Performance of rdt3.0

- rdt3.0 works, but performance could be desastrous

Example:

- 1 Gbps link, i.e. transmission rate of 10^9 bits per second
- 15 ms propagation delay,
- 1KB frame length, i.e. 8 000 bits per frame

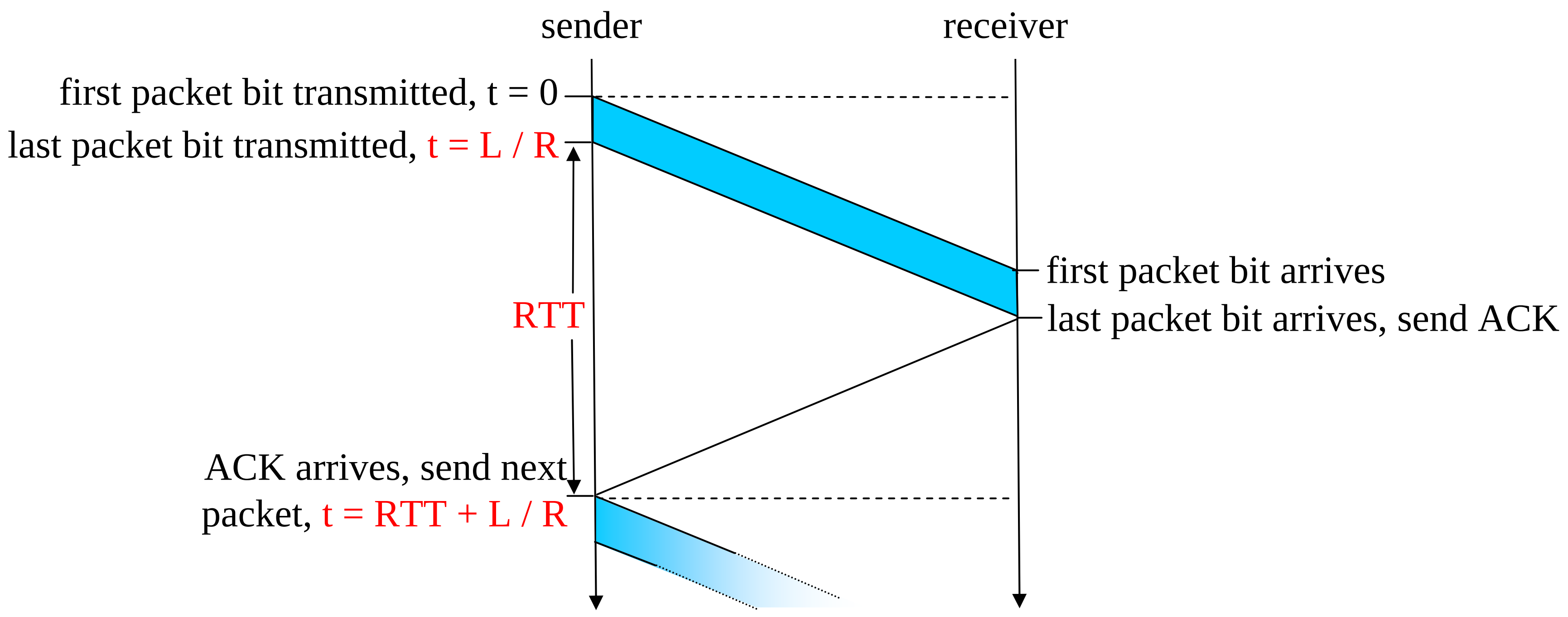
$$T_{\text{Transmission delay}} = \frac{L \text{ (packet length in bits)}}{R \text{ (transmission rate, bps)}} = \frac{8\text{kb/pkt}}{10^{**}9 \text{ b/sec}} = 8 \text{ microsec}$$

- $U_{\text{sender/channel}}$: utilization – fraction of time sender busy sending
- RTT: Round-Trip Time

$$U_{\text{sender}} = \frac{L / R}{RTT + L / R} = \frac{.008}{30.008} = 0.00027$$

- 1KB pkt every 30 msec -> 267kb/sec throughput over 1 Gbps link
- network protocol limits use of physical resources!

rdt3.0: stop-and-wait operation


sender
receiver
first packet bit transmitted, t = 0
last packet bit transmitted, t = L / R
RTT
first packet bit arrives
last packet bit arrives, send ACK
ACK arrives, send next packet, t = RTT + L / R

$$U_{\text{sender}} = \frac{L / R}{RTT + L / R} = \frac{.008}{30.008} = 0.00027$$

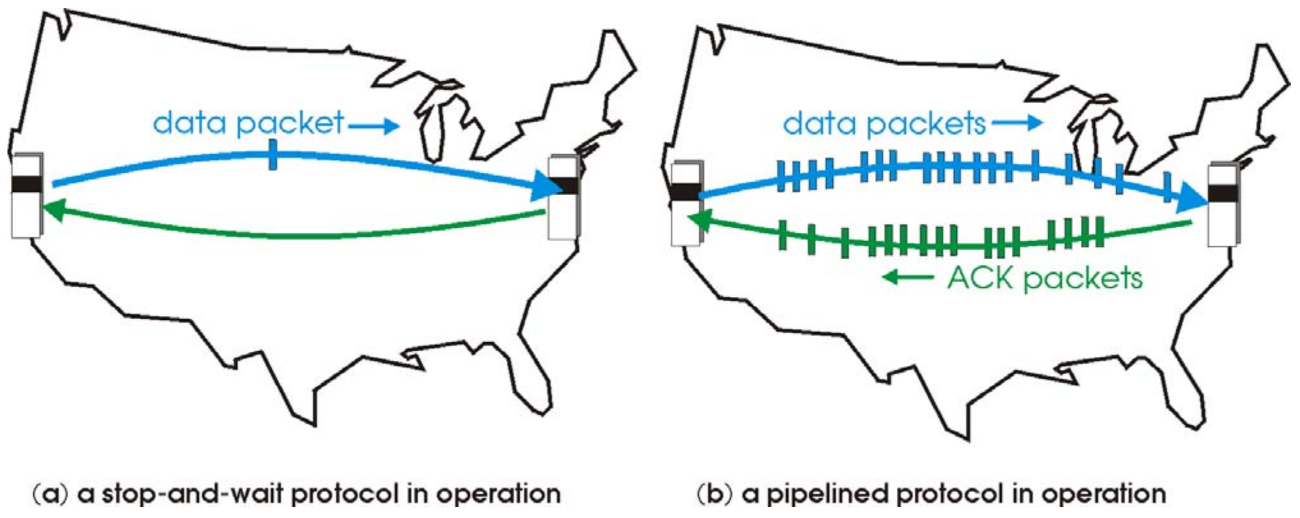
Implicit assumption so far:

Propagation delay of the medium is negligible or its bandwidth (transmission rate) is very low

If this assumption is false ---> exploitation of the bandwidth may be disastrous ---> requiring a sender to wait for an ack for each single frame before sending the next frame must be relaxed

Pipelined protocols

Pipelining: sender allows multiple, “in-transit”, yet-to-be-acknowledged frames, the sender is allowed to transmit up to *N* frames before blocking, instead of just 1.



(a) a stop-and-wait protocol in operation (b) a pipelined protocol in operation

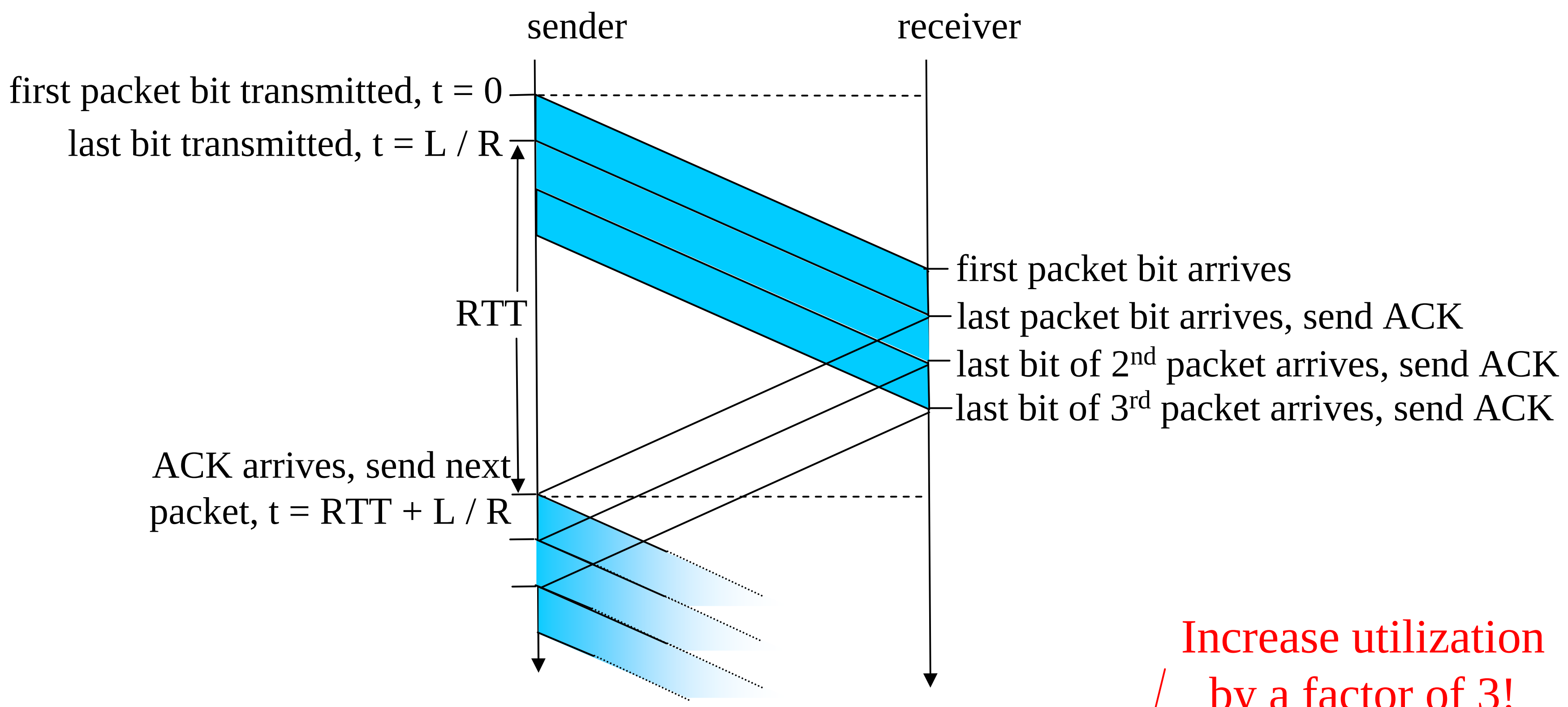
Consequences:

- range of sequence numbers must be increased
- buffering at sender

What exactly happens if a frame is lost or damaged in the middle of a long stream of transmitted frames?

Two basic approaches : *go-Back-N, selective repeat*

Pipelining: increased utilization


sender
receiver
first packet bit transmitted, t = 0
last bit transmitted, t = L / R
RTT
first packet bit arrives
last packet bit arrives, send ACK
last bit of 2nd packet arrives, send ACK
last bit of 3rd packet arrives, send ACK
ACK arrives, send next packet, t = RTT + L / R

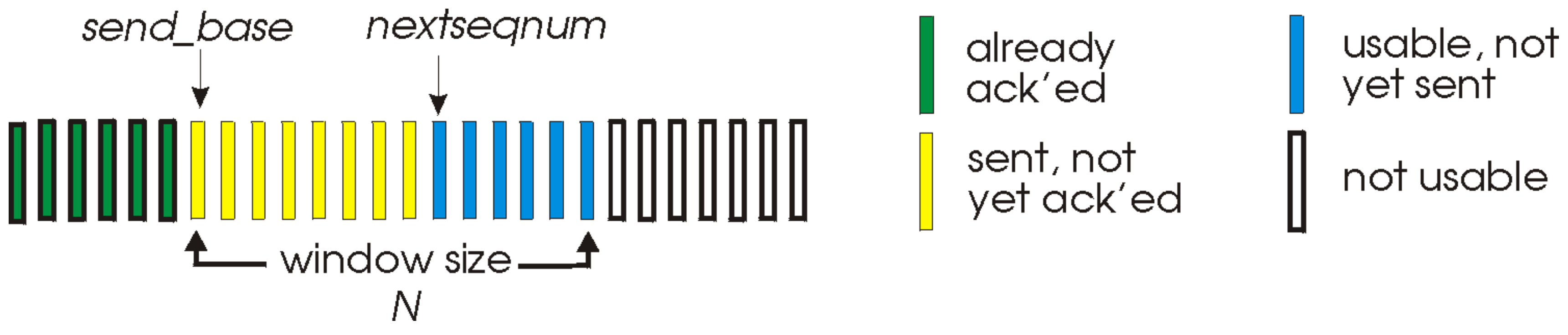
Increase utilization by a factor of 3!

$$U_{sender} = \frac{3 * L / R}{RTT + L / R} = \frac{.024}{30.008} = 0.0008$$

Go-Back-N

Sender:

- “window” of up to $N = 2^k$ consecutive unack’ed frames allowed
- k-bit seq # in frame header



- timer for each in-transit frame
- *timeout(n):* retransmit frame and all higher seq # frames in window already sent

Receiver:

- ACK(n): ACKs all frames up to, including seq # n - “cumulative ACK”
- All frames arriving after an erroneous one are simply discarded, i.e the receiving entity refuses to accept any frame except the next one to be delivered to the network layer

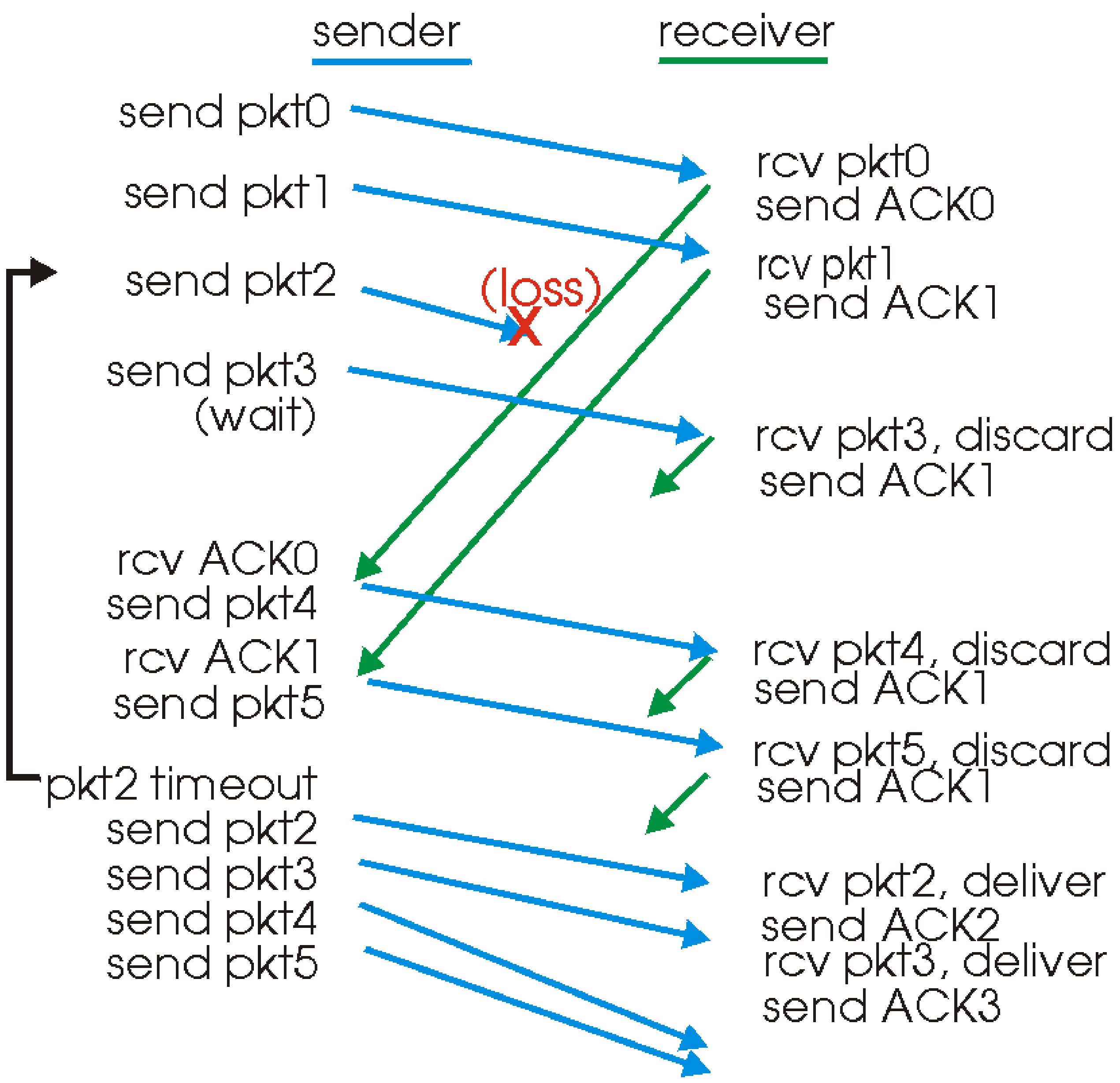
  ---> eventually, the sender will time out and retransmit all unacknowledged frames in order starting with the erroneous one

This strategy corresponds to a send window of size *N* and a receive window of size *1*.

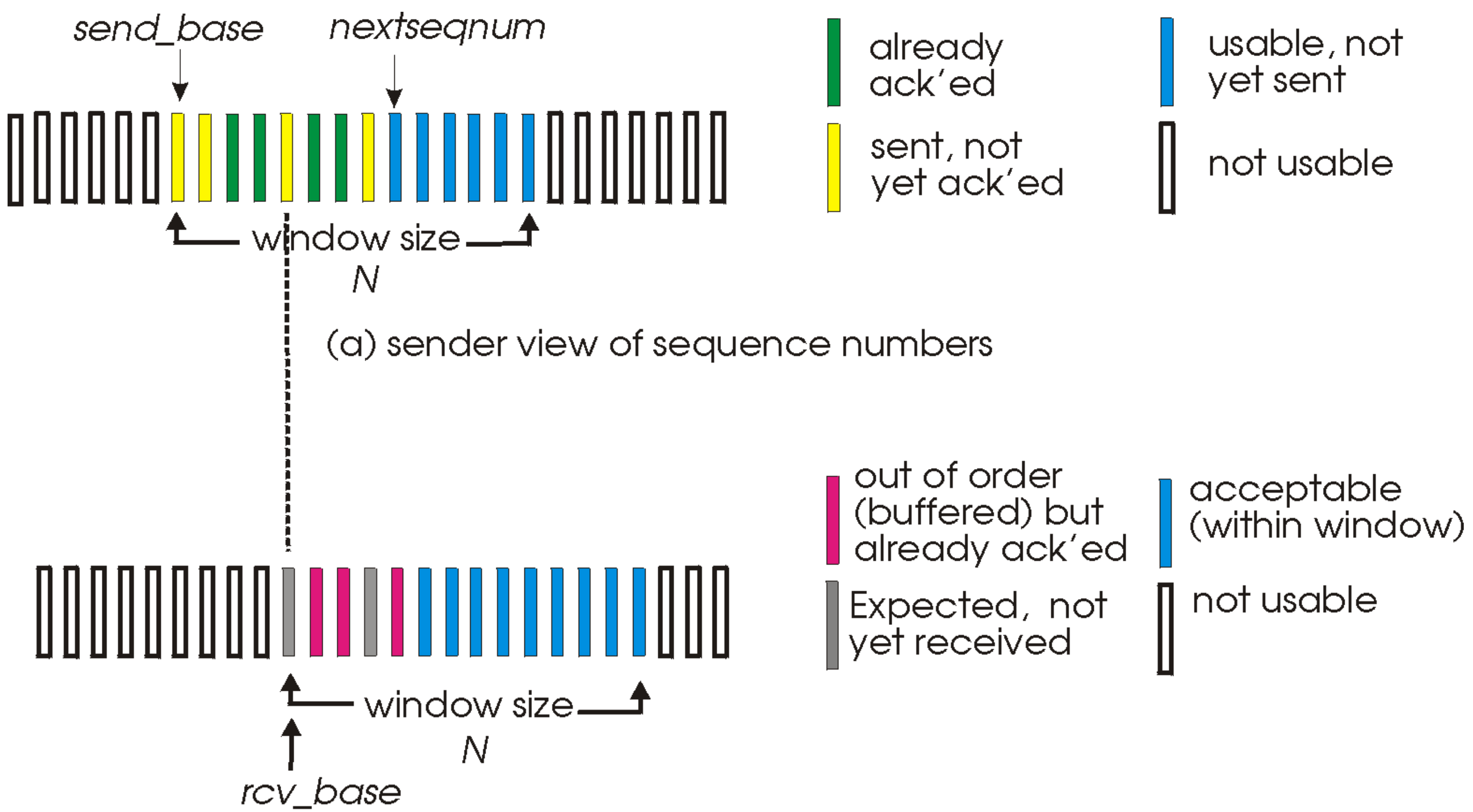
Main advantage: No additional overhead for the receiver

Main drawback: It can waste a lot of bandwidth if the error rate is high

Go-Back-N (example)

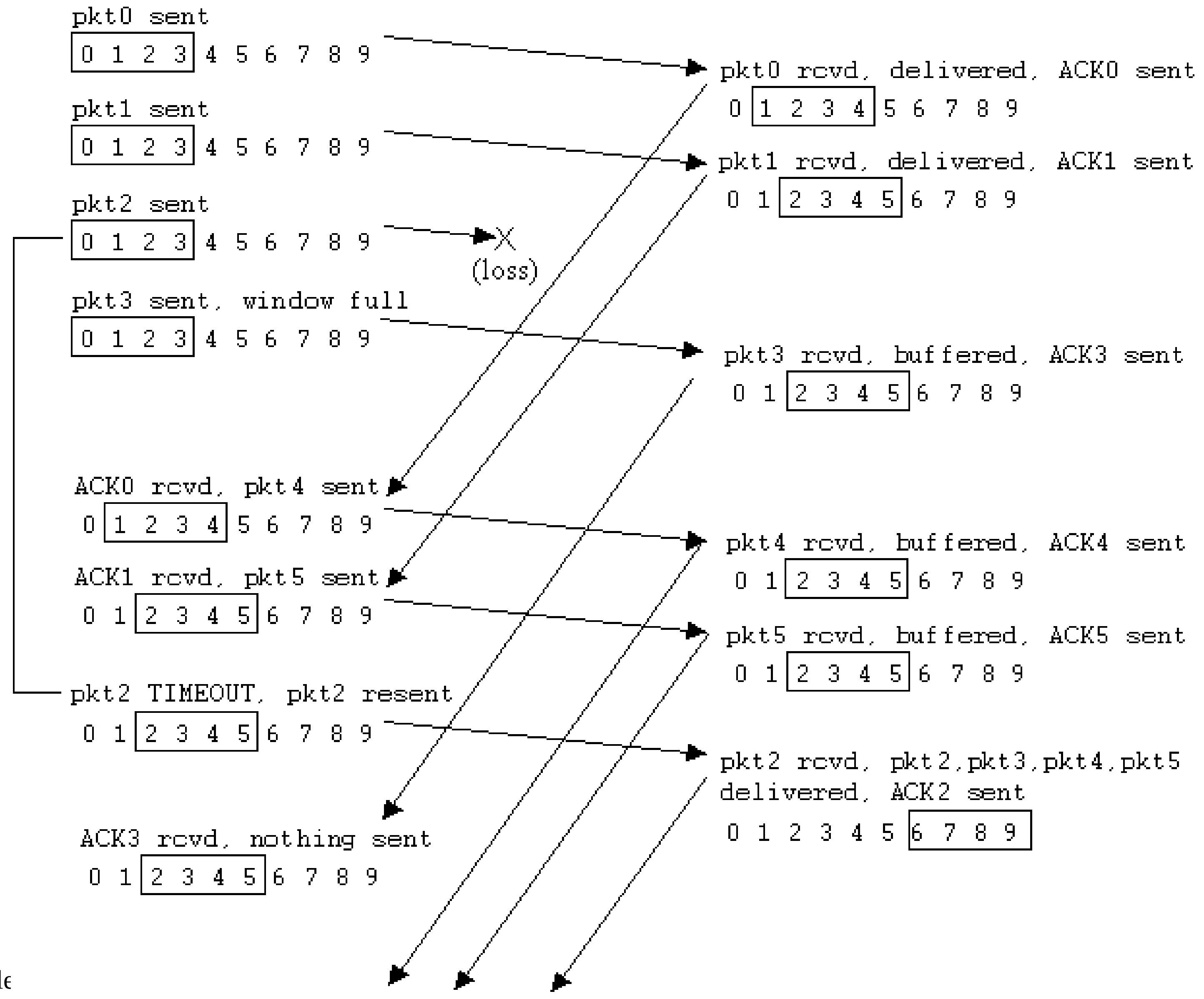


Selective repeat: send and receive windows


send_base
nextseqnum
already ack'ed
usable, not yet sent
sent, not yet ack'ed
not usable
window size N
(a) sender view of sequence numbers
out of order (buffered) but already ack'ed
acceptable (within window)
Expected, not yet received
not usable
window size N
rcv_base

(b) receiver view of sequence numbers

Selective repeat in action (Example)



Selective Repeat

- receiver *individually* acknowledges all correctly received frames, i.e. all correct frames arriving after an erroneous one are accepted by the receiver as long as they fit into the receiver buffer

  ---> must buffer frames, as needed, for eventual in-order delivery to upper layer
- sender resends frames for which ACK not received
  - sender must set a timer for each unACKed frame
- send window
  - *N* consecutive seq #'s
  - again limits seq #s of sent unACKed frames
- receive window also of size *N*
- Main drawback: It can require large amounts of data link layer buffer space

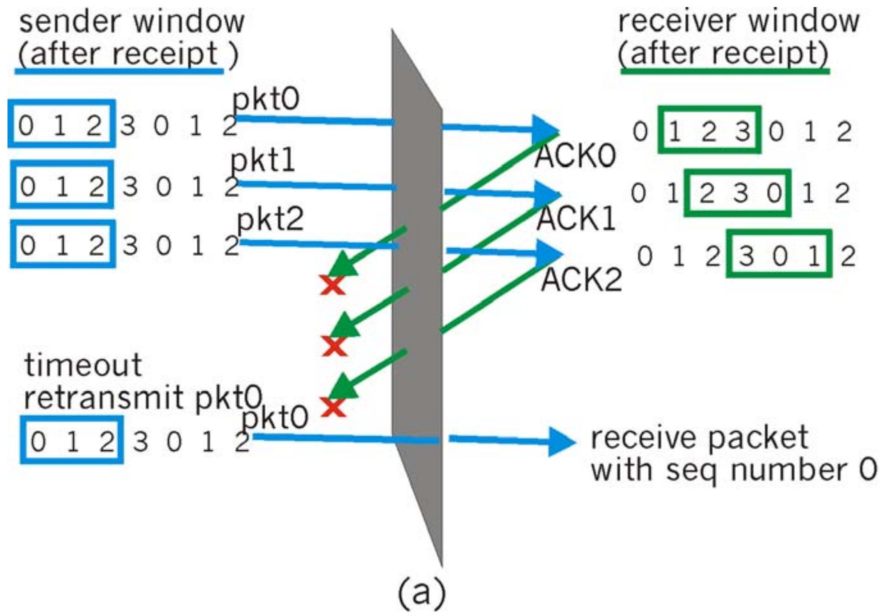
Selective repeat: dilemma

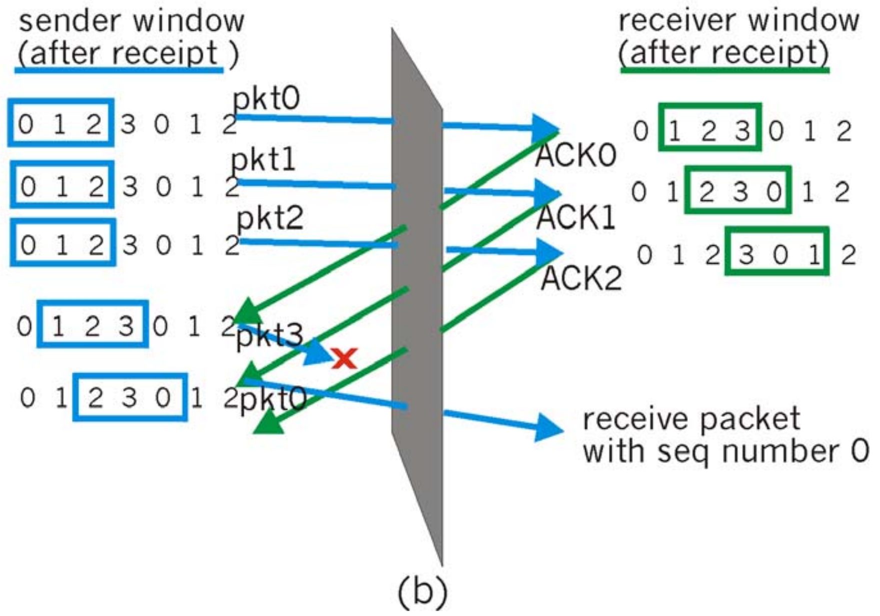
Example:

- seq #'s: 0, 1, 2, 3
- window size=3

- receiver sees no difference in two scenarios!
- incorrectly passes duplicate data as new in (a)

Q: what relationship between seq # size and window size?


sender window (after receipt)
receiver window (after receipt)
0 1 2 3 0 1 2
pkt0
pkt1
pkt2
ACK0
ACK1
ACK2
0 1 2 3 0 1 2
timeout retransmit pkt0
pkt0
receive packet with seq number 0
(a)


sender window (after receipt)
receiver window (after receipt)
0 1 2 3 0 1 2
pkt0
pkt1
pkt2
ACK0
ACK1
ACK2
pkt3
pkt0
receive packet with seq number 0
(b)

Data Link Layer(18)

Pipelining implies multiple outstanding frames.

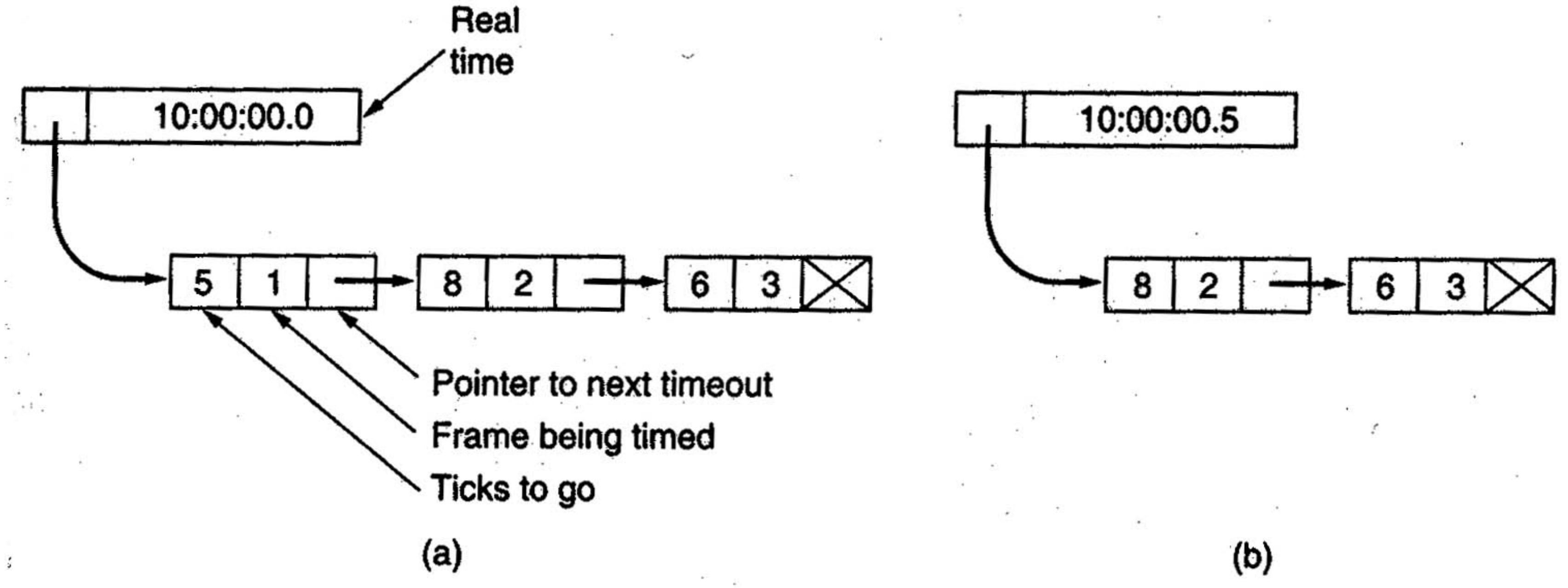
---> Each frame times out independent of all the other ones

---> It logically needs multiple timers

Simulation of multiple timers in software using a single hardware clock

The pending timeouts form a linked list

Example:



Data Link Layer(15)

Standard Internet protocols for the Data Link Layer (point-to-point)

Typical application example: A home PC acting as an Internet host

The Point-to-Point Protocol (PPP):

PPP basically provides three things:

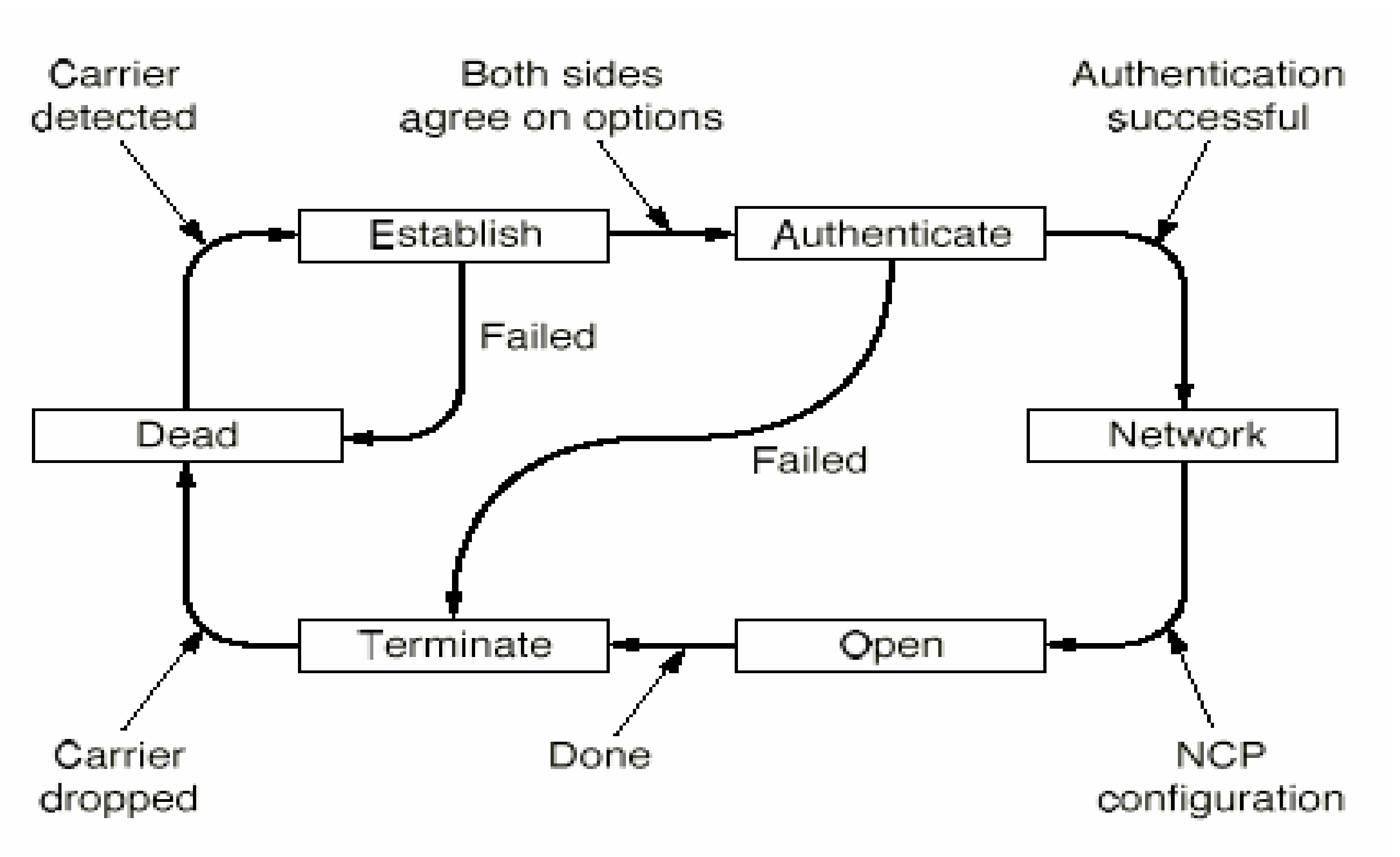
1. A framing method that unambiguously delineates the end of one frame and the start of the next one. The frame format also handles error detection.

2. A link control protocol for bringing lines up, testing them, negotiating options, and bringing them down again gracefully when they are no longer needed. This protocol is called **LCP** (**Link Control Protocol**).

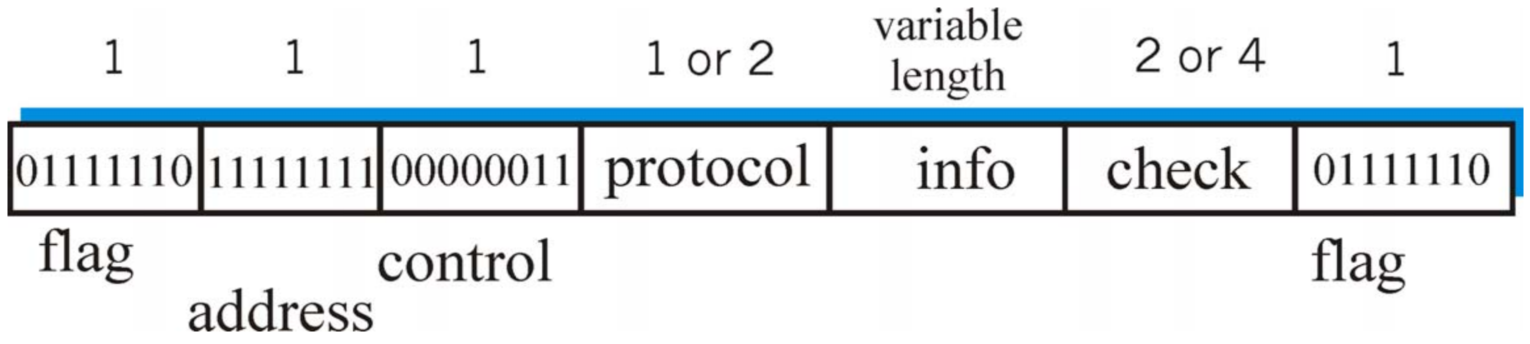
3. A way to negotiate network-layer options in a way that is independent of the network layer protocol to be used. The method chosen is to have a different **NCP** (**Network Control Protocol**) for each network layer supported.

Data Link Layer(16)

A simplified phase diagram for bringing a line up and down:



PPP Data Frame



- Flag: delimiter (framing)
- Address: does nothing (only one option)
- Control: does nothing; in the future possible multiple control fields
- Protocol: upper layer protocol to which frame delivered (eg, PPP-LCP, IP, AppleTalk, etc)
- info: upper layer data being carried (payload)
- check: cyclic redundancy check for error detection