Automatic Repeat Request (ARQ)

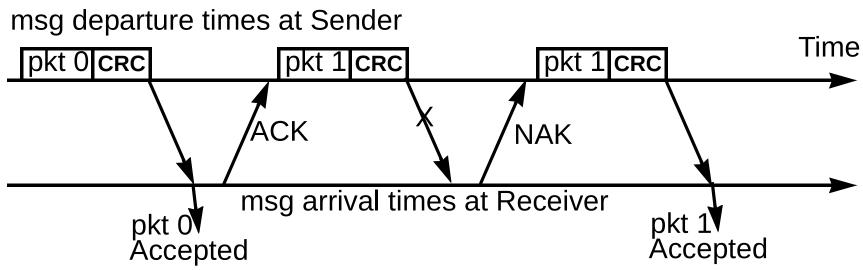
When the receiver detects errors in a frame, how does it request the transmitter to resend the corresponding packet?

The problem is that the feedback channel is error prone also!

The simplest strategy is stop and wait:

- **The sender sends a frame and waits fro an ACK or NAK; then sends new packet or resends the old packet.**

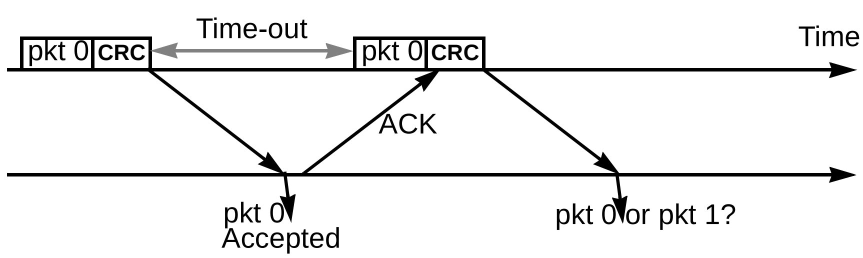
Pure Stop and Wait Protocol



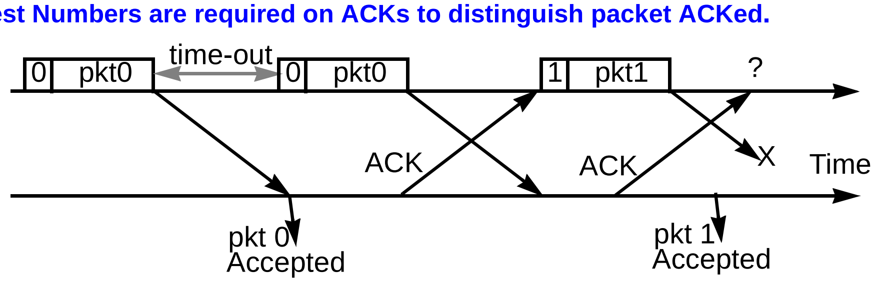
Note that the receiver does not know the content of the packet received is clean until it receives and verifies the CRC.

Sequence Number & Request Number

The use of time-outs for lost packet requires sequence numbers to distinguish the retransmit packet and the next packet.



Request Numbers are required on ACKs to distinguish packet ACKed.



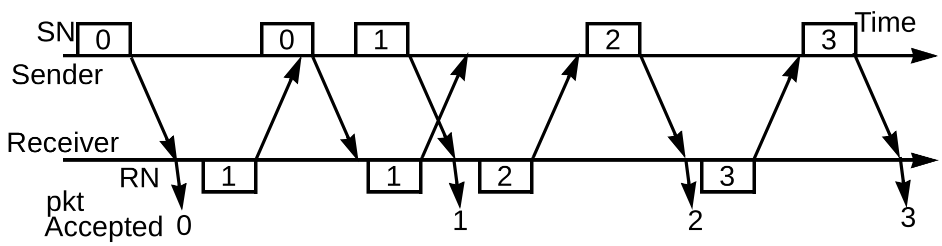
Request Number

Instead of sending ACK or NAK, the receiver sends the number of the packet currently awaited.

Sequence numbers and request numbers can be sent module 2. What is the name of this protocol?

This works correctly for all combinations of delay and time-outs assuming that

1) Frames travel in order (FCFS) on links
2) The CRC never fails to detect errors
3) The system is correctly initialized.



Go Back n ARQ & Selective Repeat ARQ

Desirable to send data while awaiting an ack.

The usual approach for this is called go back n ARQ.

Two alternate approaches:

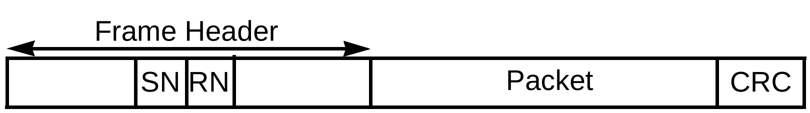
1) Selective repeat ARQ
2) ARPANET (Multiplex stop and wait schemes)

Goback n (Sliding Window) ARQ

Standard scheme used by HDLC, SDLC, ADCCP, X25.

Packets are numbered in order of arrival (SN); SN is sent in frame header (as in stop and wait).

Receiver sends "request number" RN back to transmitter; says that receiver wants packet RN next (i.e., RN is the awaited number). RN is usually "piggybacked" on return traffic.



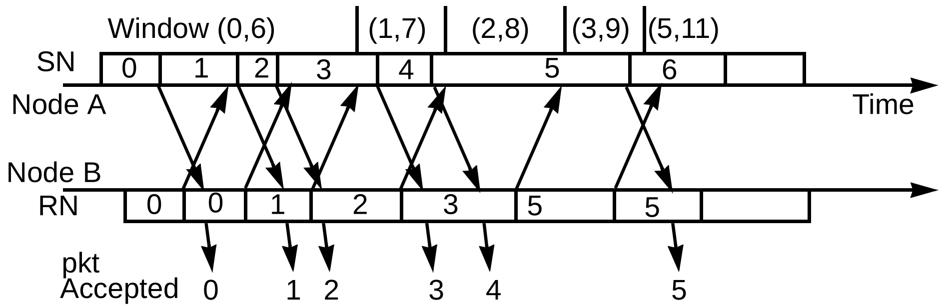
Goback n (Sliding Window) ARQ

The transmitter has a "window" of n packets that can be sent without acknowledgments.

This window ranges from the last value of RN obtained from the receiver (denoted SN_{min}) to SN_{min}+n–1.

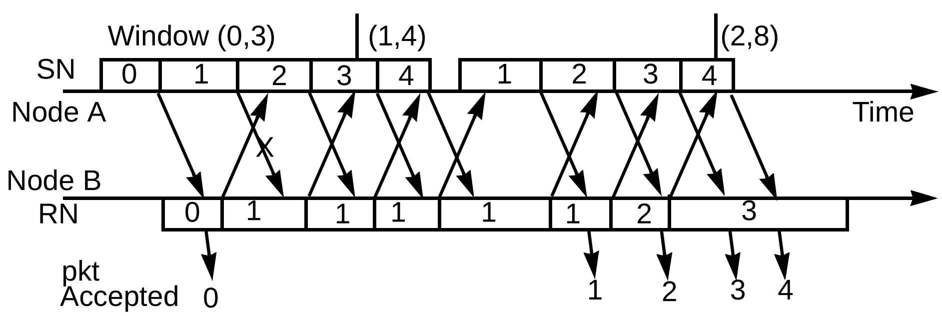
When the transmitter reaches the end of its window, or times out, it goes back and retransmits packets starting from SN_{min}.

Example of Goback 7 ARQ



Note that packet RN–1 must be accepted at Node B before a frame containing request RN can start transmission at Node B.

Retransmission Due to Errors for Goback 4 ARQ



Module m in Goback n systems

SN and RN are actually sent module m in Goback n systems.

The constraint is that n < m.

The standard choice is m=8; three bits for SN, three bits for RN.

Optional standard is m=128 (for satellite channels and other channels where round trip delay is large relative to packet transmission time).

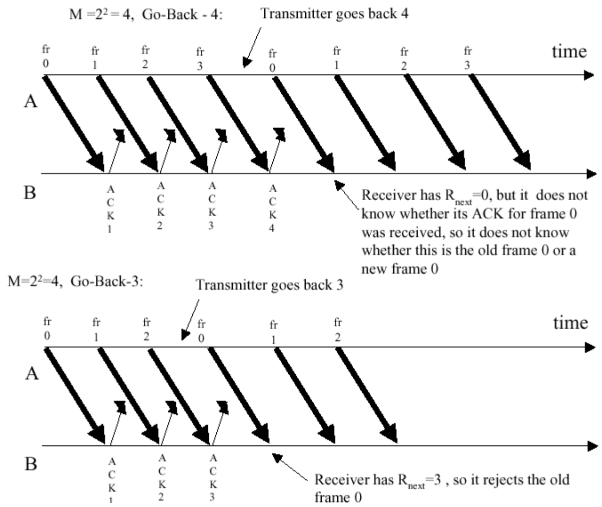
Goback n is guaranteed to work correctly if

1) System is correctly initialized.
2) No failures in detecting errors.
3) Frame travel in FCFS order.
4) Positive probability of correct reception.
5) Transmitter occasionally resends SNmin
6) Receiver occasionally sends RN.

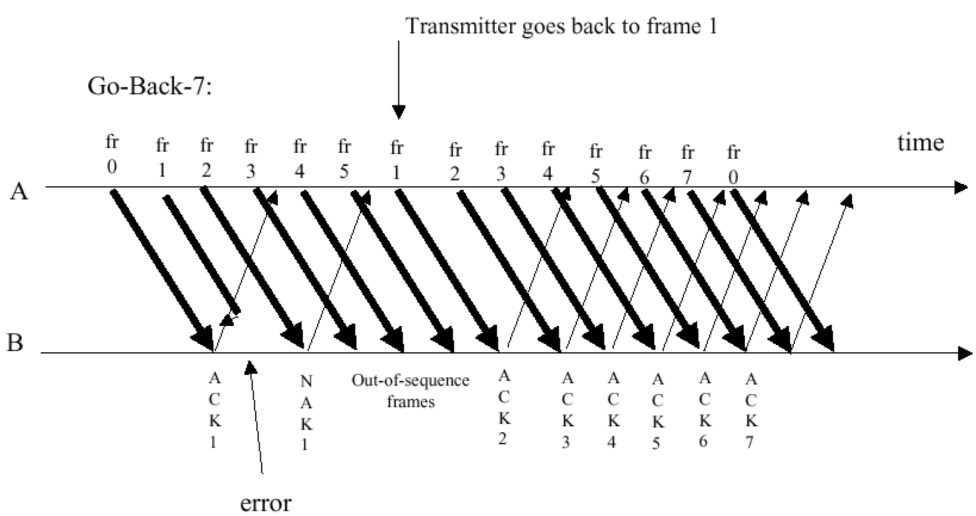
Go Back n < 2^m

- where m is the # of bits used in sequence # field.
- If we use n = 2m, we will accept retransmitted frames.

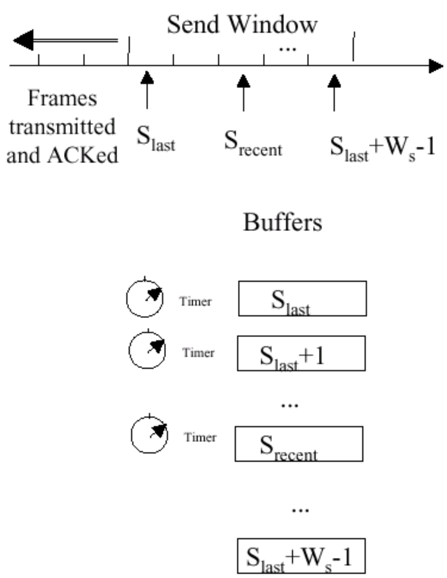
- For the following go-back-3 protocol execution, what ack msg should be sent back?

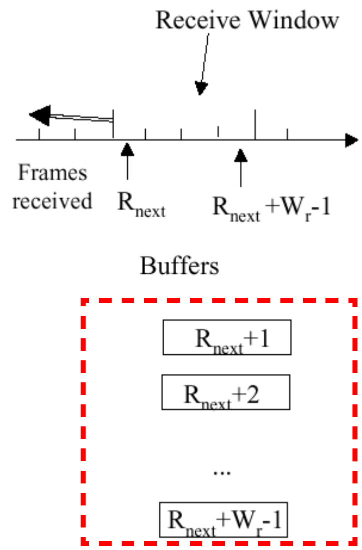


Goback N with NAK



Selective Repeat ARQ





need more buffer on receiver

can receive pkts out of order

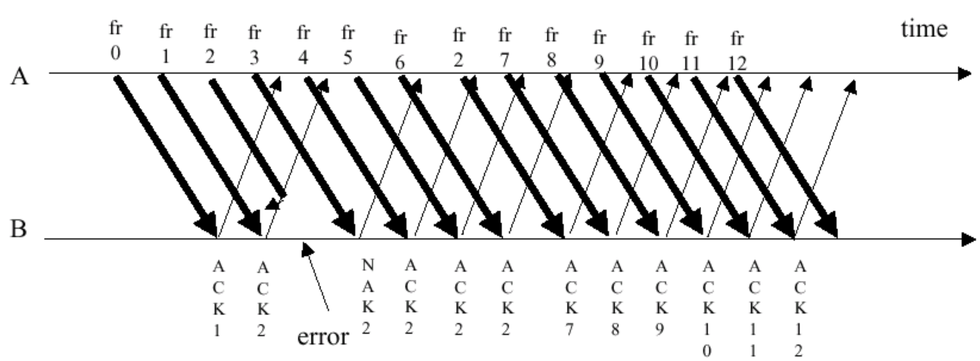
Select Repeat ARQ

Efficiency of Goback n can be increased by accepting packets out of order.

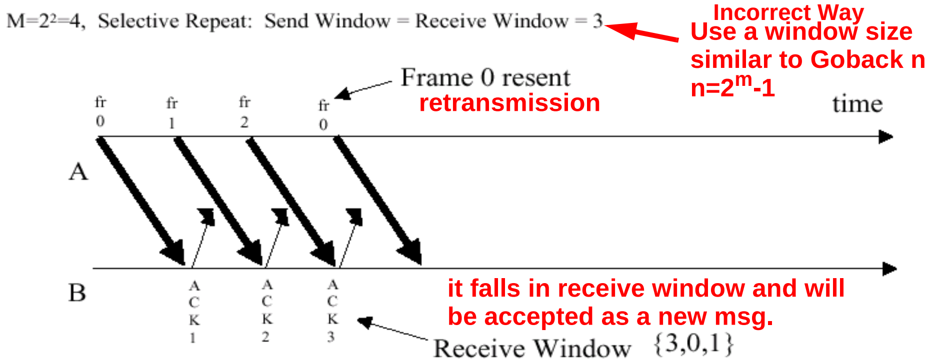
An explicit NAK (selective reject) can request retransmission of just one packet.

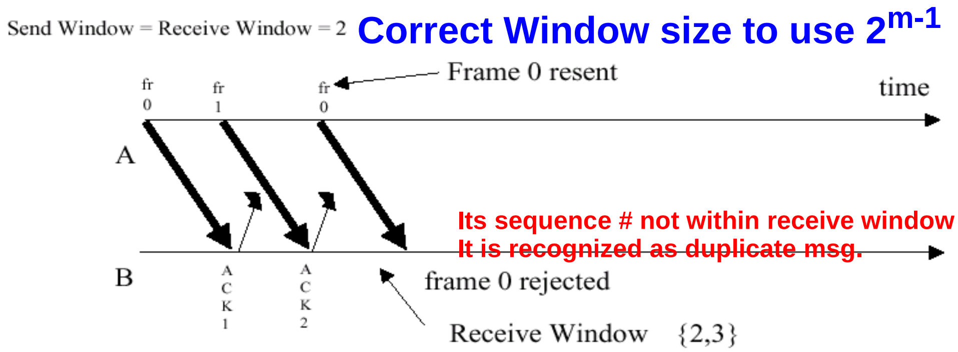
Typical frame error rates are less than 0.001; selective repeat does not gain much in efficiency unless there are very many frames in a round trip delay.

For a window size of n, the modulus must be at least 2n. or For m bit sequence #, us window size of 2^{m-1}.

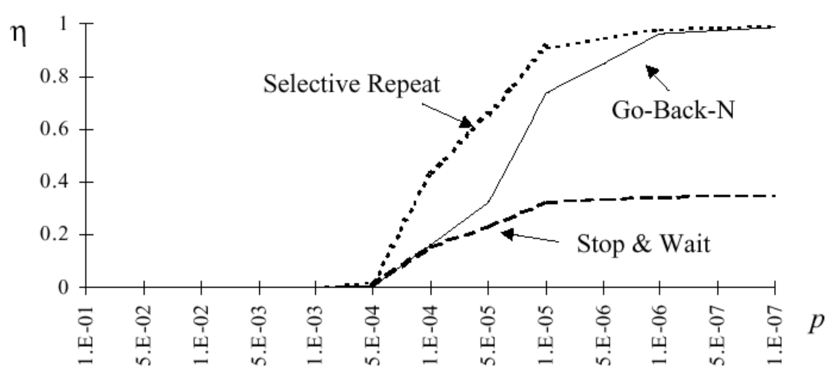


2^{m-1} window size for Selective Repeat ARQ

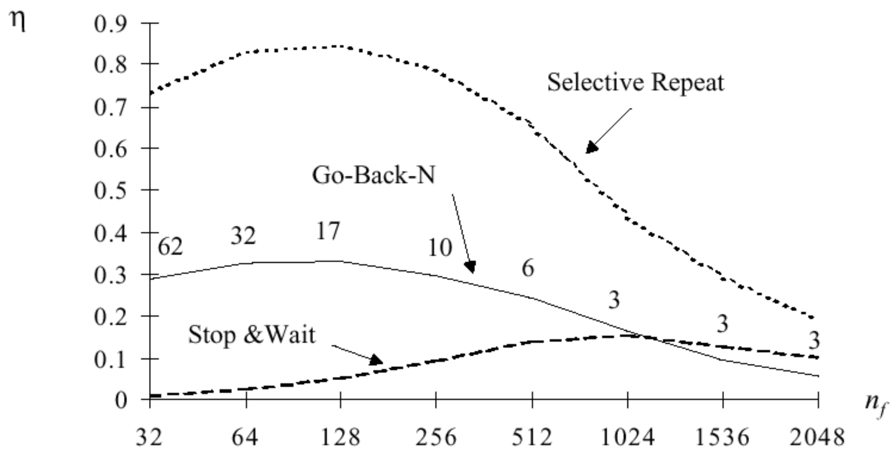




Efficiency vs. Error Rate



Efficiency vs. Optimal Frame Size



Frame Synchronization

Three approaches to find frame and idle fill boundaries:

1) Character-oriented protocols

2) Bit-oriented protocol (use flags)

3) Length counts (characters or bits).

1. Character-oriented Protocols:

In IBM BSC (Binary Synchronous Comm.), a frame begins at the end of a sequence of two or more SYN characters in the incoming signal.

Normal Mode:

SYN SYN [control and data characters] BCC BCC

8 8

↑ terminated by ITB, ETB, or ETX character

SYN SYN [Control characters]

Note: 1. SYN is a ASCII character with 00010110 pattern.

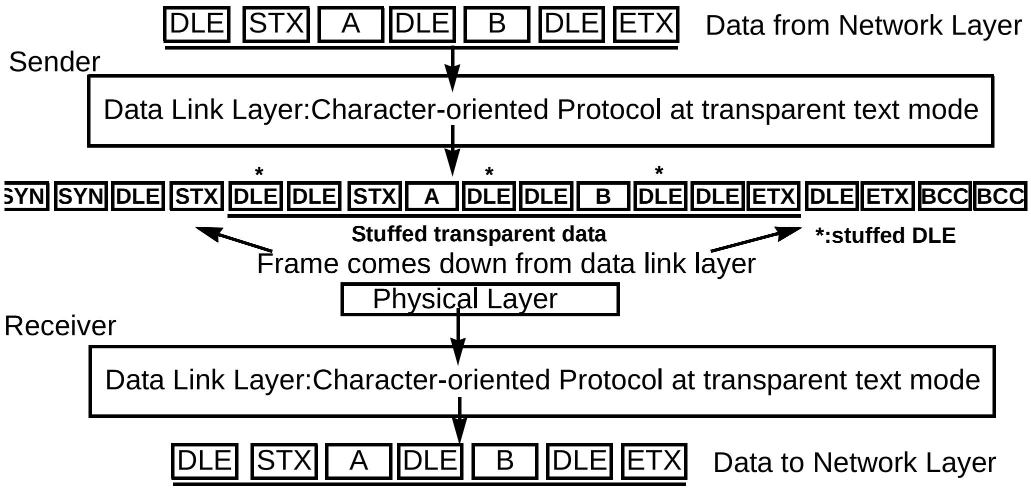
2. BCC BCC are 16 parity bits for error detection.

Transparent Text Mode:

SYN SYN DLE STX [transparent data] DLE ETX BCC BCC

The transparent data may contain DLE control character → character stuffing.

Character Stuffing



Drawbacks of character-oriented framing:

- Character code dependent
- Errors in control characters are difficult to handle.

Exercise on Character Stuffing

Using BSC protocol operating at text transparent mode, given the data DLE, DLE, A, DLE from the network layer, what will be the frame sent out?

Ans: The frame sent out is as follows (in transparent text mode):

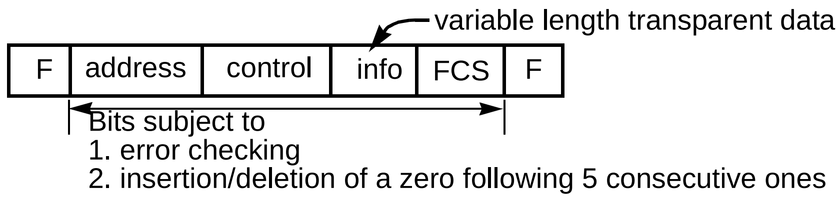
SYN SYN DLE STX DLE* DLE DLE* DLE A DLE* DLE DLE ETX BCC BCC

***:stuffed DLE**

Bit-oriented Protocol

HDLC, SDLC, ADCCP are bit-oriented protocols.

All frames look like



Flag F is the unique sequence 01111110

Bit Stuffing

A 0 is stuffed after each consecutive five 1's in the original frame.

A flag, 01111110, without stuffing, is sent at the end of the frame.

Destuffing

If 0 is preceded by 011111 in received bit stream, remove it.

If 0 is preceded by 0111111, it is the final bit of the flag.

Example: Bits to be removed are underlined below

100111110110001111011111000111110

Flag

Why is it necessary to stuff a 0 in 0111110? If not, then

0111110111→ 0111110111

011111111→ 0111110111

The overhead per frame in the flag scheme is one byte for the flag plus 1/64 times the expected frame length.

For short frame lengths, this is essentially optimally efficient.

Length Counts Framing

Some DLC protocols use a header field to give the length of the frame (in bits, or bytes). This conveys the same information as the flag scheme and uses essentially the same overhead.

Example: DECNET uses length counts approach.

A disadvantage is that resynchronization is needed after an error in the length count.

Framing Errors

An error in a flag, or a flag created by an error causes a frame to disappear or an extra frame to appear.

An error in a length count field causes the frame to be terminated at the wrong point (and makes it tricky to find the beginning of the next frame.

An error in DLE, STX, or ETX causes the same problems.

When a framing error is made, the receiver looks in the wrong place for CRC. With a 16 bit CRC, the probability of false acceptance is about 2^{-16}.

DECNET partially avoid the problem by putting CRC on packet header; inefficient.

Using a longer CRC is probably the best current solution to this problem.

DLC Standards

HDLC, ADCCP, LAPB (X.25 layer 2), and SDLC are almost the same except that LAPB and SDLC are subsets of HDLC and ADCCP (which are virtually identical).

These classes of protocols all use flags for flaming and goback n for error detection and retransmission.

8	8	8		16	8
Flag	Address	Control	Packet	CRC	Flag

The address field allow use on multipoint lines.

Polling/Final Bit

0	SN		P/F	RN	Information
1	0	Type	P/F	RN	Supervisory
1	1	Type	P/F	Type	Unnumbered

Control Byte Format

Information frames use SN and RN for goback n (mod 8)

Supervisory frames send ACKs (RN) without data

Unnumbered frames are for initiation, termination, etc.

Control Frames

There are four types of supervisory frames that send ack information.

receive ready (normal ACK)

receive not ready (ACks but requests no further data)

reject (to explicitly send a NAK)

selective reject (for primitive selective repeat)

The unnumbered frames are used to initiate and terminate the link protocol and to send various special commands.

There are 3 modes of operations - asynchronous balanced (LAPB), normal response (SDLC), and asynchronous response (SDLC). The third is rarely used, the second is for master/slave relationships (and not at all normal), and the first is normal for data networks.

The unnumbered frames initiate operation in one of these modes. The error handling on these unnumbered frames is somewhat defective.

Point-to-point data link protocol for Internet 1. SLIP

SLIP—Serial Line IP (RFC1055)

- designed by Rick in 1984 to connect Sun workstations over dial up line.
- send raw IP packet with a flag byte (0xC0) at the end for framing.
- if flag byte pattern occurs in raw IP packet, send 0xDB, 0xDC instead (what kind of stuffing is this?)
- perform TCP/IP header compression (RFC1144)
  —omit duplicated header fields,
  —send incremental value for fields with different values.
- Problems:
  —no error detection or correction. (up to the higher layer)
  —only support IP.
  —must know other's IP in advance, can't do dynamic IP address assignment
  —no authentication (for leased line it is ok, for dial up line it is not).
  —not an approved Internet standard.

Point-to-point data link protocol for Internet: PPP

PPP—Point-to-Point Protocol (RFC1661, 1662, 1663)

- designed by IETF group.
- provide error detection (check sum at the end of frame)
- Use HDLC frame structure **with character stuffing**.
  —address field always 11111111 (all stations to accept the frame).
  —control field 00000011, unnumbered frame (RFC1663 extend to numbered frame, for reliable transmission, such as wireless.)
  —a new protocol field to indicate packet type (LCP, NCP, IP, IPX, AppleTalk)
  default payload length is 1500 bytes.
- use LCP (Link Control Protocol) to bring line up, test them, negotiate options (such as omit address and control fields, one or two byte in protocol field) and bring them down gracefully.
- support multiple protocols
- used with dial-up lines, SONET, bit-oriented HDLC lines.
- use Network Control Protocol (NCP) to negotiate IP addresses.
- permit authentication
- a clear choice for future dial-up lines and leased router-router lines.

PPP Phase Diagram