Sender waits for RR, i.e. ACK, before sending the next info-frame
- In principle, if a received frame is damaged, receiver simple discards it
- If info-frame damaged
  - Sender has timeout for each info-frame
  - If no ACK within timeout, retransmit
- If ACK damaged, info-frame sender will not recognize it
  - Sender will retransmit info-frame
  - Receiver gets two copies of the same info-frame
- Thus, info-frames still has to be numbered
- Use ACK0 and ACK1, i.e. RR with one bit field

Stop and Wait ARQ: Example

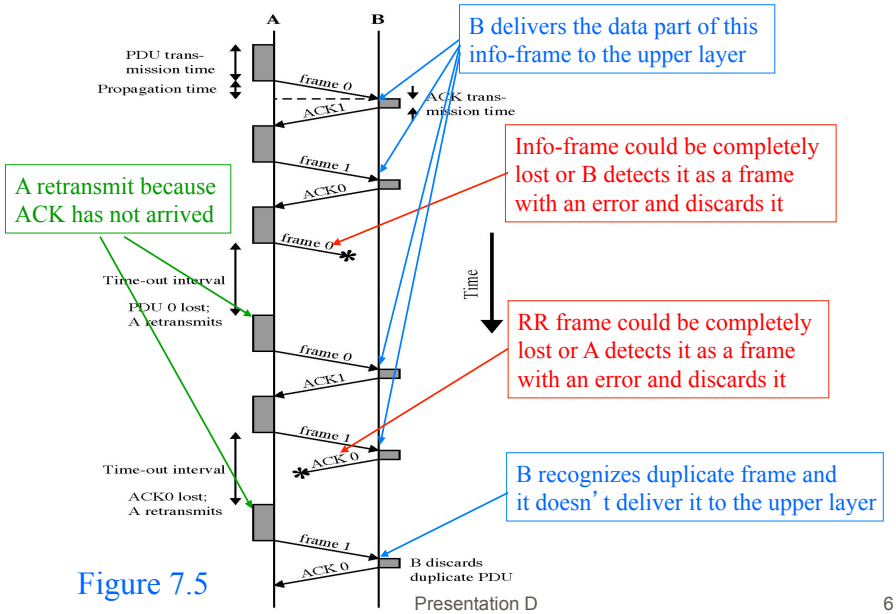


Figure 7.5

Stop and Wait ARQ: Summary

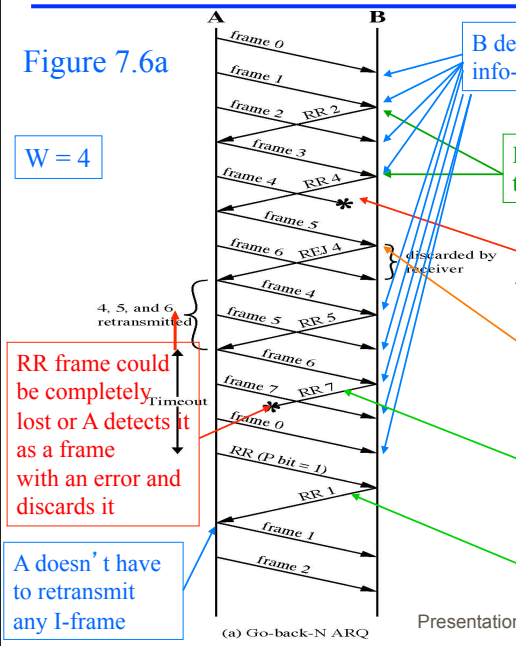
- This mechanism uses sequence numbers for info-frames (1-bit send sequence number field in a header of info-frames), positive acknowledgments (1-bit receive sequence number field), info-frame retransmission after time-out and stop and wait flow control (W=1).
- How to determine a length of a time out? It is usually 2-4 round trip times. More advanced implementations may change it in time, if a round trip time changes.
- How many retransmission attempts?
- If after a maximum number of retransmissions, a receiver still does not respond, a sender assumes that data link is broken, i.e. non-operational.
- Simple to implement but inefficient
- Link utilization $U = (1-P)/(2a+1)$, where P is probability of frame in error

Go-back-N ARQ

- This mechanism is based on sliding window and uses:
  - sequence numbers, N-bit send sequence number field in a header of info-frames,
  - window size $W \leq 2^N-1$ for Sliding-Window Flow Control,
  - positive acknowledgments, RR control frames with N-bit receive sequence number field,
  - **after info-frame time out, send RR with P bit set and after a response info-frame retransmission possible**
  - negative acknowledgment, REJ control frame with N-bit receive sequence number field,
  - piggybacking, info-frames include N-bit receive sequence number field, thus if there are info-frames to send no need for RR frames to be responded with.

Go-Back-N ARQ: Example

Figure 7.6a



W = 4

B delivers the data part of this info-frame to the upper layer

B has waited for the second I-frame, and then acknowledged both by one RR.

Info-frame could be completely lost or B detects it as a frame with an error and discards it

REJ sent because I-frame 5 received after I-frame 3

RR sent as acknowledgement for 3 I-frames

B has to answer with an appropriate RR, when it receives RR with P=1, and it acknowledges 4 I-frames.

RR frame could be completely lost or A detects it as a frame with an error and discards it

A doesn't have to retransmit any I-frame

Go-back-N ARQ: Details

- Info-frame *i* lost or damaged and transmitter sends info-frame *i+1*:
  - Receiver gets info-frame *i+1* out of sequence
  - Discard that frame and all future frames until missing info-frame in received correctly,
  - Receiver send reject frame REJ(i),
  - Transmitter goes back to info-frame *i* and retransmits it plus all subsequent.
- Info-frame *i* lost and no additional frame sent:
  - Receiver gets nothing and returns neither acknowledgement nor rejection,
  - Transmitter times out and sends RR frame with P bit set
  - Receiver interprets this as command and it acknowledges with RR frame with the number of the next info-frame it expects (frame *i*),
  - Transmitter then retransmits frame *i.*

Go-back-N ARQ: Details (continued)

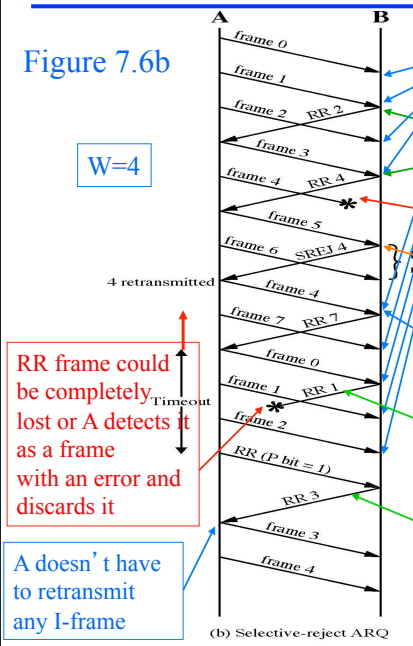
- Receiver gets info-frame *i* and sends acknowledgement RR(*i+1*) which is lost or damaged:
  - Since acknowledgements are cumulative, next acknowledgement RR(*i+n*) may arrive before transmitter times out on frame *i*,
  - If transmitter times out, it sends acknowledgement RR with P bit set,
  - Receiver interprets this RR frame as command which it acknowledges sending an RR with the number of the next info-frame it expects (frame *i+1*),
- Only one REJ frame is sent and if REJ frame lost, same as the case Info-frame *i* lost and no additional frame sent.

Selective Reject ARQ

- Similar to Go-back-N ARQ, except:
  - SREJ used instead REJ
  - Only rejected frames are retransmitted
  - Subsequent frames are accepted by the receiver and buffered
- Minimizes retransmission
- But receiver must maintain large enough buffer
- Also, more complex at transmitter
- Link utilization
  - $U = W\times(1-P)/(2a+1)$ if $W \le 2a+1$
    $= 1-P$ if $W \ge 2a+1$
    (P is probability of frame in error)

Selective Reject ARQ: Example

Figure 7.6b



W=4

B delivers the data part of this I-frame to the upper layer

B has waited for the second I-frame, and then acknowledged both by one RR.

I-frame could be completely lost or B detects it as a frame with an error and discards it

SREJ sent because I-frame 5 received after I-frame 3

B delivers the data parts of (buffered) I-frames 5 and 6 to the upper layer

RR sent as acknowledgement for 3 I-frames

B has to answer with an appropriate RR, when it receives RR with P=1, and it is acknowledging 4 I-frames

RR frame could be completely lost or A detects it as a frame with an error and discards it

A doesn't have to retransmit any I-frame

Selective Reject ARQ and Window Size

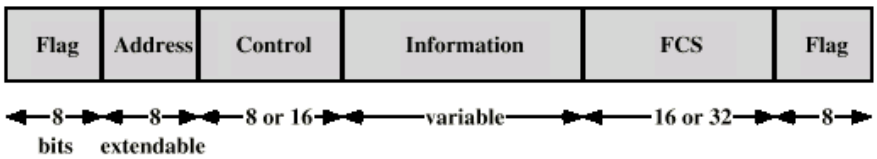
- Window size limitation is more restrictive for selective-reject than for go-back-N.
- For N-bit sequence number field, go-back-N ARQ can have as the largest possible $W=2^N-1$. For example, if N=3, than $W \leq 7$.
- For N-bit sequence number field, selective-reject ARQ can have as the largest possible $W=2^{N-1}$. For example, if N=3, than $W \leq 4$.
- On the bottom of the page 221, there is a scenario that is suppose to prove necessity for this more restrictive W than for Go-back-N ARQ.
- Why is the scenario not correct?

High Level Data Link Control - HDLC

- HDLC uses:
  - Go-back-N and Selective reject ARQ
  - Flow and error control piggybacked on information frames
- HDLC station can be one of several types:
  - Combined station may issue commands and responses and that is most widely used.
- HDLC link can be in one of several configurations:
  - Balanced with two combined stations is most widely used.
- Used normally in synchronous transmission
- Single frame format for all data and control exchanges

HDLC Frame Structure

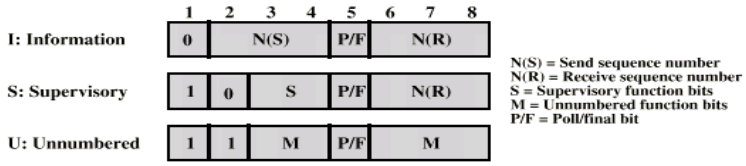
- Flag = 01111110 delimits frame at both ends
- May close one frame and open another
- Receiver hunts for flag sequence to synchronize
- Bit stuffing used to avoid confusion with data containing bit sequence 01111110
- Address field, usually 8 bits long
- Frames with the address of sender are responses
- Frames with the address of receiver are commands



(a) Frame format Figure 7.7

HDLC Frame Structure (continued)

- Control field, 8 (usually) or 16 bits long
  - Defines frame type: I-frame, S-frames (RR, RNR, REJ and SREJ) and U-frames (SABM, UA, DISC, and many more)
- Info field, variable length
  - found only in I-frames (and some U-frames)
- Frame Check Sequence (FCS) field, usually 16 bits
  - Error detection with CRC



(c) 8-bit control field format

Figure 7.7

HDLC Operations

• Three phases: Initialization (link setup), data transfer and disconnect

Figure 7.9

HDLC Operations (continued)

Figure 7.9