Chapter 7
Flow and Error Control

Introduction

- In the physical layer of the OSI model, we have transmission but not communication.
- Communication requires two or more devices to send and/or receive data in a coordinated way – we need flow control and error control.
- **Flow control** defines how much data can be sent at any time.
- **Error control** defines how errors can be corrected.
- Flow and error control can be done either at the link level by the data link layer, or end-to-end by the transport layer.

Flow Control

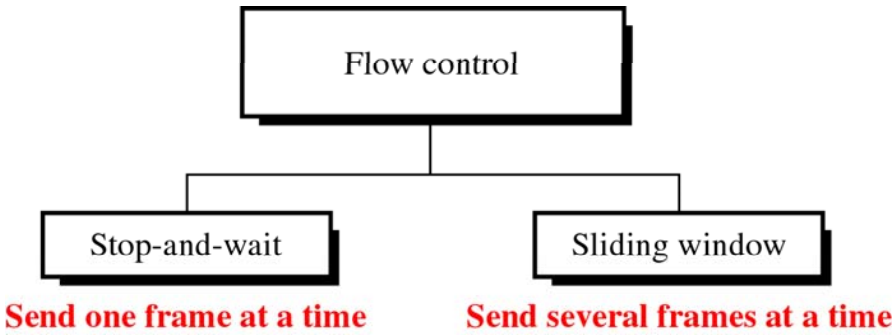
- Flow control is a set of procedures that tells the sender how much data to transmit before it must wait for an acknowledgement (ACK) from the receiver.
- Flow control ensures that the flow of data will not overwhelm the receiver.
- A receiving device has a limited speed to process incoming data, and a limited amount of memory to store incoming data.

Flow Control

- Incoming data must be checked and processed before they can be used. The rate of processing is usually slower than the rate of transmission.
- Each receiving device uses a buffer to store incoming data until they are processed.
- If the buffer begins to fill up, the receiver must be able to tell the sender to halt transmission until the data in the buffer have been processed.
- Two methods are used to control the flow of data: **stop-and-wait** and **sliding window**.

Figure 7-1

Categories of Flow Control

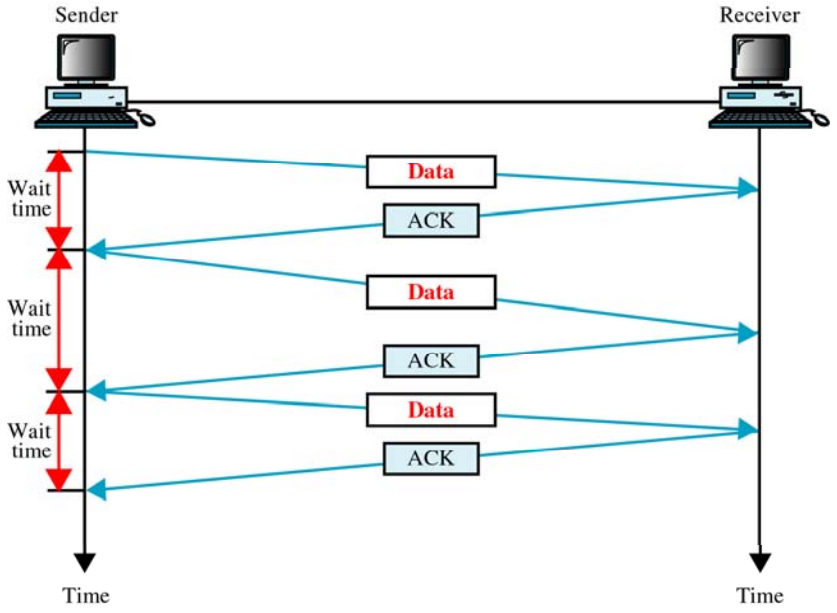


Stop-and-Wait

- The sender sends out a frame and then waits for an ACK before it sends out the next frame.
- This process of alternately sending and waiting repeats until the sender transmits an end of transmission (EOT) frame.
- The advantage is simplicity: each frame is checked and acknowledged before the next frame is sent.
- The disadvantage is inefficiency: it is slow; each frame travels all the way to the receiver and an ACK travels all the way back before the next frame can be sent.

Figure 7-2

Stop-and-Wait



Sliding Window

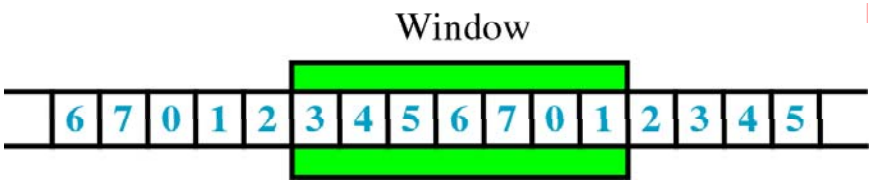
- The sender can transmit several frames before needing an ACK.
- The link can carry several frames at once and its capacity is used more efficiently than stop-and-wait method.
- The receiver acknowledges only some of the frames, using a single ACK to confirm the receipt of multiple frames.

Sliding Window

- The sliding window refers to imaginary boxes that hold data frames at both the sender and the receiver.
- Its size is the upper limit on the number of frames that can be transmitted before an ACK is required.
- Inside the window, the frames are numbered modulo *n*. The size of the window is *n*-1 frames.
- When the receiver sends an ACK, it includes the number of the next frame it expects to receive (say *k*).
- When the sender sees the ACK, it knows all frames up to frame *k*-1 have been received.

Figure 7-3

Sliding Window

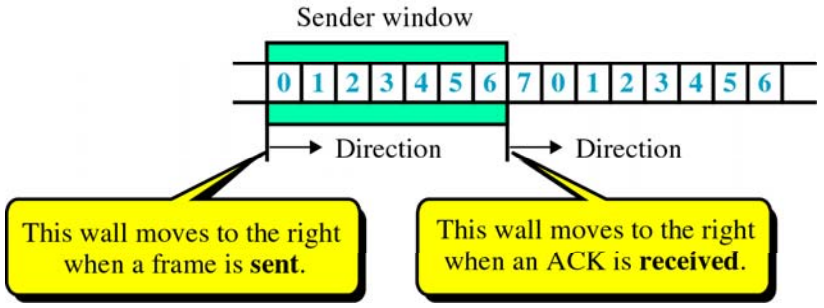


Sender Window

- At the beginning of a transmission, the sender's window contains *n*-1 frames.
- As frames are sent out, its left boundary moves inward, shrinking the size of the window.
- Once an ACK arrives, the window expands to allow in a number of new frames equal to the number of frames acknowledged by the ACK.

Figure 7-4

Sender Sliding Window of Size 7



Receiver Window

- At the beginning of transmission, the receiver window contains *n*-1 spaces for frames.
- As new frames come in, the size of the receiver window shrinks.
- It represents the number of frames that may still be received before an ACK must be sent.
- As each ACK is sent out, the receiving window expands to include as many new placeholders as newly acknowledged frames.

Figure 7-5

Receiver Sliding Window of Size 7

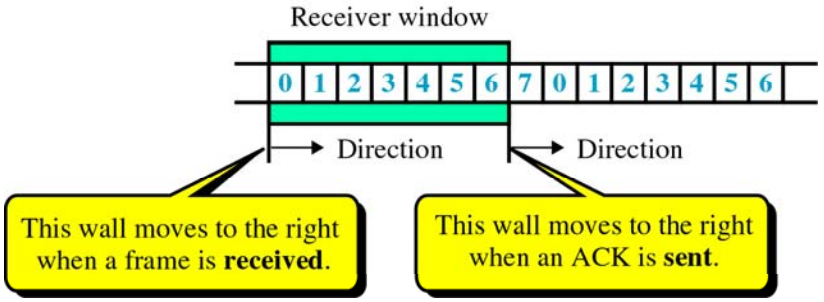
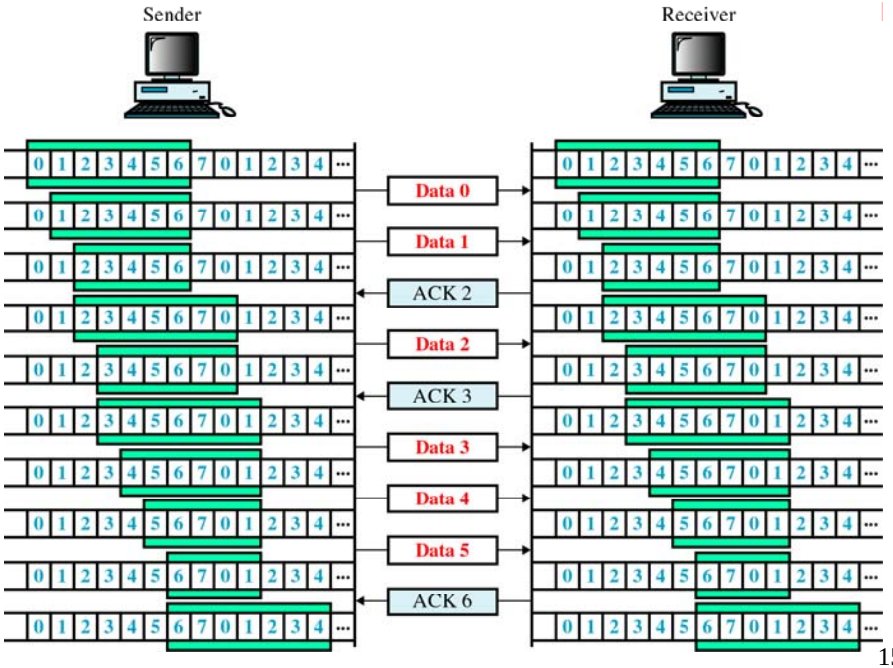


Figure 7-6

Example of Sliding Window of Size 7

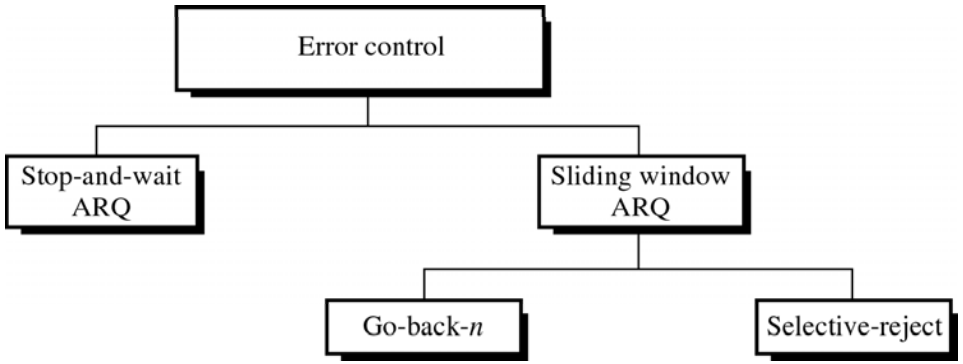


Error Control

- In the data link layer, the term *error control* refers primarily to methods of error detection and retransmission.
- **Automatic repeat request (ARQ)** is used to control the errors – any time an error is detected, a negative acknowledgement (NAK) is returned and the specified frame is retransmitted.
- ARQ error control is implemented in the data link layer as an adjunct to flow control.

Figure 7-7

Categories of Error Control



Stop-and-Wait ARQ

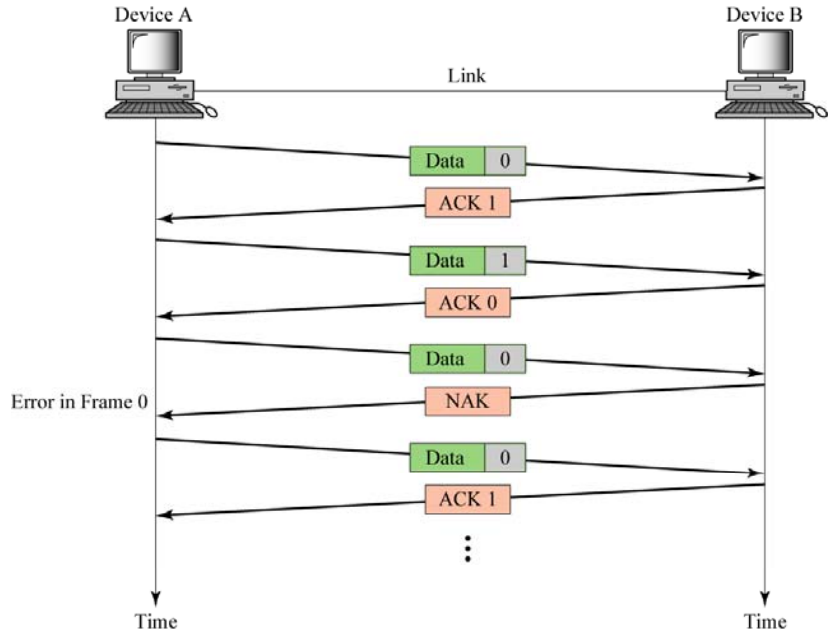
- Stop-and-wait ARQ is a form of stop-and-wait flow control extended to include retransmission of data in case of lost or damaged frames.
- Four features are added to the basic stop-and-wait flow control mechanism to make retransmission work.

Four Features Added to The Basic Flow Control Mechanism

1. The sending device keeps a copy of the last frame transmitted until an ACK is received.
2. Data frame and ACK frame are numbered alternately 0 and 1.
3. If an error is found in a data frame, a NAK frame is returned. The NAKs are not numbered. They tell the sender to retransmit the last frame sent.
4. The sending device has a timer. If ACK is not received within an allotted time period, the sender assumes the last data frame was lost and sends it again.

Figure 7-8

Stop-and-Wait ARQ, Damaged Frame



Lost Frame

- Either a data frame, or an ACK frame, or a NAK frame can be lost in transit.
- The sender starts its timer every time a data frame is sent. If it does not receive an ACK or NAK before the timer goes off, it retransmits the last data frame, restarts its timer, and waits for an ACK.
- If an ACK was lost and a new frame is received, the receiver discards the first copy and returns an ACK.
- If a NAK was lost and a new frame is received, the receiver accepts the new copy and returns an ACK.

Figure 7-9

Stop-and-Wait ARQ, Lost Data Frame

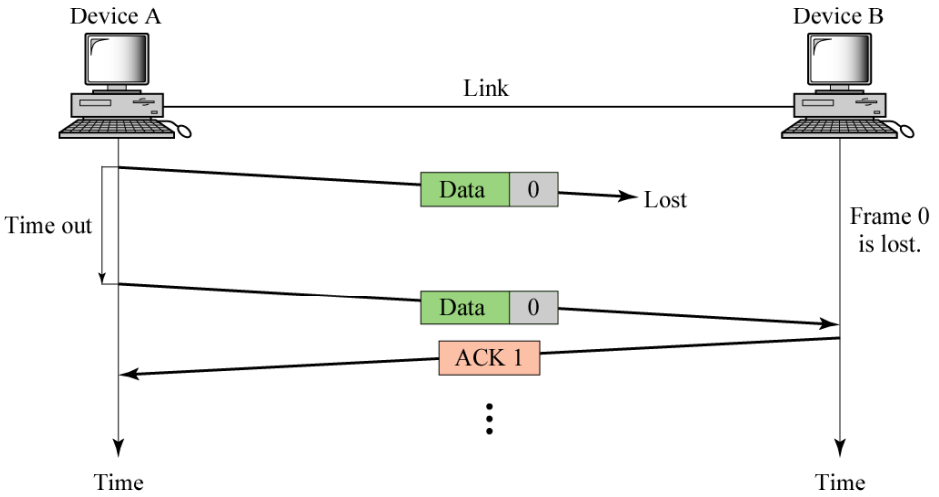
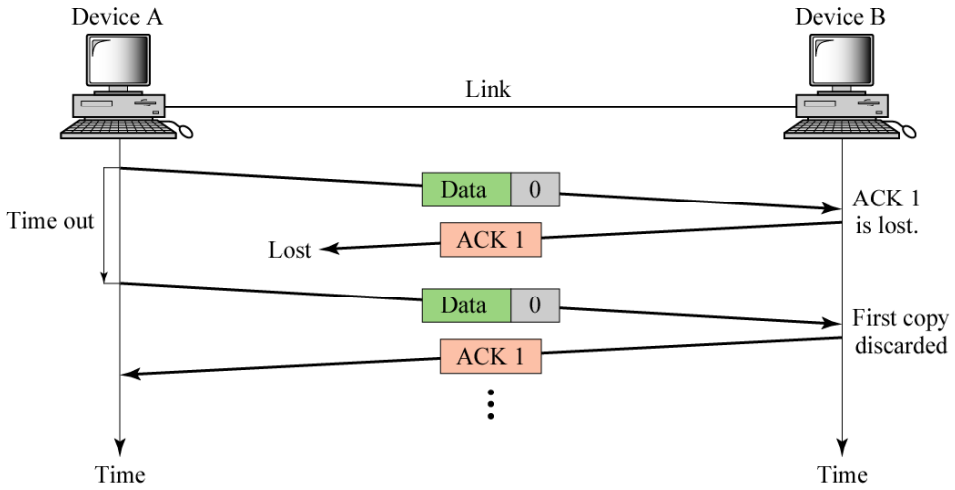


Figure 7-10

Stop-and-Wait ARQ, Lost ACK



Sliding Window ARQ

- Go-back-*n* ARQ and selective-reject ARQ are two popular error control protocols that are based on sliding window flow control.
- To extend sliding window to cover retransmission of lost or damaged frames, three features are added to the basic flow control.

Features Added to The Basic Flow Control

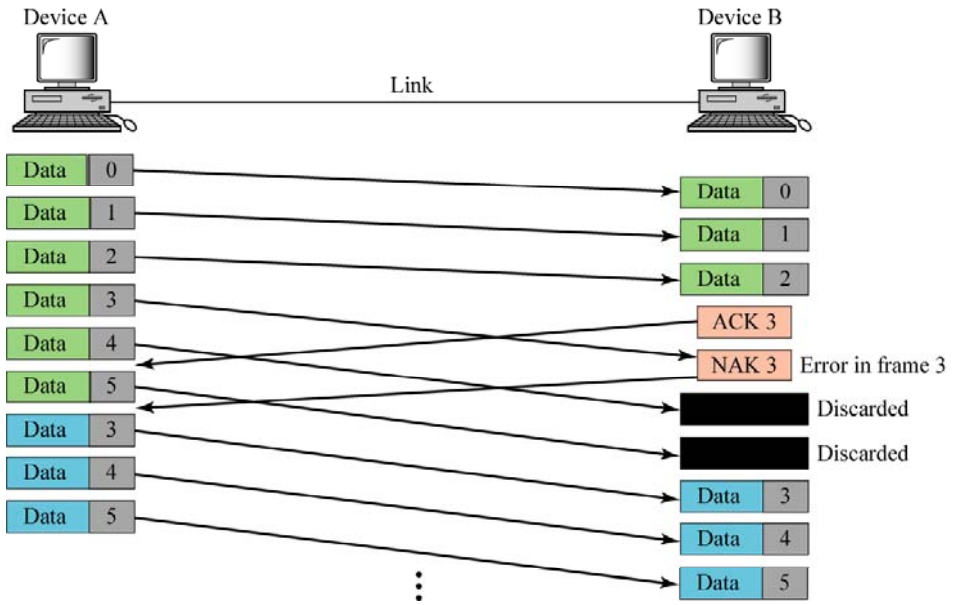
1. The sending device keeps copies of all transmitted frames until they have been acknowledged.
2. The receiver uses both ACK and NAK frames. ACK carries the number of next frame expected. NAK carries the number of damaged frame. An ACK can acknowledge multiple frames. A NAK acknowledges only one damaged frame.
3. The sender starts the timer if *n*-1 frames are waiting for ACKs. If the allotted time has run out with no ACK, the sender retransmits all *n*-1 frames.

Go-Back-*n* ARQ

- In the sliding window go-back-*n* ARQ method, if one frame is lost or damaged, all frames sent since the last frame acknowledged are retransmitted.
- NAK frame means two things:
  a) A positive acknowledgement of all frames received prior to the damaged frame
  b) A negative acknowledgement of the frame indicated.

Figure 7-11

Go-Back-n, Damaged Frame



Lost Frame

- Sliding window protocols require data frames be transmitted sequentially. If the frame received is out of sequence, it is considered by the receiver that one or more frames have been lost.
- The sender is not expecting to receive an ACK for every data frame it sends. It can send as many frames as the window allows before waiting for an acknowledgement.

Figure 7-12

Go-Back-n, Lost Frame

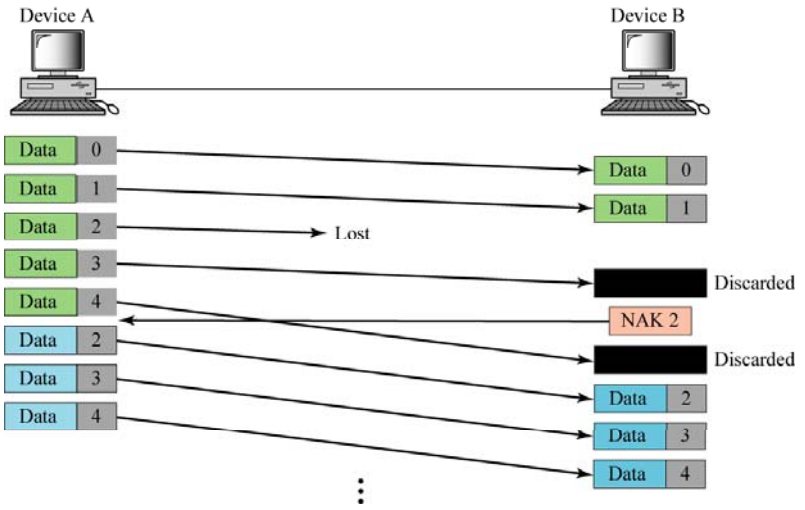
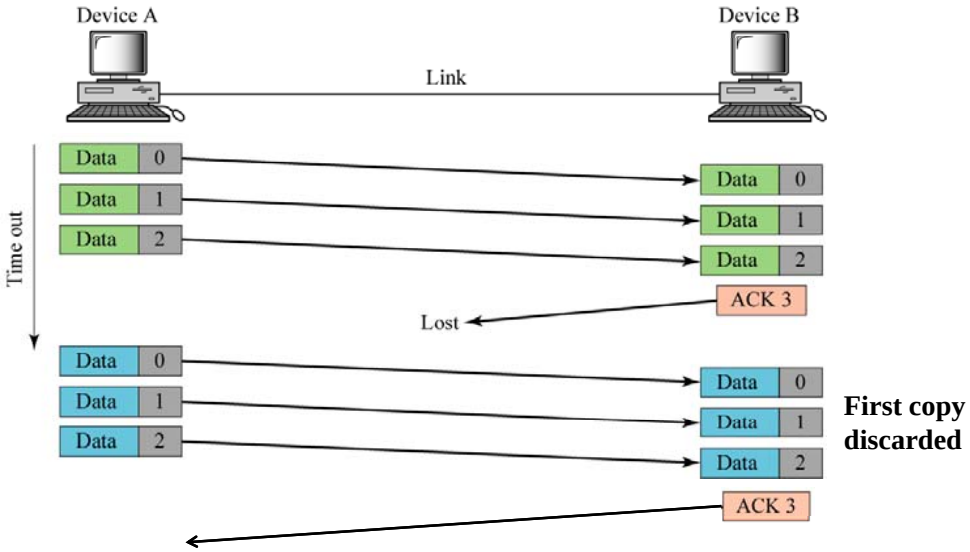


Figure 7-13

Go-Back-n, Lost ACK



Selective-Reject ARQ

- In selective-reject ARQ, only the specific damaged or lost frame is retransmitted.
- The retransmitted frame will be out of sequence when it is received.
- The receiving device must be able to sort the frames it has and insert the retransmitted frame into its proper place in the sequence.

Selective-Reject ARQ

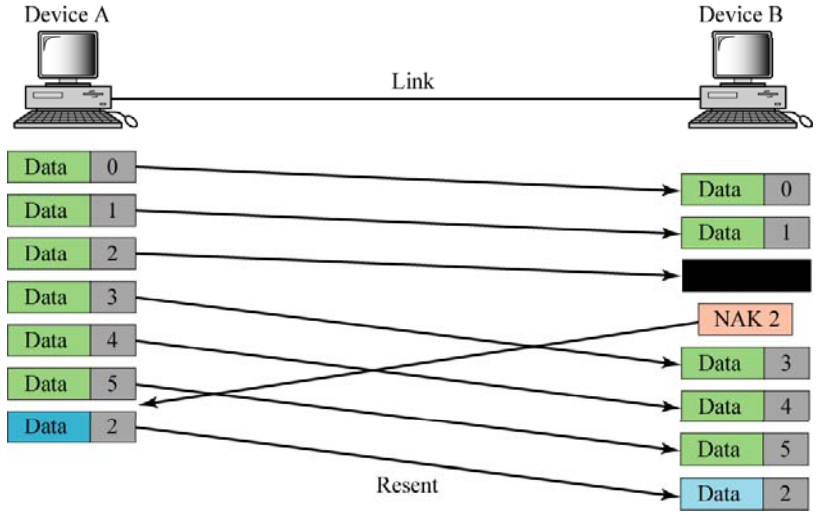
- Select-reject ARQ system differs from go-back-*n* system in the following:
  1) The receiving device must contain sorting logic to reorder frames received out of sequence. It must also be able to store frames received after a NAK has been sent until the damaged frame is replaced.
  2) The sending device must contain a searching mechanism that allows it to find and select only the requested frame for retransmission.

Selective-Reject ARQ

3) A buffer in the receiver must keep all previously received frames on hold until all retransmissions have been sorted and any duplicated frames have been identified and discarded.
4) ACK numbers, like NAK numbers, must refer to the frame received (or lost) instead of the next frame expected.
5) It is recommended that the window size be less than or equal to $(n+1)/2$, where $n-1$ is the go-back-n window size.

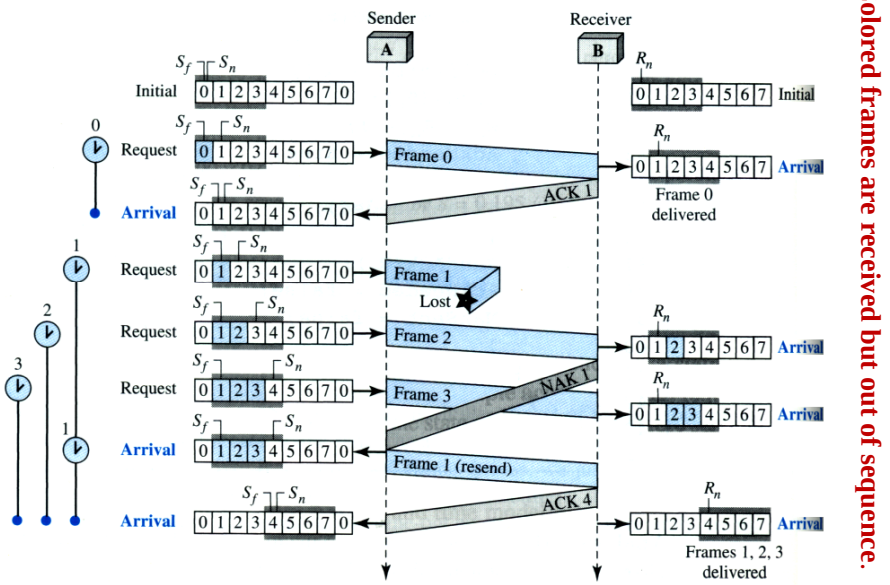
Figure 7-14

Selective-Reject, Damaged Frame



Selective-Reject, Lost Frame

Colored frames are sent but not acknowledged.



Colored frames are received but out of sequence.

Summary

- Flow control is a set of procedures governing the amount of data the sender can transmit.
- Stop-and-wait and sliding window are two methods to control the flow of data.
- In stop-and-wait flow control, an ACK is needed for every frame sent.
- In sliding window flow control, one ACK can acknowledge more than one frame.

Summary

- In data link layer the term “error control” refers primarily to methods of error detection and correction.
- ARQ is the mechanism used to retransmit data at the data link layer.
- ARQ error control is implemented as an adjunct to flow control.

Summary

- In the stop-and-wait ARQ method, if a frame is lost or damaged, the frame is retransmitted before any other frames are sent.
- In the sliding window go-back-*n* method, if a frame is lost or damaged, all frames sent since the last frame acknowledged are retransmitted.
- In the sliding window select-reject ARQ method, only the specific damaged or lost frame is retransmitted.