Data Link Layer

Design Issues

- Uses the physical layer to send and receive bits over a communication channel
- Defines an interface to the network layer
- Deals with transmission errors
- Regulates the flow of data
  - unless an eager sender overwhelms a slow receiver
- IN CASE OF A SHARED CHANNEL
  - Provides Medium Access Control (MAC) services

Services provided to network layer

- Data link layer can provide
  - unacknowledged connectionless service
  - acknowledged connectionless service
  - acknowledged connection-oriented service

Framing

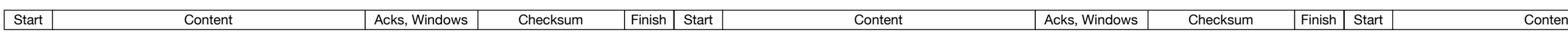
- Physical layer can send a raw bit stream
- Network layer provides a bit stream or a stream of packages
- Usually, data link layer breaks network layer stream into *frames*
- Frames carry metadata for
  - Error detection / control
  - flow control
  - acknowledgments

Framing


Packet
Frame
Header
Packet
Trailer
Packet
Frame
Header
Packet
Trailer

Framing

- Frames need to be delimited
  - So that receiver can recognize the frame and its parts
  - Four methods:
    - Byte count
    - Flag bytes with byte stuffing
    - Flag bits with bit stuffing
    - Physical layer coding violations



Byte Count

- Can start out a frame with the byte count.
  - Receiver reads the byte count
  - Throws byte count away
  - Reads as many bytes as in the byte count as the frame
  - Divide the following byte stream into frames

0x04	0x03	0x0a	0x32	0xf1	0x05	0x04	0x04	0x04	0x04	0x04	0x03	0xff	0x0b3	0x0b3

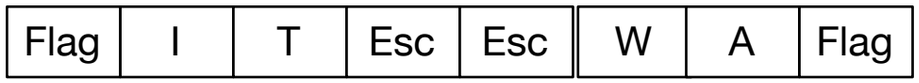
  - Once synchronization is lost, cannot recover framing
  - Byte counts can never be corrupted

Flag Bytes

- Use a special flag byte as beginning and end marker
- Use another byte as an escape if the flag appears in the text
- Use a double escape in order to escape an escape

Flag bytes

- What is the encoding of



Flag bytes

- Stuffing bytes adds to the size of the stream
  - If a text contains 1/256 flags and 1/256 escapes per byte, then we add 2/256 bytes or about 1% to the size of the text
  - Flag bytes is used in the Point-to-Point Protocol
  - Flag bytes assume that all data is in the form of bytes

Flag bits

- Developed for the High-level Data Link Control protocol
- Each frame starts and ends with the pattern 01111110 = 0x7E
- To prevent this pattern from appearing in the text of the frame
  - After five consecutive ones, sender inserts a zero
  - After receiving five consecutive ones, receivers drops the following zero.

Flow Control

- True simplex traffic without feedback:
  - Sending pictures from Mars - Mariner expeditions
  - All messages / frames are sent with additional error control bits
  - Receiver can reconstruct original message even if the received message is distorted by noise

Flow Control

- To provide reliable, connection-oriented service
  - Receiver provides sender with feedback
    - in form of special control frames
  - Receiver resends frame after negative feedback
    - or sometimes based on a timer
      - because a frame can be completely lost in a noise burst
- Usually, frames are numbered

Flow control

- Feedback-based flow control
  - Receiver tells sender when it is ok to send more frames
- Rate-based flow control
  - Sender has mechanism that limits the number of frames per time unit

- A Network Interface Card (NIC) runs at “wire speed” if it can handle all frames that can appear on the wire
  - Then there is no need for flow control at the data link layer

Error Detection / Correction

- Error detection:
  - Receiver can tell that message contains errors
- Error correction:
  - Receiver can reconstruct true message
- Errors:
  - Burst errors (a high error rate for the duration of the burst or several bits in a row are transmitted in error)
  - Erasures (receiver’s physical layer cannot decode a bit)
  - Random errors (bits switch value)

Flow Control

- Sender's network layer gives packets to the data link layer
- Data link layer needs to get exactly the same sequence of packets delivered
- Feedback protocols:
  - Data can get destroyed or corrupted
  - Acks can get destroyed or corrupted
    - Frames can be resend by mistake
  - Need frame numbering and timers

Flow-Control

- Automatic Repeat reQuest (ARQ) / Positive Acknowledgment with Retransmission (PAR)
  - Frames are numbered with a single bit
    - Increment switches 0 to 1 and vice versa
  - Sender sends frame, then waits for Ack
    - If Ack does not arrive in time, then resends frame
    - NEVER sends a new frame without an Ack
    - Increments frame number
- Receiver sends an Ack for each successful frame
    - Increments expected frame number
    - Can send a No-Ack to ask for resending a corrupted frame

Exercise

- Play through all scenarios to determine whether a frame can be lost or duplicated.

- Frame fine, Ack fine
- Frame bad, No-Ack sent, lost
- Frame bad, No-Ack sent, and received
- Frame fine, Ack sent, and lost
- Frame bad, No-Ack sent and lost

Flow Control

- ARQ does not work with long delays
  - Exercise:
    - Satellite link has 100 msec delay and 100Mbps bandwidth
    - How much of the channel can actually be used
    - Assume frames of 10Kb.

Answer

- Time to send a frame:
  - 10Kb/100Mbps = $10^4/10^8$ sec = 10^{-4} sec = 10^{-1} msec

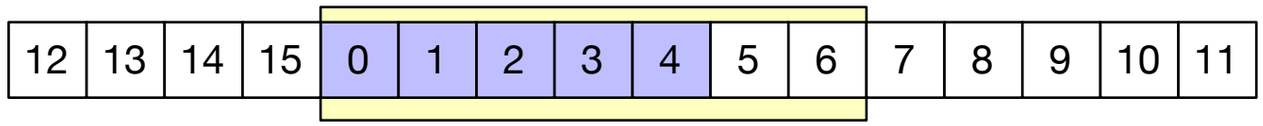
satellite	a c k	waiting for signal to reach ground	trans missi on	waiting for signal to reach satellite	a c k	waiting for signal to reach ground	trans missi on	waiting for signal to reach satellite	a c k		

- Useful time proportion:
  - $$\frac{10^{-1}}{2 \times 10^2 + 10^{-1}} = 0.000499975$$

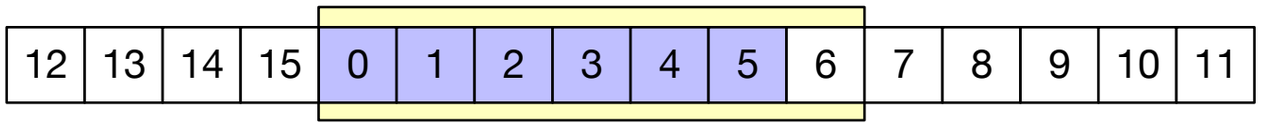
Sliding window protocol

- For better use of physical link, use sliding window protocols
  - Idea: Sender sends a number of frames without waiting for acks
  - When acks are missing, resend frames after a while
  - Fundamental problem: Frames need numbers, but numbers need to roll over
    - Use a sliding window: numbers repeat

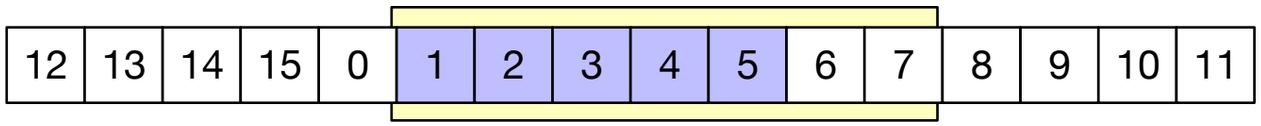
Five frames sent



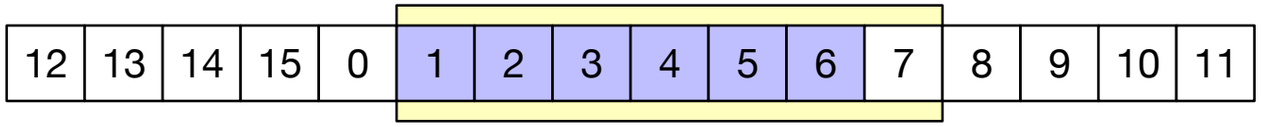
Six frames sent



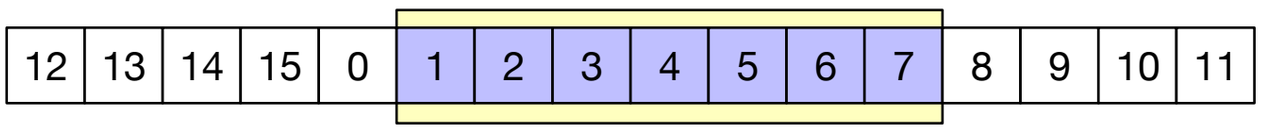
Ack for frame 0 received



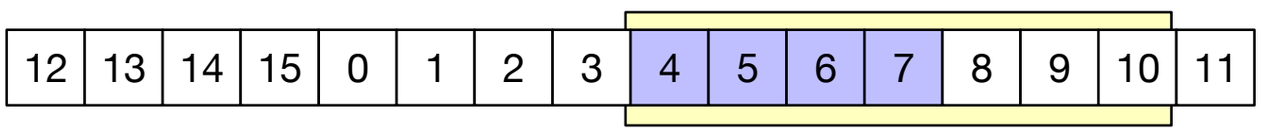
Seven frames sent



Eight frames sent, buffer is full, cannot send anymore



Received acks for frames 1, 2, 3, can now send three more frames



Sliding window protocol

- Sender needs to buffer all unacknowledged frames
- Acknowledgments can be done cumulatively
  - When we ack frame *n,* we also ack all preceding frames *n*-1, *n-2, …* in the sliding window
- Some protocols have resend messages for garbled frames, others just relay on not acknowledging them
- Selective repeat:
  - Receiver buffers all frames that arrive after a garbled one
  - Sends a resend request to sender
  - Gives frames to the network layer only in order received