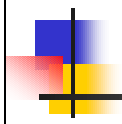


Data Link Layer

Flow Control

1

Flow Control

- Flow Control is a technique for speed-matching of transmitter and receiver. Flow control ensures that a transmitting station does not overflow a receiving station with data
- We will discuss two protocols for flow control:
  - Stop-and-Wait
  - Sliding Window
- For the time being, we assume that we have a perfect channel (**no errors)**

Copyright by Jorg Liebeherr 98,99

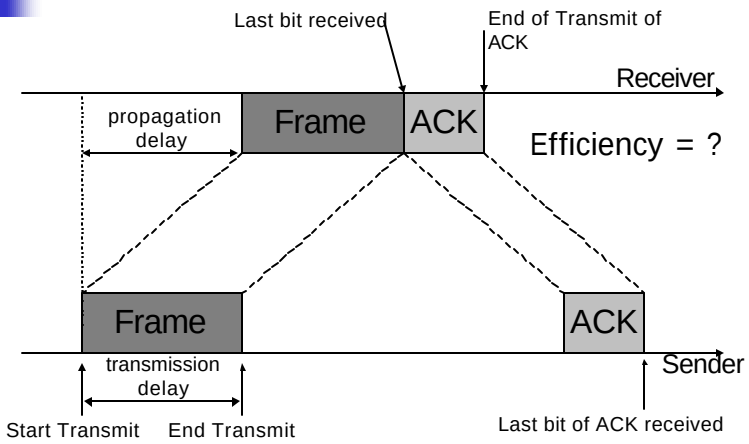
2

Stop-and-Wait Flow Control

- Simplest form of flow control
- In Stop-and-Wait flow control, the receiver indicates its readiness to receive data for each frame
- **Operations:**
  1. **Sender:** Transmit a single frame
  2. **Receiver:** Transmit acknowledgment (ACK)
  3. Goto 1.

Copyright by Jorg Liebeherr 98,99

Analysis of Stop-and-Wait



Copyright by Jorg Liebeherr 98,99

Sliding Window Flow Control

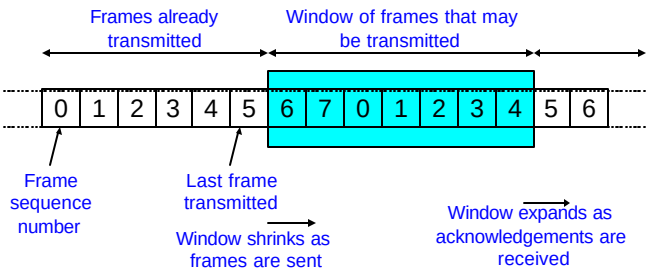
- **Major Drawback of Stop-and-Wait Flow Control:**
  - Only one frame can be in transmission at a time
  - This leads to inefficiency if propagation delay is much longer than the transmission delay
- **Sliding Window Flow Control**
  - Allows transmission of multiple frames
  - Assigns each frame a k-bit sequence number
  - Range of sequence number is $[0..2^k-1]$, i.e., frames are counted modulo 2^k

Copyright by Jorg Liebeherr 98,99

5

Operation of Sliding Window

- **Sending Window:**
  - At any instant, the sender is permitted to send frames with sequence numbers in a certain range (the *sending window*)

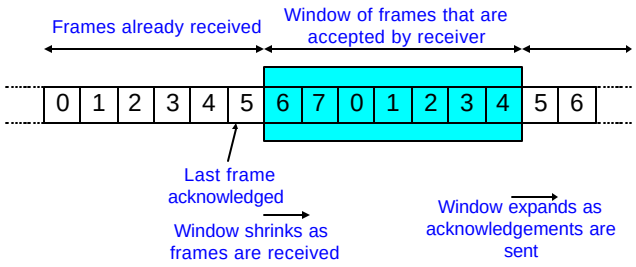


Copyright by Jorg Liebeherr 98,99

6

Operation of Sliding Window

- **Receiving Window:**
  - The receiver maintains a *receiving window* corresponding to the sequence numbers of frames that are accepted



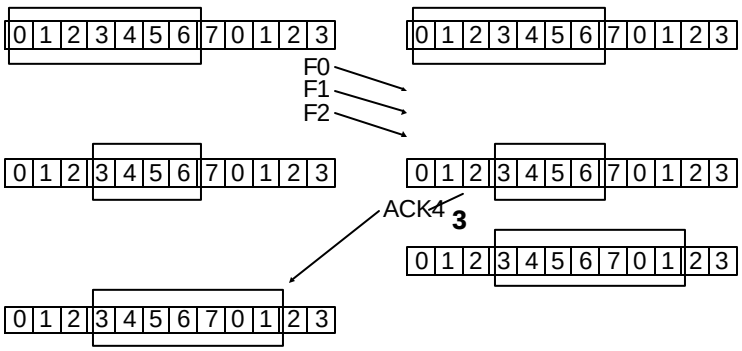
Copyright by Jorg Liebeherr 98,99

Operation of Sliding Window

- **How is "flow control" achieved?**
  - Receiver can control the size of the sending window
  - By limiting the size of the sending window data flow from sender to receiver can be limited
- **Interpretation of *ACK N* message:**
  - Receiver acknowledges all packets until (but not including) sequence number N

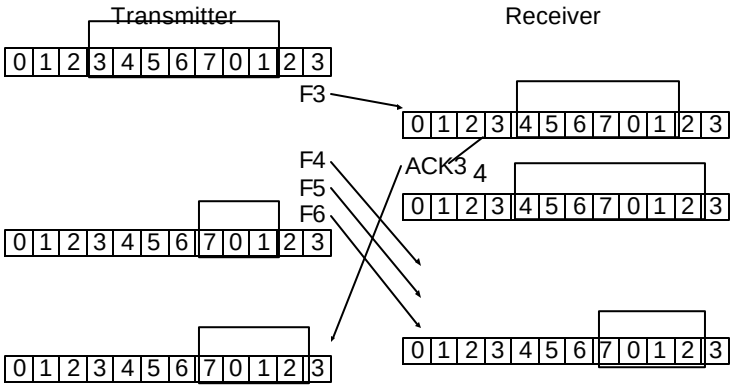
Copyright by Jorg Liebeherr 98,99

Example



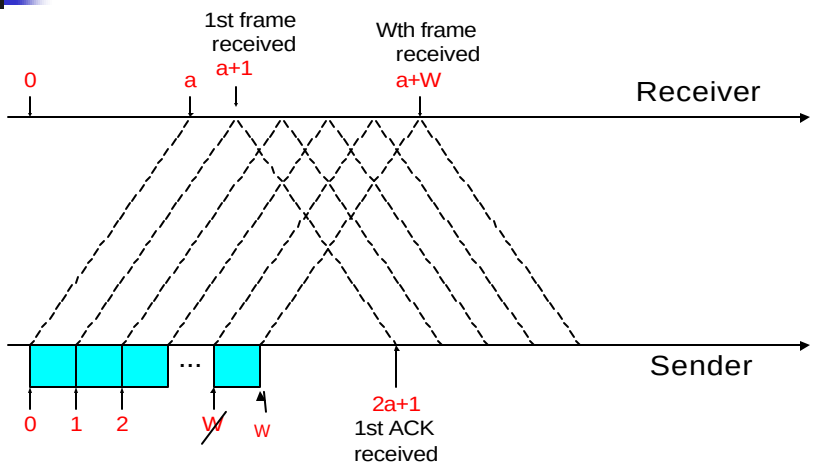
Copyright by Jorg Liebeherr 98,99

Example Continued



Copyright by Jorg Liebeherr 98,99

Analysis of Sliding Windows



Copyright by Jorg Liebeherr 98,99

Analysis of Sliding Windows

- If the window size is sufficiently large the sender can continuously transmit packets:
- **W ≥ 2a+1**: Sender can transmit continuously

$$normalized\ \ efficiency = 1$$

- **W < 2a+1**: Sender can transmit *W* frames every *2a+1* time units

$$normalized\ \ efficiency = \frac{W}{1+2a}$$

Copyright by Jorg Liebeherr 98,99

ARQ Error Control

- **Types of errors:** Lost frames, damaged frames
- Most Error Control techniques are based on (1) Error Detection Scheme (e.g., Parity checks, CRC), and (2) Retransmission Scheme
- Error control schemes that involve error detection and retransmission of lost or corrupted frames are referred to as ***Automatic Repeat Request (ARQ)*** error control

Copyright by Jorg Liebeherr 98,99

ARQ Schemes

- The most common ARQ retransmission schemes:
  - Stop-and-Wait ARQ
  - Go-Back-N ARQ
  - Selective Repeat ARQ
- The protocol for sending ACKs in all ARQ protocols are based on the sliding window flow control scheme

Copyright by Jorg Liebeherr 98,99

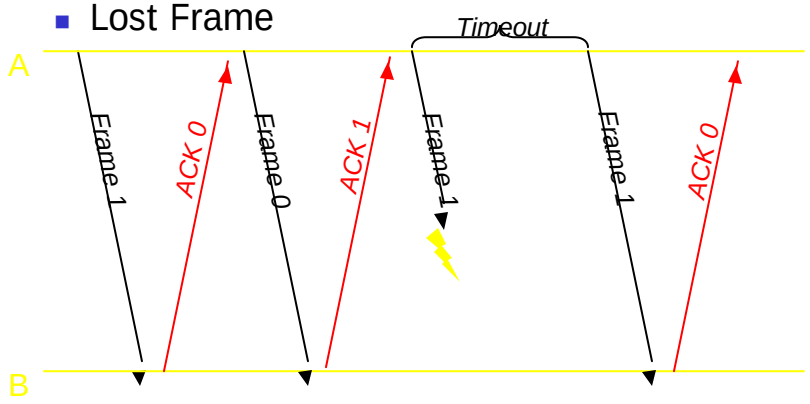
Stop-and-Wait ARQ

- **Stop-and-Wait ARQ** is an addition to the Stop-and-Wait flow control protocol:
- Frames have 1-bit sequence numbers (*SN* = 0 or 1)
- Receiver sends an *ACK (1-SN)* if frame *SN* is correctly received
- Sender waits for an *ACK (1-SN)* before transmitting the next frame with sequence number *1-SN*
- If sender does not receive anything before a timeout value expires, it retransmits frame SN

Copyright by Jorg Liebeherr 98,99

Stop-and-Wait ARQ

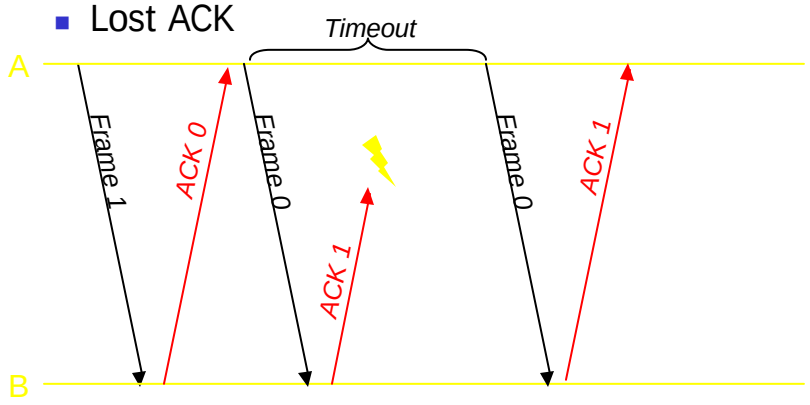
- Lost Frame



Copyright by Jorg Liebeherr 98,99

Stop-and-Wait ARQ

- Lost ACK



Copyright by Jorg Liebeherr 98,99

Go-Back-N ARQ

- Go-Back-N uses the sliding window flow control protocol. If no errors occur the operations are identical to Sliding Window

Copyright by Jorg Liebeherr 98,99

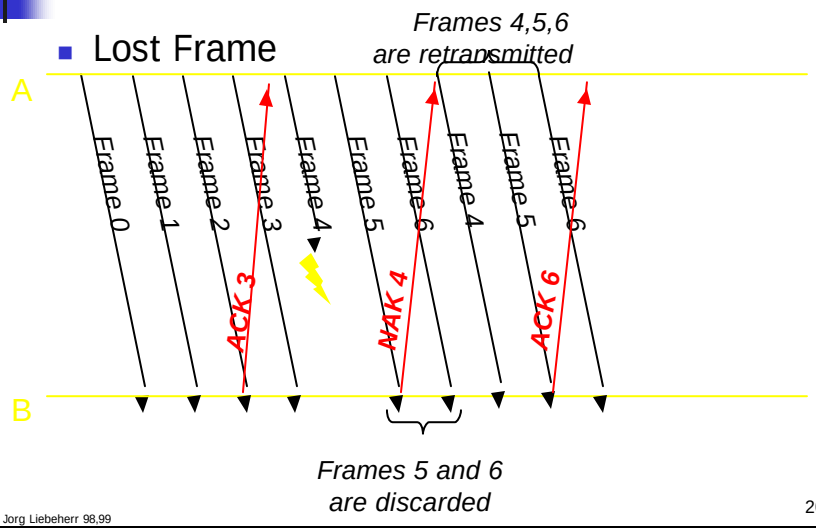
Go-Back-N ARQ

- **Operations:**
  - A station may send multiple frames as allowed by the window size
  - Receiver sends a ***NAK i*** if frame ***i*** is in error. *After that, the receiver discards all incoming frames until the frame in error was correctly retransmitted*
  - *If sender receives a **NAK i** it will retransmit frame **i** and all packets **i+1, i+2,...** which have been sent, but not been acknowledged*

Copyright by Jorg Liebeherr 98,99

Go-Back-N ARQ

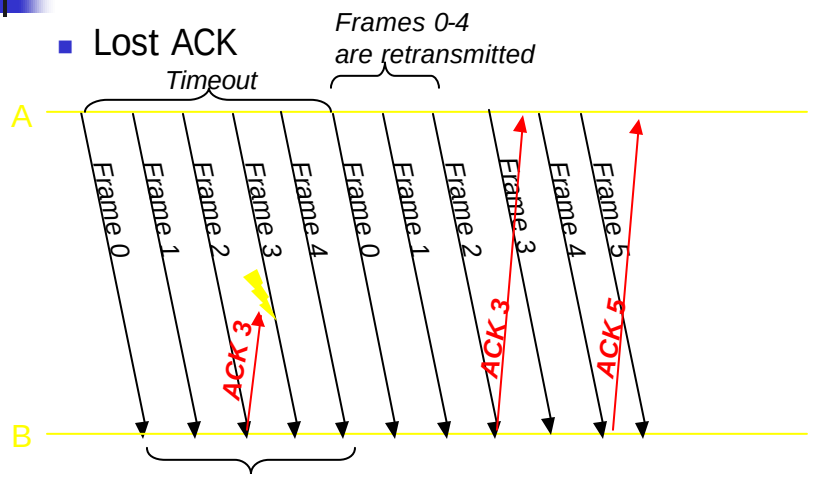
- Lost Frame



Copyright by Jorg Liebeherr 98,99

Go-Back-N ARQ

- Lost ACK



Copyright by Jorg Liebeherr 98,99

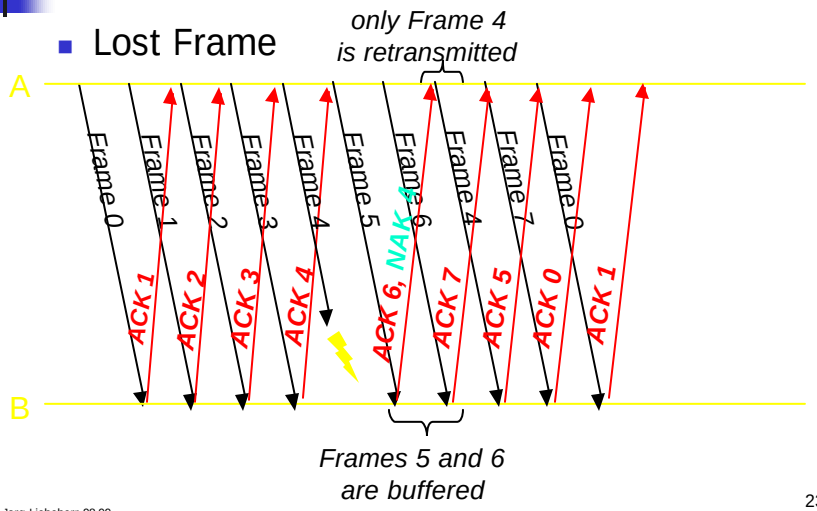
Selective-Repeat ARQ

- Similar to Go-Back-N ARQ. However, the sender only retransmits frames for which a **NAK** is received
- **Advantage over Go-Back-N:**
  - Fewer Retransmissions.
- **Disadvantages:**
  - More complexity at sender and receiver
  - Each frame must be acknowledged individually (no cumulative acknowledgements)
  - Receiver may receive frames out of sequence

Copyright by Jorg Liebeherr 98,99

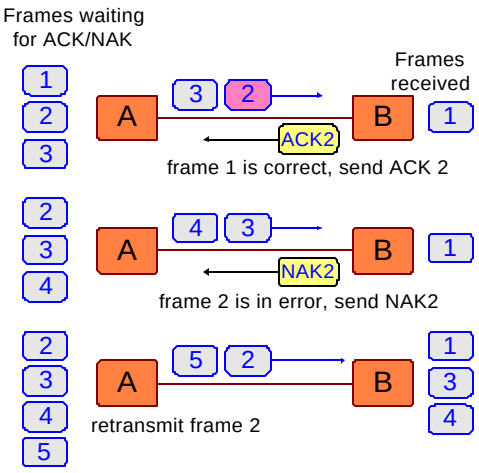
Selective-Repeat ARQ

- Lost Frame



Copyright by Jorg Liebeherr 98,99

Example of Selective-Repeat ARQ



Receiver must keep track of `holes' in the sequence of delivered frames

Sender must maintain one timer per outstanding packet

Copyright by Jorg Liebeherr 98,99