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)
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)

Analysis of Stop-and-Wait
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 \(2^k\)

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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)
Operation of Sliding Window

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

- **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.
Example

Transmitter

Receiver

Example Continued

Transmitter

Receiver
If the window size is sufficiently large the sender can continuously transmit packets:

- \( W \geq 2a+1 \): Sender can transmit continuously
  
  \[ \text{normalized efficiency} = 1 \]

- \( W < 2a+1 \): Sender can transmit \( W \) frames every \( 2a+1 \) time units
  
  \[ \text{normalized efficiency} = \frac{W}{1+2a} \]
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

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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
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

Lost Frame

- **Frame 0**: A
- **Frame 1**: B
- **ACK 0**: Frame 0
- **ACK 1**: Frame 1
- **Timeout**: Frame 1
- **ACK 0**: Frame 1

Stop-and-Wait ARQ

- Lost ACK

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.
Go-Back-N ARQ

**Operations:**

- A station may send multiple frames as allowed by the window size.
- Receiver sends a **NAK** 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** it will retransmit frame \( i \) and all packets \( i+1, i+2, \ldots \) which have been sent, but not been acknowledged.

[Diagram of Go-Back-N ARQ showing lost frames and retransmission process]

Frames 4, 5, 6 are retransmitted

Frames 5 and 6 are discarded
Go-Back-N ARQ

- Lost ACK
  - Timeout

Frames 0-4 are retransmitted

- Frames 3 and 4 are discarded

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
Selective-Repeat ARQ

- Lost Frame
  - only Frame 4 is retransmitted

Frames 5 and 6 are buffered

Example of Selective-Repeat ARQ

Frames waiting for ACK/NAK

Frames received

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

Sender must maintain one timer per outstanding packet