CSCI 234

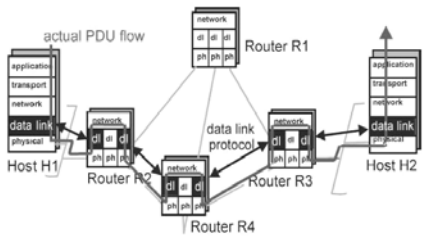
Design of Internet Protocols:
Flow Control

George Blankenship

Outline

- Data Link layer
- Connection Oriented and Connectionless
- Flow control rational
- Unbuffered flow control
- Buffered flow control
- Sliding window flow control

Data Link Layer



DL Layer Fundamental Functions

- Frame Synchronization
  - Data sent in blocks called frames
- Flow Control
  - Sender must not send frames faster than the receiver can absorb
- Error Control
  - bit errors introduced by transmission system should be corrected
- Addressing
  - On multipoint line (i.e. LAN) identity of sender/receiver must be specified

DL Layer Operational Functions

- Control and data on same link
  - Usually undesirable (possible) to have physically separate path
  - Receiver must be able to distinguish control information from data
- Link Management
  - Initiation, maintenance and termination of a sustained data exchange (coordination)
- Service Classes
  - unconfirmed connectionless service
  - confirmed connectionless service
  - connection-oriented service

Unconfirmed Connectionless

- Transmission of isolated, independent units (frames)
  - loss of data units possible (no correction from DL)
- Features
  - no flow control
  - no connect or disconnect
- Applications
  - Very low error bit rate PHY layer
  - Corrections possibly higher layers
  - Possibly for real-time data transfer
  - Timing errors more critical than errors in the voice data
  - Often used in LANs

Confirmed Connectionless

- Receipt of data units (implicitly) acknowledged
  - no loss
  - each single frame is acknowledged
  - timeout and retransmit
- Features
  - no flow control
  - no connect or disconnect
  - duplicates and sequences errors due to retransmissions
- Applications
  - High error bit rate PHY layer (e.g. mobile communications)

Connection Oriented

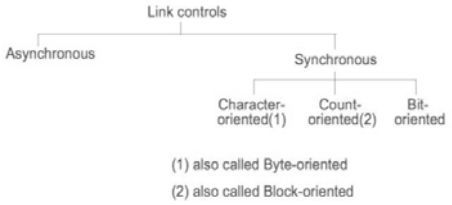
- Connection delivers error free channel
  - no loss, no duplication, no sequencing error
- **Flow control**
  - 3-phased communication:
  - **Connect by initializing**
    - Counters
    - Variables

    … of sender and receiver
  - **Data transfer**
  - **Disconnect**

Connection Oriented

- Data link acknowledgements
  - Only for optimization but not indispensable
  - May be done at transport layer
- Transport layer acknowledgements
  - A transport layer message (segment) consists out of n (generally more than one) data link layer frames
  - An error in an individual frame causes the retransmission of whole transport segment
  - Transport layer recovery is expensive, but required

DL Operation Mode



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Flow Control Operation

- Adjusts sender rate to receiver rate
- "Sophisticated" schemes can protect against:
  - Deletion
  - Insertion
  - Duplication
  - Reordering
- Receiver must process before passing to high-level software. Use flow control to:
  - Optimize channel utilization
  - Ensure data not sent faster than they can be processed
    - sending data too slowly is wasteful
    - avoid data clogging transmission links
    - sending data too fast can cause congestion

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Flow Control Operational Environment

- Data path may contain limited capacity transfer points for sharing with multiple sender-receiver pairs (buffer)
- A "good" flow control scheme may prevent such pair from wasting all available storage space

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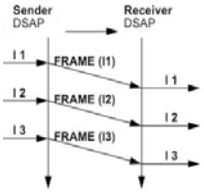
Flow Control Relationships

- Error control and flow control are usually interlinked
- Rate control vs. flow control:
  - reference to frame sequence (not single frames)
  - used with continuous-media data (audio, video)

Error Free Operation

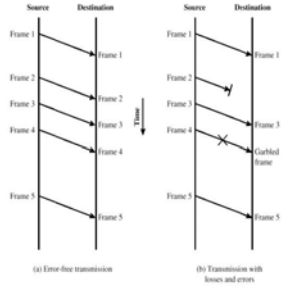
- Assumptions
  - error-free communication channel
  - receiving buffer infinitely large
  - receiving process infinitely fast
- Reality
  - finite buffer, finite processor, etc.
  - sender floods receiver with data faster than able to process



Flow Control: Prerequisites

- Absence of errors
  - No frames are lost
  - None arrives with error
- A vertical-time sequence diagram
- Data sent in a sequence of frames
  - a data portion + control information
  - transmission time
    - time taken to emit all bits into medium proportional to the length of frame
  - propagation time
    - time for a bit to traverse the medium

Frame Transmission



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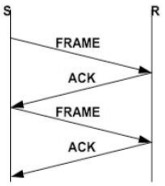
Unbuffered Flow Control

Assumptions

- Error-free communication channel
- NOT [receiving buffer infinitely large]
- NOT [receiving process infinitely fast]
- Always fast enough to process a frame



Reality

- noisy channel introduces errors
- too slow

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Software Control

- Oldest and least reliable flow control
  - From the days of the teletype
  - Software flow control
- X-ON signal indicates a system ready to receive messages
- X-OFF signal indicates a system too busy to receive (suspend transmission)
- Extra control characters in data stream can cause problems

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Hardware Control

- Hardware flow control uses RS-232-C hardware pins RTS and CTS (request-to-send and clear-to-send) to produce same result
- Hardware flow control is more reliable
  - reverse channel used to send the X-ON/X-OFF might become backlogged (data is delayed) and result in data loss on the other channel

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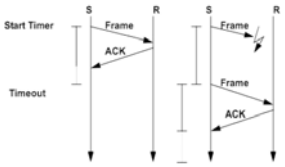
Frame Acknowledgement

Problems with Stop-Wait

- Locks down when both data frames
- Locks down when ACK are lost



Solution: acknowledement

timeout interval problem

- Too short: unnecessary sending of frames
- Too long: unnecessary waiting in case of error

- ***What happens if ACK is lost?***

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Sequence Number

Problem

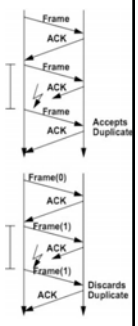
- loss of ACKs leads to block duplication

Solution

- each frame contains a sequence number
- sequence number kept during retransmissions

Range

- Stop-and-Wait: 0, 1
- In general: [0, k], k = 2^{n-1}, *n* is a *window* size
  Example n=1



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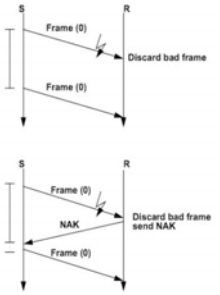
Negative Acknowledgement

Passive error control no differentiation between

- missing frames
- faulty frames
- if errors occur, a lot of traffic is ACK
  i.e. overhead



Active error control

- only negative ACK, NACK

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Data Fragmentation

- Source breaks large data blocks into smaller blocks
- Transmits data in many frames
- Motivation
  - limited buffer size of the receiver
  - errors detected sooner (when whole frame received)
  - on error, retransmission of smaller frames is needed
  - prevents one station occupying medium for long periods
  - stop-and-wait becomes inadequate

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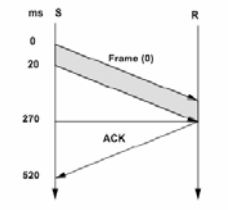
Problems Stop-and-Wait Summary

- lost frames
- damaged frames
- poor utilization

A satellite channel

- transmission rate: 50 kbps
- roundtrip delay: 500 ms
- frame size: 1000 bits



ACK is short and negligible:

- Sending takes 1000 bits / 50,000 bps = 20 ms
- Sender is blocked for 500 ms out of 520 ms
- Channel Utilization < 4%

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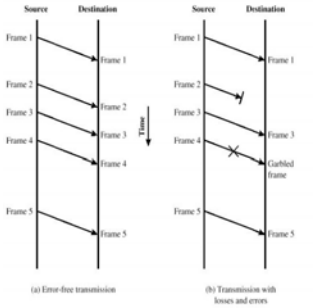
Model of Frame Transmission



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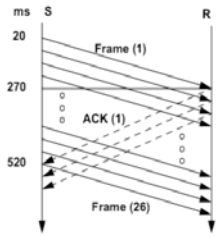
Pipelining

- Solution for low channel utilization
  - Sending more than 1 frame one by one
  - Waiting for acknowledgement for every frame
- efficiency can greatly improve by allowing multiple frames to be in transit at the same time



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Sliding Windows Flow Control

- A and B connected via a full-duplex line
  - B allocates buffer space for W frames
  - A allowed to send W frames without waiting for any ACK
  - Each frame labeled to keep track of frames have been ACK
- B ACKs a frame by sending
  - sequence number of expected next frame
  - implicitly announces prepared to receive next W frames
- A maintains list of frames allowed to send
- B maintains list of frames prepared to receive

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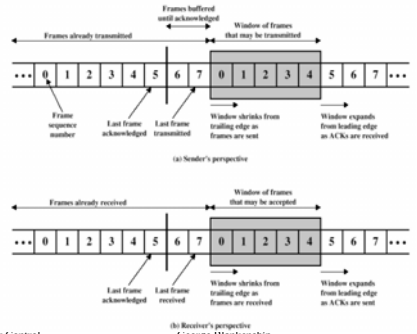
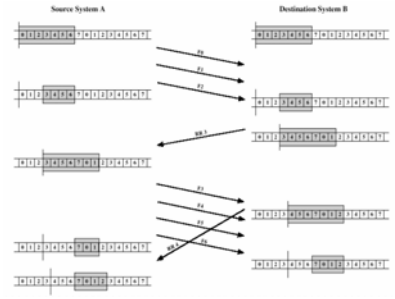
Sliding Window Diagram



Frame Transmission with Window



Notes on Sliding Window

- Provides a form of flow control
  - Receiver must only be able to accommodate seven frames beyond the one has last acknowledged
  - Most real protocols also allow a station to cut off the flow of frames from the other side by sending a Receiver Not Ready (RNR) message
- Acknowledges former frames but forbids transfer of future frames
  - Example: RNR5 means 'I received all frames through number 4, but unable to accept any more'
  - The transmission of new frames enabled by Receive Ready (RR)
- 'Sliding Window' more efficient than stop-and-wait
- Transmission link treated as a pipeline
- Stop-and-Wait is window size is equal to 1

Sliding Window Enhancements

- If two stations exchange data, each needs to:
  - maintain two windows one for transmit and one for receive
  - send data and acknowledgement to the other
- Piggybacking is provided
  - each data frame includes a field holding sequence number used for ACK
  - sending data with acknowledgement in one frame
- ACK but no data
  - send a separate acknowledgement frame, such as RR or RNR
- Data but no ACK
  - must repeat last ACK sequence number it sent
  - Because: data frame includes a field for a ACK, field can not be empty
- Receiving duplicate ACK -- simply ignore it

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Remarks on Efficiency

- Efficiency depends on
  - type and amount of errors at physical layer
  - amount and rate of data
  - end-to-end delay on physical layer
  - window size
- Resources and QoS (Quality of Service)

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