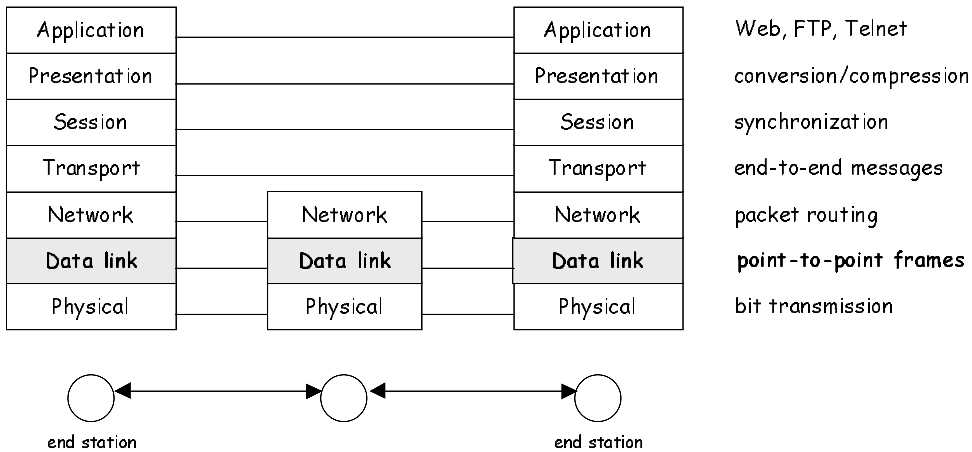
The Data Link Layer

OSI 7-layer reference model:



- **The physical layer** provides an unreliable bit-transmission facility - **unreliable bit pipe.**

- **The data link** follows special procedures (*data link protocols*) in order to transmit packets **reliably** over unreliable bit pipes - **reliable packet link**.

- Main functions of the data link layer:

  1) **framing** - mandatory for the data link layer!
  2) **error control** } - can appear in one of the upper layers,
  3) **flow control** } typically in the transport layer

Question:
Sometimes, error control is performed within the transport layer.
If you are given a reliable/unreliable physical medium (fiber/wireless), where would you place the error control function? (At the data link or at the transport layer?)

1) Framing

packet	↔	**network layer**
frame	↔	**data link layer**

(A frame consists of an embedded packet and some control (header) information.)

frame = [*frame marker* + **packet** + **checksum** + *frame marker* **]**

1.1) Character count

(A bit in the header specifies the number of characters in the frame)

1.2) Starting and ending characters, with character stuffing

(Each sequence starts with the ASCII character sequence DLE STX and ends with the sequence DLE EXT.

- sender inserts an additional DLE before each 'accidental' DLE in the data
- receiver removes the DLE before the data are given to the network layer)

1.3) Starting and ending flags, with bit stuffing

(Each frame begins and ends with a special bit pattern 01111110 - *flag byte*. Whenever the sender encounters 5 consecutive ones in the data, it stuffs a 0 bit into the outgoing bit stream. ...)

1.4) Physical layer coding violations

(Each bit of data is encoded by using 2 physical bits: 01 or 10.
The combinations 00 and 11 are not used for data.)

(Textbook) Problem 2:

The following data fragment occurs in the middle of a data stream for which the character stuffing algorithm is used: DLE, STX, A, DLE, B, DLE, ETX.
What is the output after stuffing?

(Textbook) Problem 4:

When bit stuffing is used, is it possible for the loss, insertion, or modification of a single bit to cause an error not detected by the checksum? If not, why not? If so, how? Does the checksum length play a role here?
(How does this problem relate to the problem of incorrect synchronization at ATM?)

2) Error control

error control = {error detection, error correction}

- Error correction codes include enough redundant information with each block of data to enable both the detection & correction or erroneous data.

Hamming distance - the number of bit positions in which two codewords differ.
Example: HD (1101, 1111) = 1

- To detect d errors we need a distance (d+1) code, whereas to correct d errors we need a (Hamming) distance (2d+1) code.

ERROR DETECTION FOLLOWED BY RETRANSMISSION IS PREFFERED BECAUSE IT IS MORE EFFICIENT.

(Textbook) Problem 5:
Can you think of any circumstances under which 'error-correction' based protocol might be preferable to the 'error-detection' type of protocol (such as ABP, SRP, ...)?

Question: PARITY BIT code - the parity bit is chosen so that the number of 1 bits in the codeword is even (or odd).

even parity: 010 → 010 1 odd parity: 010 → 010 0

A code with a single parity bit has a distance D=2. How many bits can this code correct, i.e. detect?

(Textbook) Problem 7:
One way of detecting errors is to transmit data as a block of n rows of k bits per row and adding parity bits to each row and each column. Will this scheme detect all single errors? Double errors? Triple errors?

❖ **Services Provided to the Network Layer using error detection based protocols:**

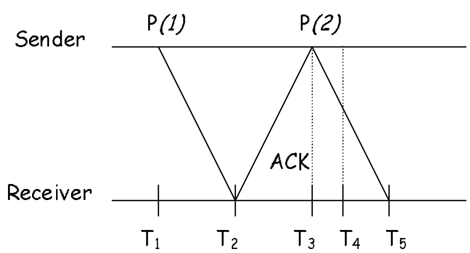
1) Unacknowledged connectionless service
- the receiver's data link layer simply drops the incorrect packets

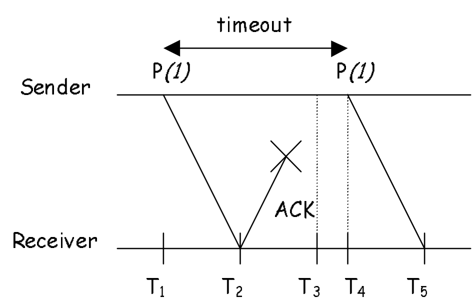
2) Acknowledged connectionless service
- each frame sent is individually acknowledged
- if an acknowledgment has not arrived within a specified time interval, it can be sent again

3) Acknowledged connection-oriented service
- each frame sent is individually acknowledged
- at the network layer each frame is received exactly once and all frames are received in the right order
- **examples: ABP, SRP, Go back N**

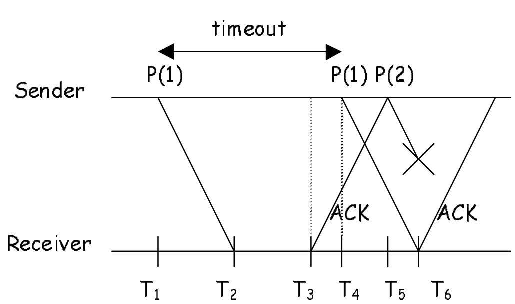
The use of error detection, timers, acknowledgments, and retransmission is referred to as Automatic Repeat reQuest (ARQ).

- packets must be numbered



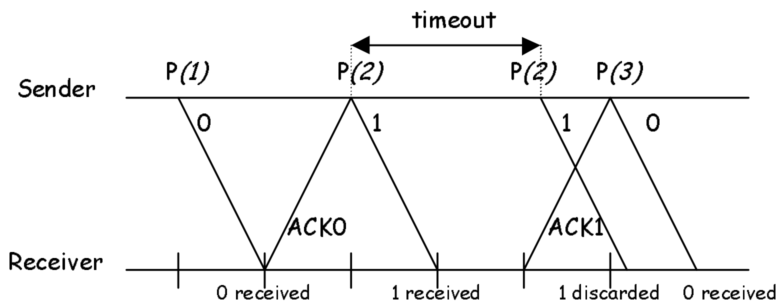


- ACK must be numbered



We are looking for data link protocols that necessitate the storage of only limited number of packets.

Alternating Bit Protocol (ABP = stop & wait)



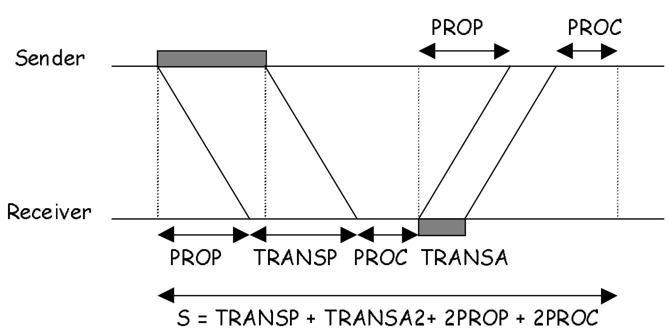
- the sender transmits a frame and waits for its ACK before sending the next one
- the receiver waits and accepts correct packets, and ignores the incorrect ones
- the packets and their ACK are numbered 0,1,0,1,...

Advantages of ABP:

1) **its simplicity**
2) **its small buffering requirements**: the sender needs to keep only a copy of the packet that it last transmitted, and the receiver does not need to buffer packets at the data link layer

Disadvantages of ABP:

1) **it is not very efficient** - the sender must wait for each packet to be ACK before it can send the next packet



EFFICIENCY IN THE ABSENCE OF ERROR: $\eta(\mathbf{ABP,0}) = \frac{\mathbf{TRANSP}}{\mathbf{S}}$

EFFICIENCY IN THE PRESENCE OF ERROR: $\eta(\mathbf{ABP,p}) = \frac{\mathbf{(1-p)\times TRANSP}}{\mathbf{S}}$

Question (Problem 9.1 from Stallings' book):

Consider a half-duplex point-to-point link using a stop-and-wait scheme.

a) What is the effect on line utilization of increasing the number of frames for a constant message size?

b) What is the effect on line utilization of increasing frame size?

L - length of a frame

R - data rate on the link [bps]

d - distance of the link between two stations

V - velocity of propagation of the signal along the link

$$\eta(ABP,0) = \frac{TRANSP}{S} = \frac{\frac{L}{R}}{\frac{L}{R} + 2\frac{d}{V}} = \frac{1}{1 + 2\frac{d/V}{L/R}} = \frac{1}{1+2a}$$

$$a = \frac{\text{propagation time}}{\text{transmission time}} = \left.\frac{d \cdot R}{V \cdot L}\right|_{V = const}$$

Question (Variation on Problem 11 from Textbook):

The efficiency of a channel that uses stop-and-wait protocol (ABP) is 50%. What is the bit-rate of the channel, if the frame size is 100[bit] and the propagation delay is 20[msec].

Question (Variation on Problem from Walrand's Book)

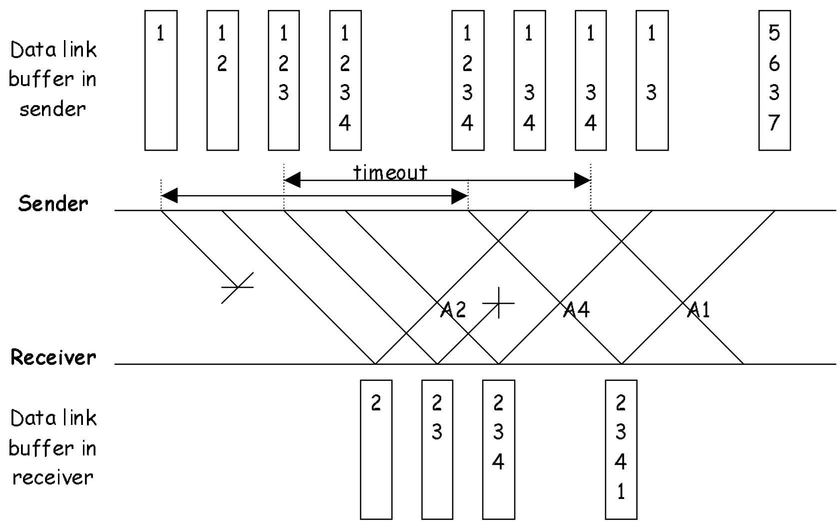
a) Consider a transmission line of 500[km] at 50[kbps]. If the packets and ACKs have 1000[bits], PROC=1[msec], and the propagation speed is 2×10^8[m/sec], find the channel efficiency.

b) Consider now an optical fiber of 500[km] at 10[Mbps], and assume that the packets and ACKs have 1000[bits]. PROC and propagation speed are the same as in a). What is the channel efficiency in this case?

c) **Discuss results!**

Selective Repeat Protocol (SRP)

- The SRP improves on the efficiency of ABP by permitting more than a single unacknowledged packet.



- the sender and receiver use buffers of size W
- the packets are numbered 0,1,2, … 2W-1
- packets from another window cannot be transmitted while a packet from the previous window is still unacknowledged
- the receiver acknowledges the reception of a correct packet with an ACK that has the same number as the packet
- the receiver stores the packet it receives out of order, and it delivers the packet in order

EFFICIENCY IN THE ABSENCE OF ERROR: $\eta(\mathbf{SRP,0}) = \min\left\{\frac{W \times TRANSP}{S}, 1\right\}$

Advantages of SRP:

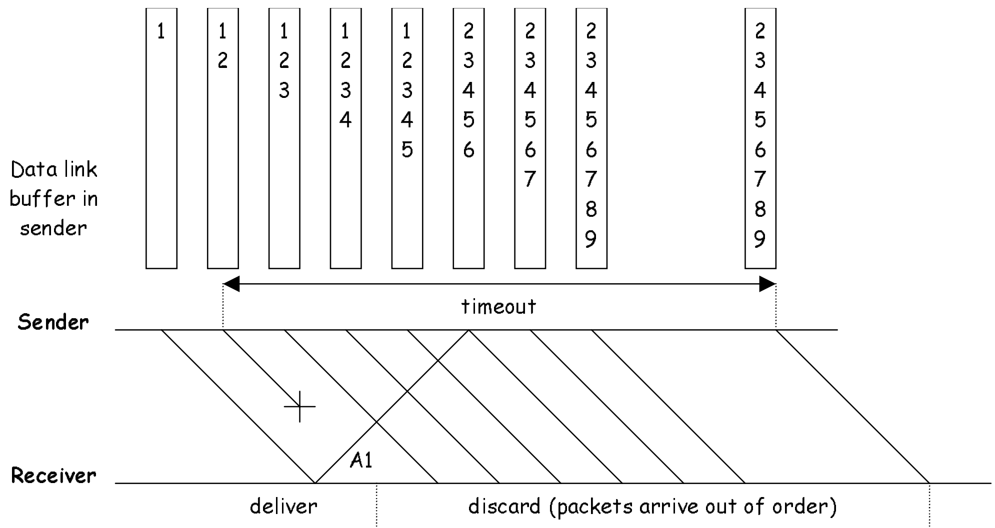
It is more efficient in terms of the bandwidth than ABP.

Disadvantages of SRP:

It requires buffering packets at both the sender and the receiver.

Go Back N

❖ The efficiency of the Go Back N protocol falls between ABP and SRP.



❖ the sender uses a buffer of size W
❖ the packets are numbered consecutively 0,1,2,... W
❖ the receiver delivers packet in order, and it discards packets received out of order
❖ the sender can have up to W unacknowledged packets
❖ when the sender does not receive the acknowledgment of a packet before a timeout, it retransmits copies of that packet and of all the subsequent packets.

EFFICIENCY IN THE ABSENCE OF ERROR: $\eta(\textbf{Go back N},0) = \min\left\{\frac{W \times TRANSP}{S}, 1\right\}$

Advantages of Go Back N:

No buffering is required at the receiver.

Disadvantages of Go Back N:

It is less efficient than SRP in the presence of errors.

(Textbook) Problem 22:

Frames of 1000 bits are sent over a 1-Mbps satellite channel. Acknowledgments are always piggybacked onto data frames. The headers are very short. Three-bit sequence numbers are used. What is the maximum achievable channel utilization for

a) stop-and-wait

b) SRP

c) Go Back N