Chapter 7: Data Link Control

Data Link Control Protocols

- Need layer of logic above Physical to manage exchange of data over a link
  - frame synchronization
  - flow control
  - error control
  - addressing
  - control and data
  - link management

Background information

Begin(...

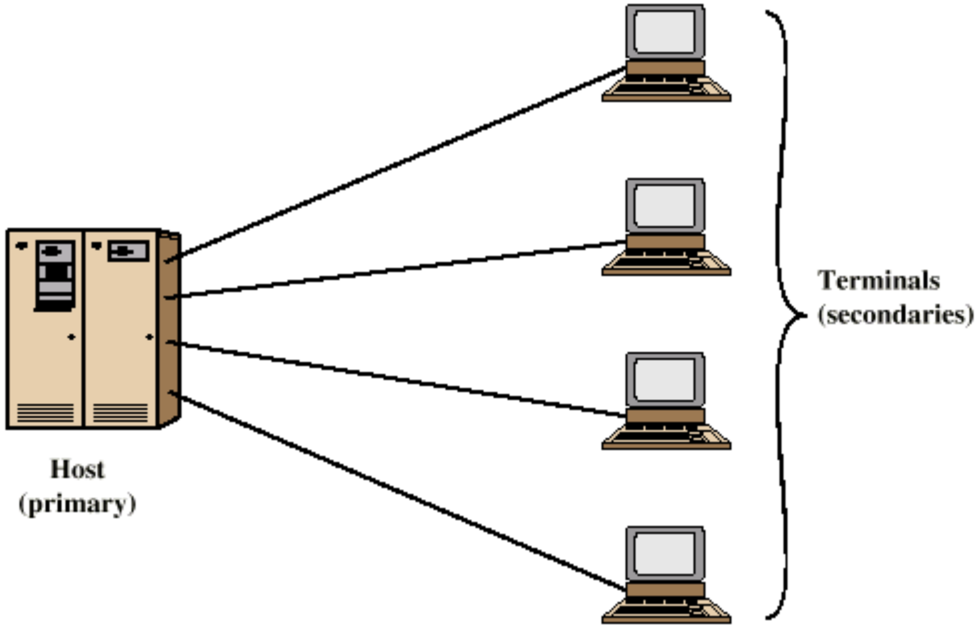
- —Speaking of Physical Layer:
- —let's consider the physical layer and the characteristics of interfaces

- —Let's just quickly go though this to the **...)END** slide

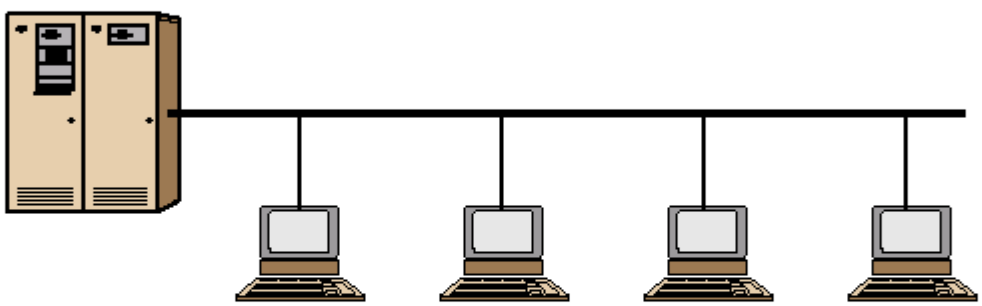
Line Configuration

- Topology
  - Physical arrangement of stations on medium
  - Point to point
  - Multi point
    - Computer and terminals, local area network
- Half duplex
  - Only one station may transmit at a time
  - Requires one data path
- Full duplex
  - Simultaneous transmission and reception between two stations
  - Requires two data paths (or echo canceling)

Traditional Configurations



(a) Point-to-point

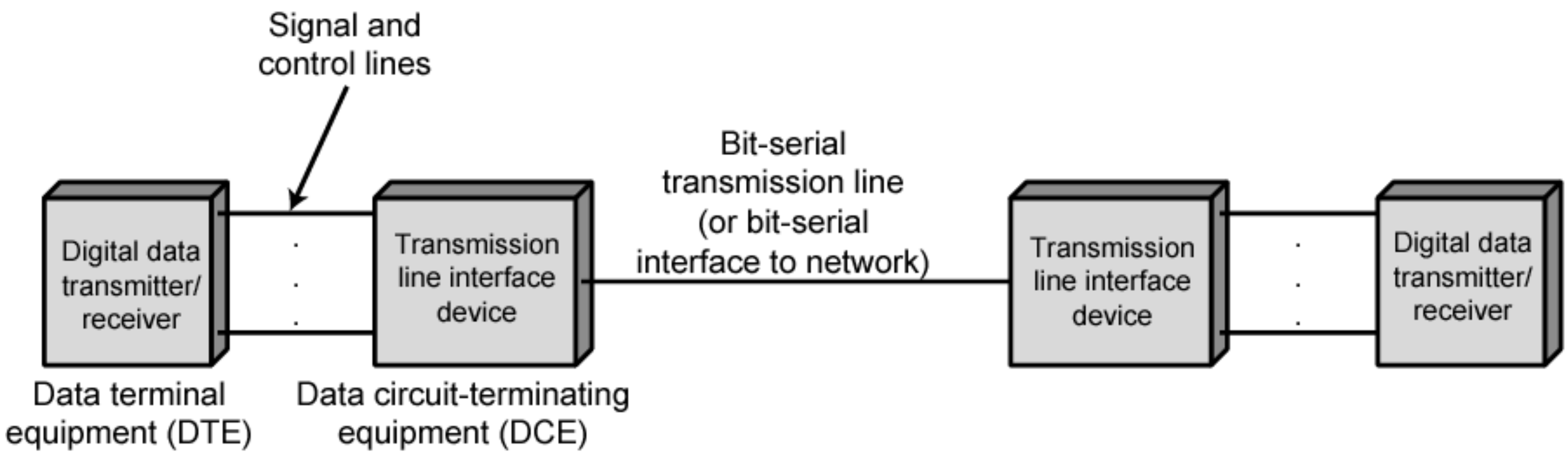


(b) Multipoint

Interfacing

- Data processing devices (or data terminal equipment, DTE) do not (usually) include data transmission facilities
- Need an interface called data circuit terminating equipment (DCE)
  - e.g. modem, NIC
- DCE transmits bits on medium
- DCE communicates data and control info with DTE
  - Done over interchange circuits
  - Clear interface standards required

Data Communications Interfacing



(a) Generic interface to transmission medium

(b) Typical configuration

Characteristics of Interface

- Mechanical
  - —Connection plugs
- Electrical
  - —Voltage, timing, encoding
- Functional
  - —Data, control, timing, grounding
- Procedural
  - —Sequence of events

V.24/EIA-232-F

- ITU-T v.24

ITU = Intl. Telecom. Union
ITU-T = ITU Telecom. Standardization Sector

- Only specifies functional and procedural
  - References other standards for electrical and mechanical
- EIA-232-F (USA) (first issued in 1962)
  - RS-232
  - Mechanical ISO 2110
  - Electrical v.28
  - Functional v.24
  - Procedural v.24

EIA = Electronic Industry Alliance
RS-232 first issued in 1962
V.24 issued in 1996
V.28 issued in 1993

Mechanical Specification

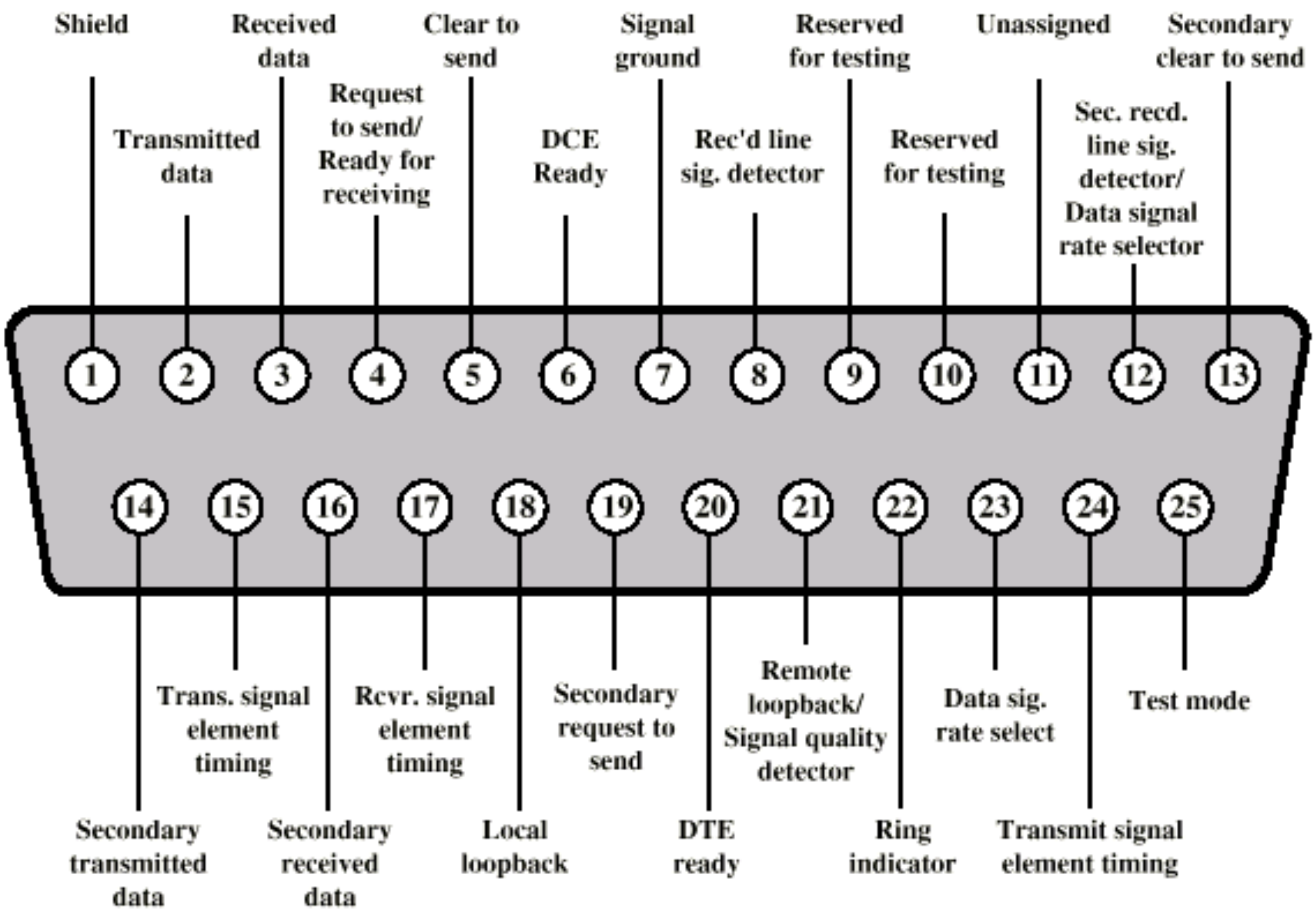


Figure 6.5 Pin Assignments for V.24/EIA-232 (DTE Connector Face)

Electrical Specification

- Digital signals
- Values interpreted as data or control, depending on circuit
- Less than -3V is binary 1, more than +3V is binary 0 (NRZ-L)
- For control,
  - less than -3V is off,
  - more than +3V is on
- Signal rate < 20kbps
- Distance <15m

Functional Specification

- Circuits grouped in categories
  - Data
  - Control
  - Timing
  - Ground
- One circuit in each direction
  - Full duplex
- Two secondary data circuits
  - Allow halt or flow control in half duplex operation
- DTE = data terminal equipment
- DCE = data circuit-terminal equipment

Functional Specification

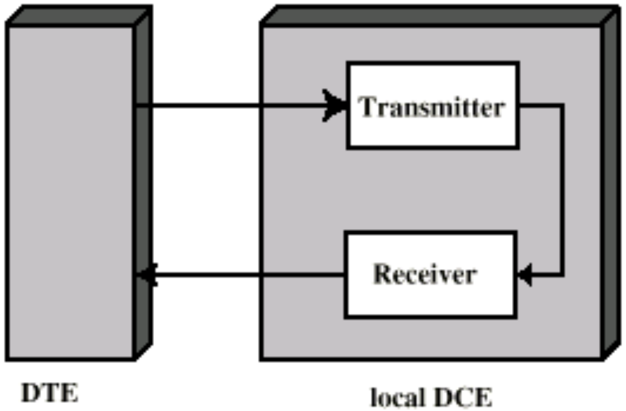
Table 6.1 V.24/EIA-232-F Interchange Circuits

V.24	EIA-232	Name	Direction to:	Function
		DATA SIGNALS		
103	BA	Transmitted Data	DCE	Transmitted by DTE
104	BB	Received Data	DTE	Received by DTE
118	SBA	Secondary Transmitted Data	DCE	Transmitted by DTE
119	SBB	Secondary Received Data	DTE	Received by DTE
		TIMING SIGNALS		
113	DA	Transmitter signal element timing	DCE	Clocking signal; transitions to ON and OFF occur at center of each signal element
114	DB	Transmitter signal element timing	DTE	Clocking signal; both 113 and 114 relate to signals on circuit 103
115	DD	Receiver signal element timing	DTE	Clocking signal for circuit 104
		GROUND		
102	AB	Signal ground/common return		Common ground reference for all circuits

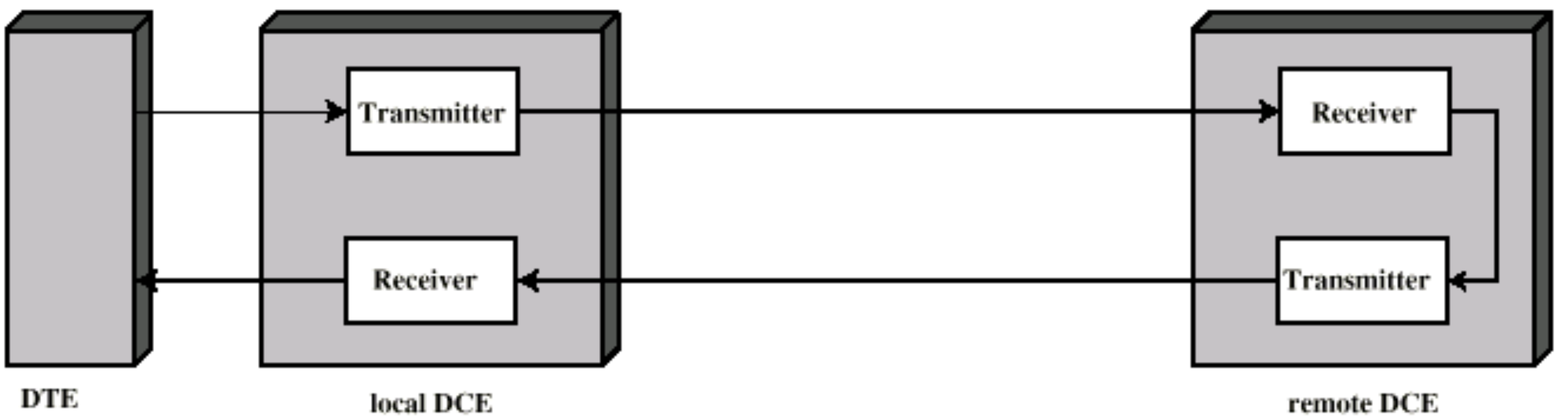
Functional Specification

CONTROL SIGNALS				
105	CA	Request to send	DCE	DTE wishes to transmit
106	CB	Clear to send	DTE	DCE is ready to receive; response to Request to send
107	CC	DCE ready	DTE	DCE is ready to operate
108.2	CD	DTE ready	DCE	DTE is ready to operate
125	CE	Ring indicator	DTE	DCE is receiving a ringing signal on the channel line
109	CF	Received line signal detector	DTE	DCE is receiving a signal within appropriate limits on the channel line
110	CG	Signal quality detector	DTE	Indicates whether there is a high probability of error in the data received
111	CH	Data signal rate selector	DCE	Selects one of two data rates
112	CI	Data signal rate selector	DTE	Selects one of two data rates
133	CJ	Ready for receiving	DCE	On/off flow control
120	SCA	Secondary request to send	DCE	DTE wishes to transmit on reverse channel
121	SCB	Secondary clear to send	DTE	DCE is ready to receive on reverse channel
122	SCF	Secondary received line signal detector	DTE	Same as 109, for reverse channel
140	RL	Remote loopback	DCE	Instructs remote DCE to loop back signals
141	LL	Local loopback	DCE	Instructs DCE to loop back signals
142	TM	Test mode	DTE	Local DCE is in a test condition

Local and Remote Loopback



(a) Local loopback Testing

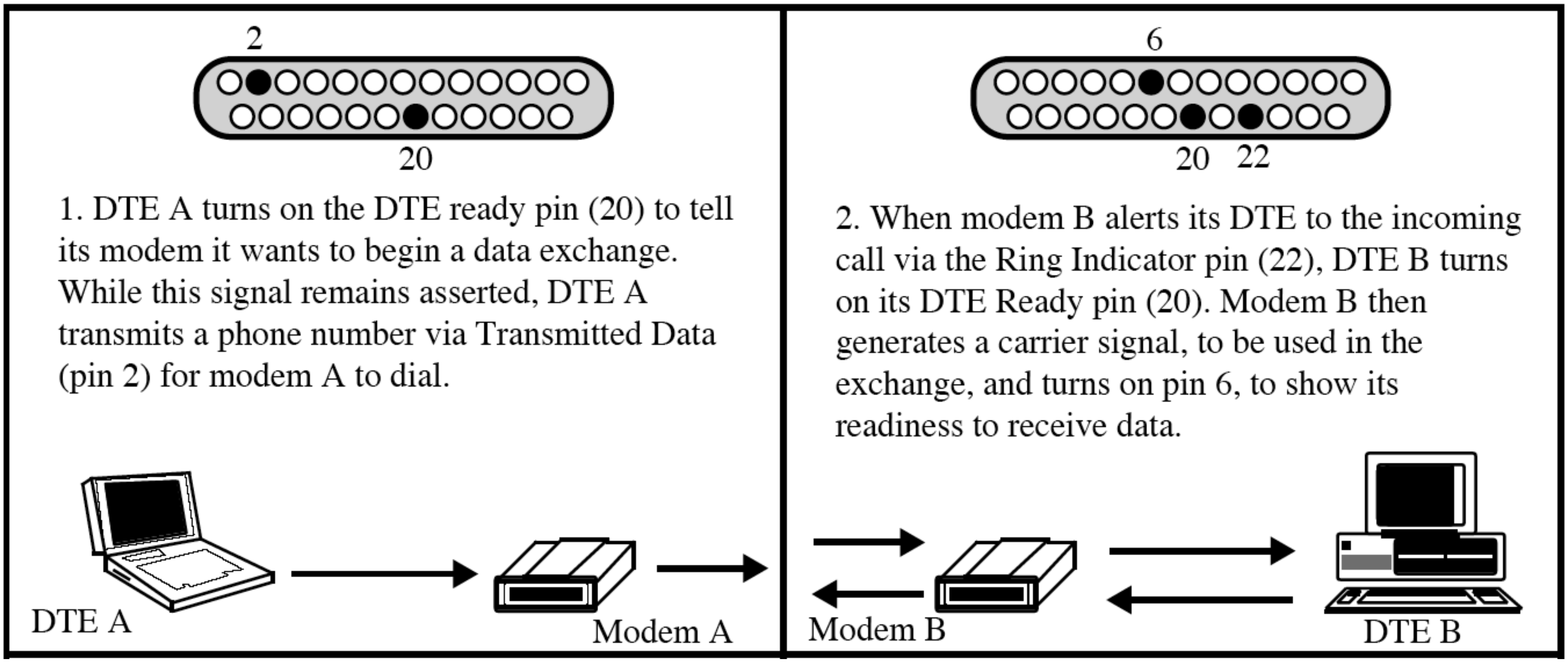


(b) Remote loopback Testing

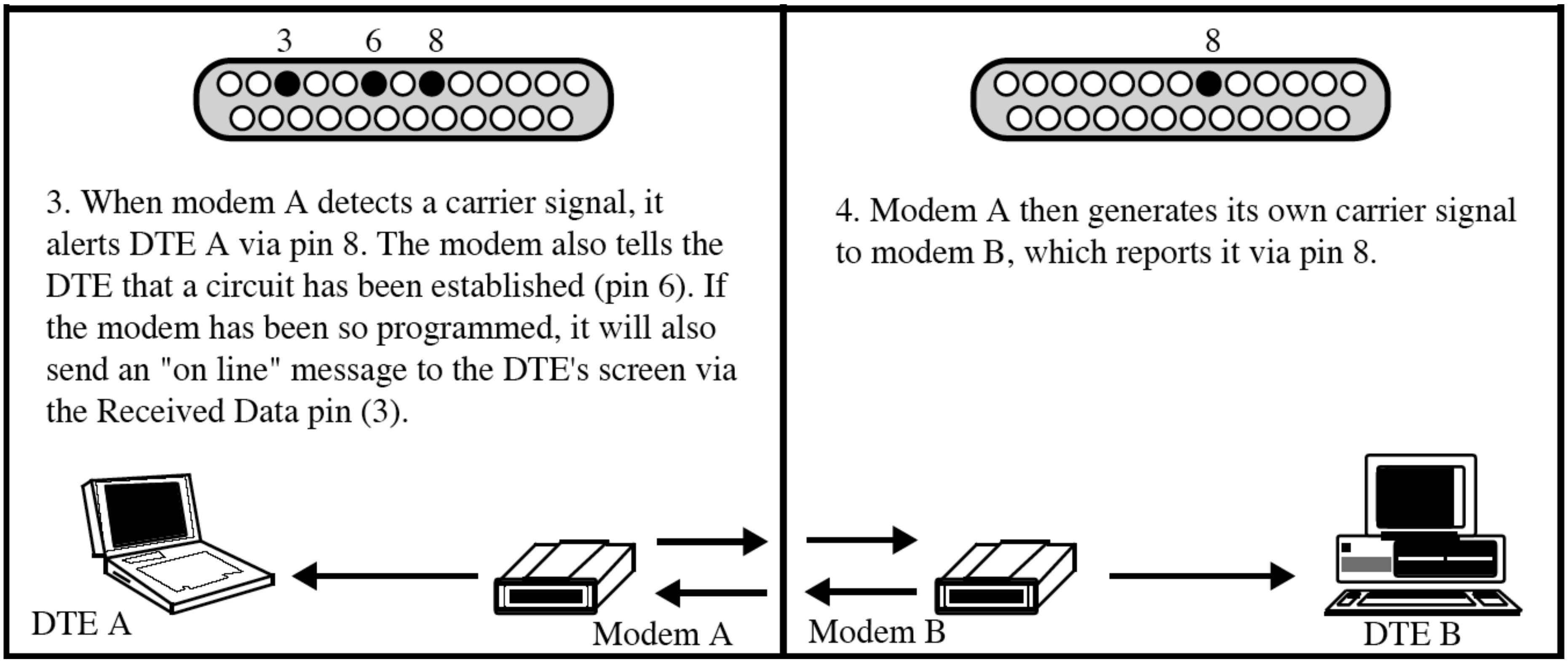
Procedural Specification

- Example: Asynchronous private line modem
- When turned on and ready, modem (DCE) asserts DCE ready
- When DTE ready to send data, it asserts Request to Send
  - Also inhibits receive mode in half duplex
- Modem responds when ready by asserting Clear to Send
- DTE sends data
- When data arrives, local modem asserts Receive Line Signal Detector and delivers data

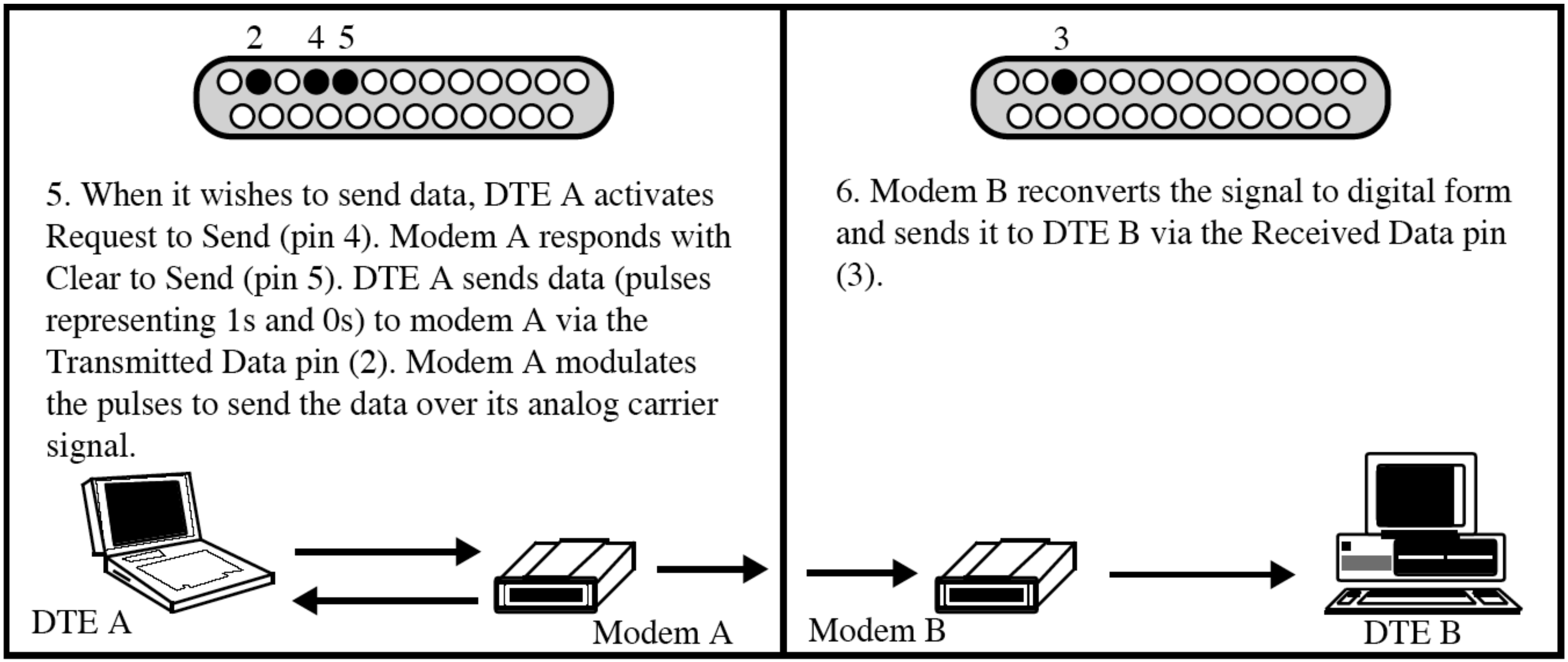
Dial Up Operation (1)



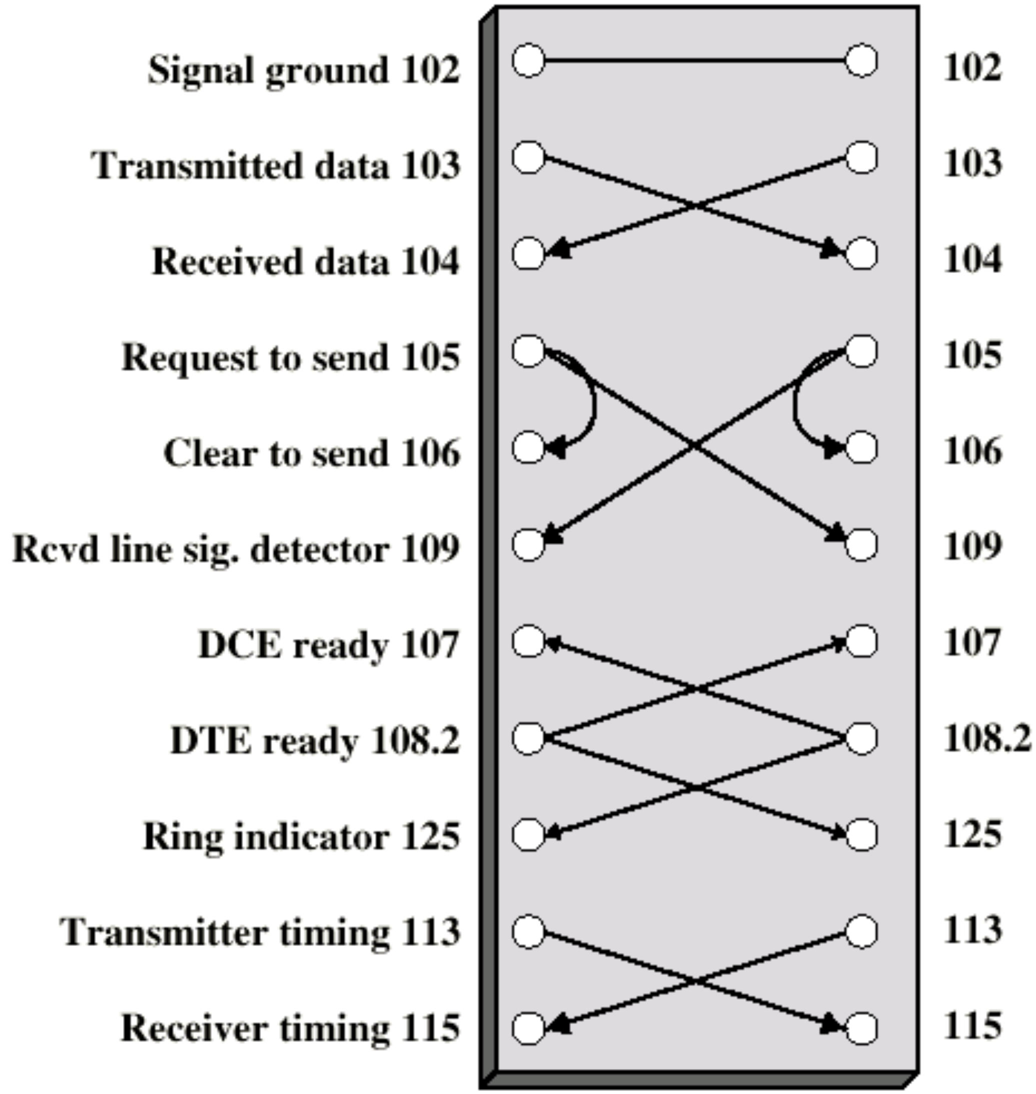
Dial Up Operation (2)



Dial Up Operation (3)

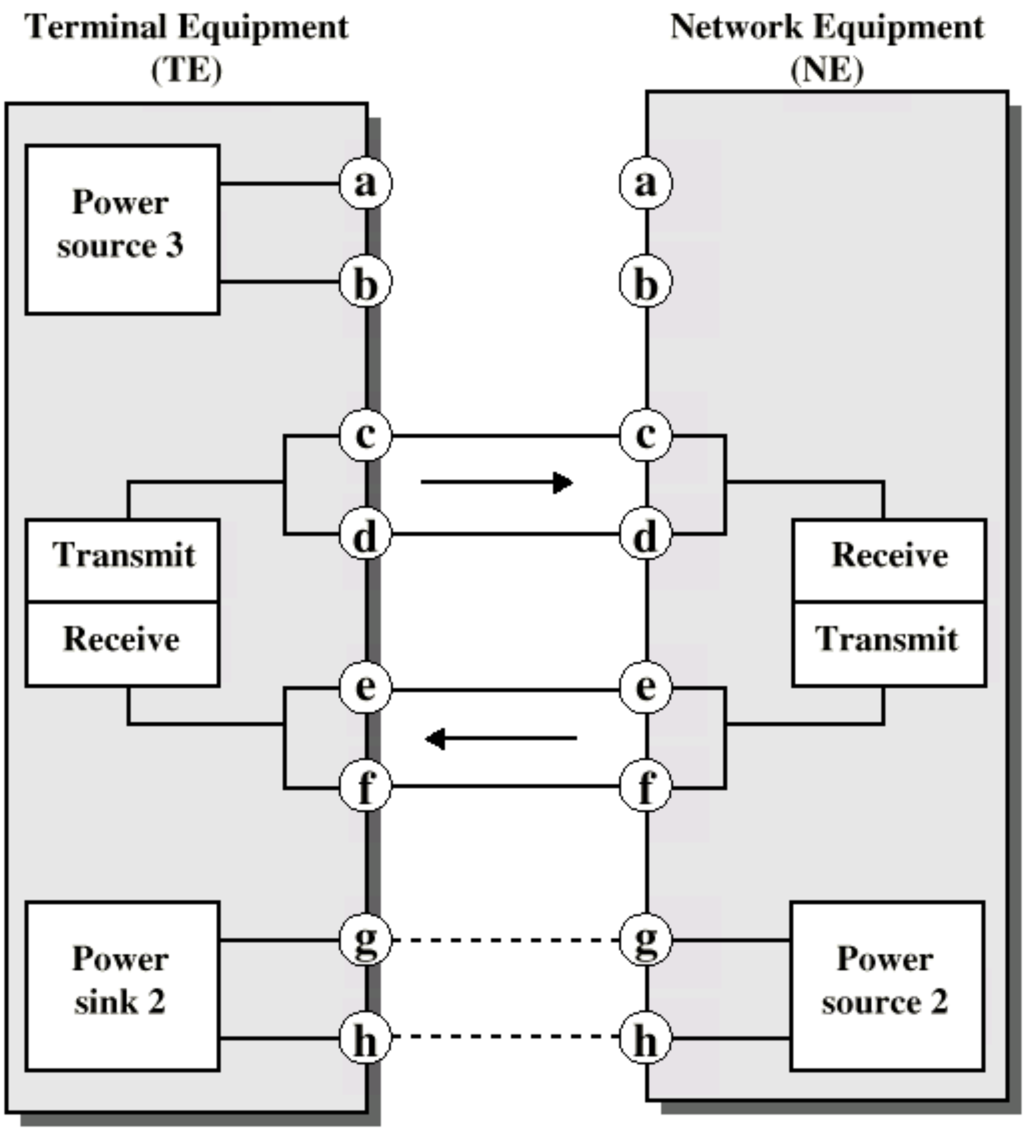


Null Modem



Signal ground 102
Transmitted data 103
Received data 104
Request to send 105
Clear to send 106
Rcvd line sig. detector 109
DCE ready 107
DTE ready 108.2
Ring indicator 125
Transmitter timing 113
Receiver timing 115
102
103
104
105
106
109
107
108.2
125
113
115

ISDN Physical Interface Diagram



Integrated
Service
Digital
Network

ISDN Physical Interface

- Connection between
  - terminal equipment (c.f. DTE) and
  - network terminating equipment (c.f. DCE)
- ISO 8877
- Cables terminate in matching connectors with 8 contacts
- Transmit/receive carry both data and control

ISDN Electrical Specification

- Balanced transmission
  - Carried on two lines, e.g. twisted pair
  - Signals as currents down one conductor and up the other
  - Differential signaling
  - Value depends on direction of voltage
  - Tolerates more noise and generates less
  - (Unbalanced, e.g. RS-232 uses single signal line and ground)
  - Data encoding depends on data rate
  - Basic rate 192kbps
    - uses pseudoternary
  - Primary rate: two options
    - 1.544 Mbps uses AMI and B8ZS
    - 2.048 Mbps uses AMI and HDB3
    - reason for different schemes is historical, no advantage of disadvantage

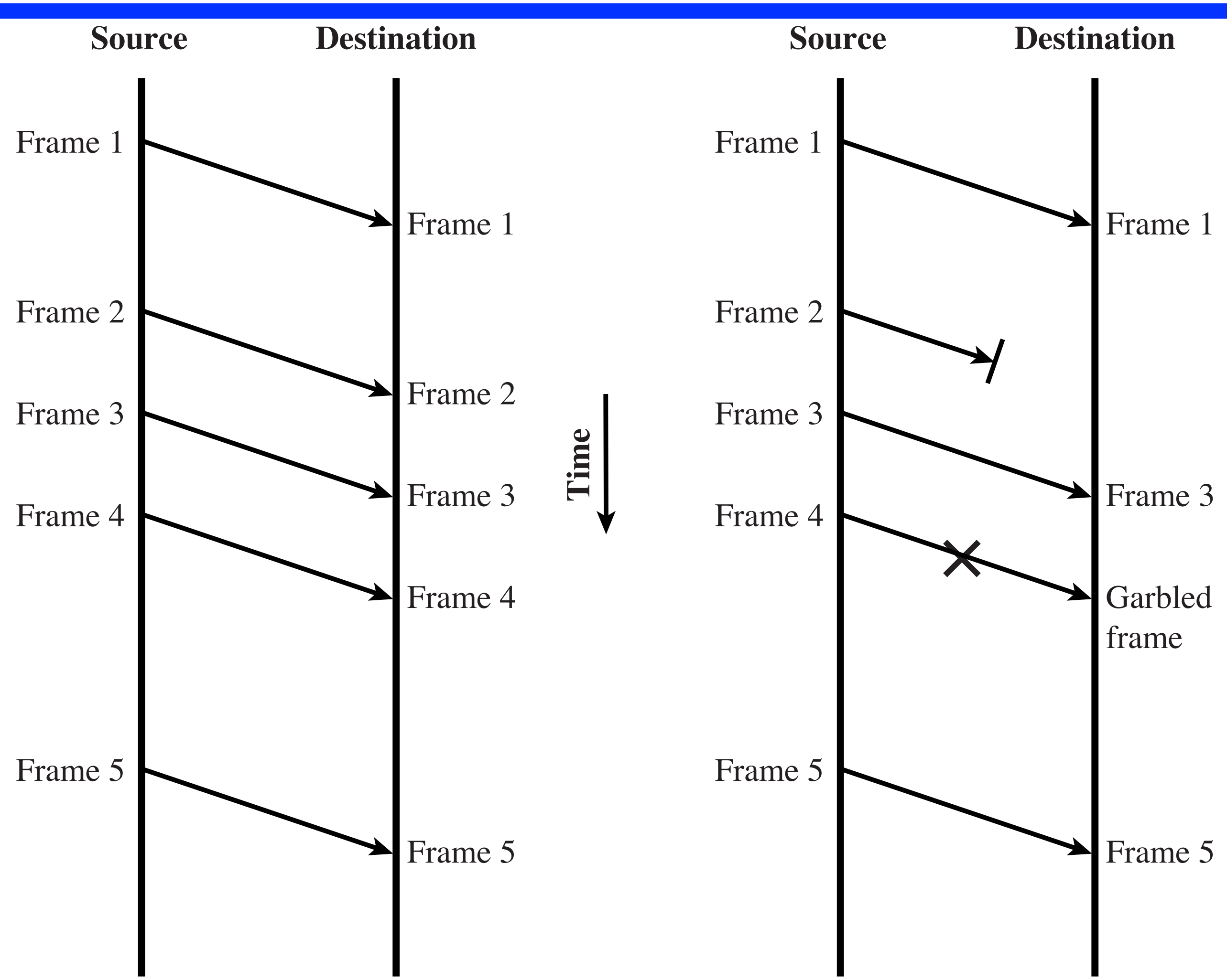
End of Background Information

…)END

Flow Control

- Ensuring the sending entity does not overwhelm the receiving entity
  - Preventing buffer overflow
- Transmission time
  - Time taken to emit all bits into medium
- Propagation time
  - Time for a bit to traverse the link

Model of Frame Transmission



(a) Error-free transmission

(b) Transmission with losses and errors

Data Link Basics

- Flow Control
  - Define:
    - L = length of a message (frame, packets, etc.) in bits
    - R = bit rate of the *A* to *B* link in bps
    - x = time to transmit a packet = L/R seconds
    - P = propagation delay from *A* to *B* in seconds
  - Two basic protocols
    - Stop and wait
    - Sliding window

Stop and Wait

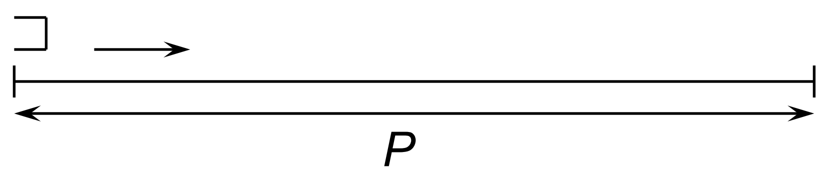
- Source transmits frame
- Destination receives frame and replies with acknowledgement
- Source waits for ACK before sending next frame
- Destination can stop flow by not send ACK
- Works well for a few large frames

Fragmentation

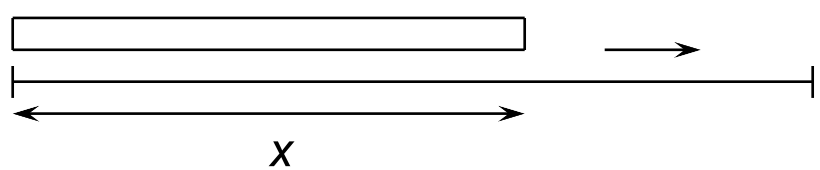
- Large block of data may be split into small frames
  - Limited buffer size
  - Errors detected sooner (when whole frame received)
  - On error, retransmission of smaller frames is needed
  - Prevents one station occupying medium for long periods
- Stop and wait becomes inadequate

Data Link Basics

- Stop and Wait Flow Control
  - also called Idle RQ (Repeat Request)
  - after *A* sends a message (packet), it waits for an ACK from *B* before sending the next packet.
  - analysis:
    1. At time (t_0), *A* starts transmission of first bit in packet:

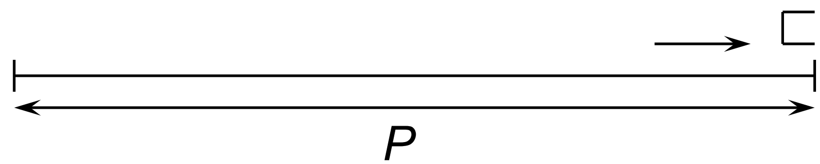


    2. At time ($t_0 + x$), *A* finished packet transmission

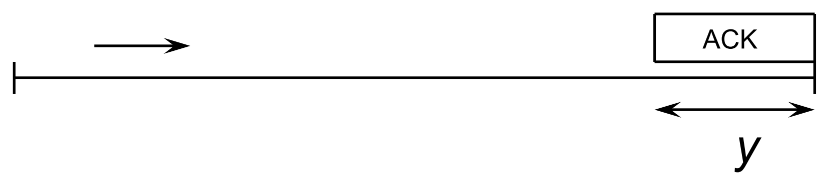


Data Link Basics

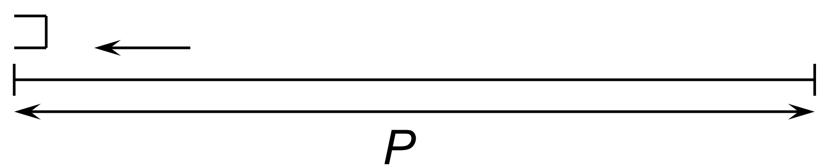
3. At time ($t_0 + x + P$), last bit of packet reaches B, true for both $P > x$ and $P < x$



4. At time ($t_0 + x + P + y$), last bit of ACK leaves *B,* given *m* bits in ACK packet and $y = m/R$ seconds



5. At time ($t_0 + x + P + y + P$), last bit of ACK reaches *A* and *A* can start next packet transmission



Data Link Basics

- Link Utilization:
  - Maximum Utilization of *A - B* link

$$U = \frac{x}{x + y + 2P}$$

$$= \text{ data transmission time/overhead time}$$

$$= \frac{x}{x + 2P}, \text{ neglecting } y$$

$$= \frac{1}{1 + 2\left(\frac{P}{x}\right)}$$

$$= \frac{1}{1 + 2a}, \ a = \left(\frac{P}{x}\right) \text{ is normalized propagation delay}$$

Data Link Basics

- How many bits are "stuck" in the media?

$$B = R\frac{d}{v}$$

where:

B = length of the link in bits

R = rate of the link, in bps

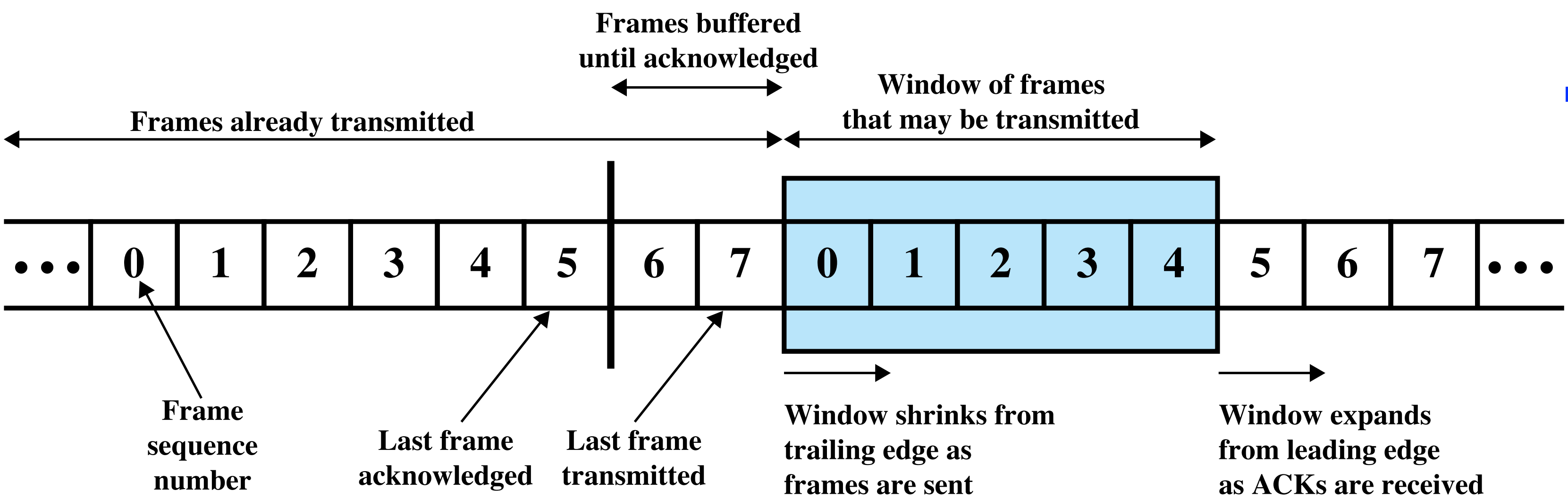
d = length in m

v = velocity of propagation, in m/s

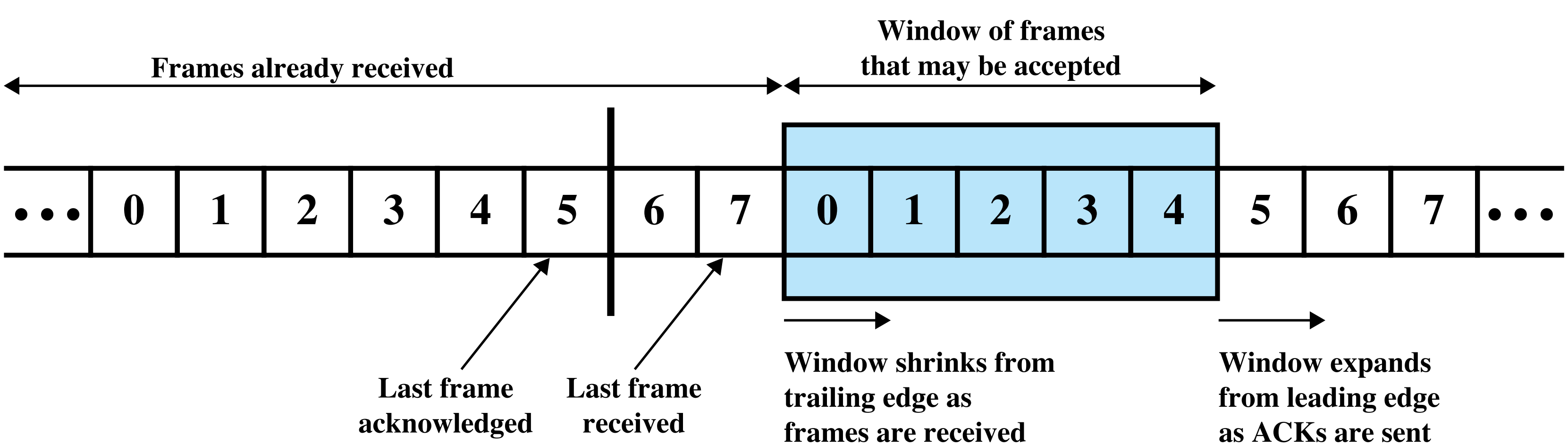
Sliding Windows Flow Control

- Allow multiple frames to be in transit
- Receiver has buffer of size *W*
- Transmitter can send up to *W* frames without ACK
- Each frame is numbered
- ACK includes number of next frame expected
- Sequence number bounded by size of field (*k*)
  - Frames are numbered modulo 2^k

Sliding Window Diagram

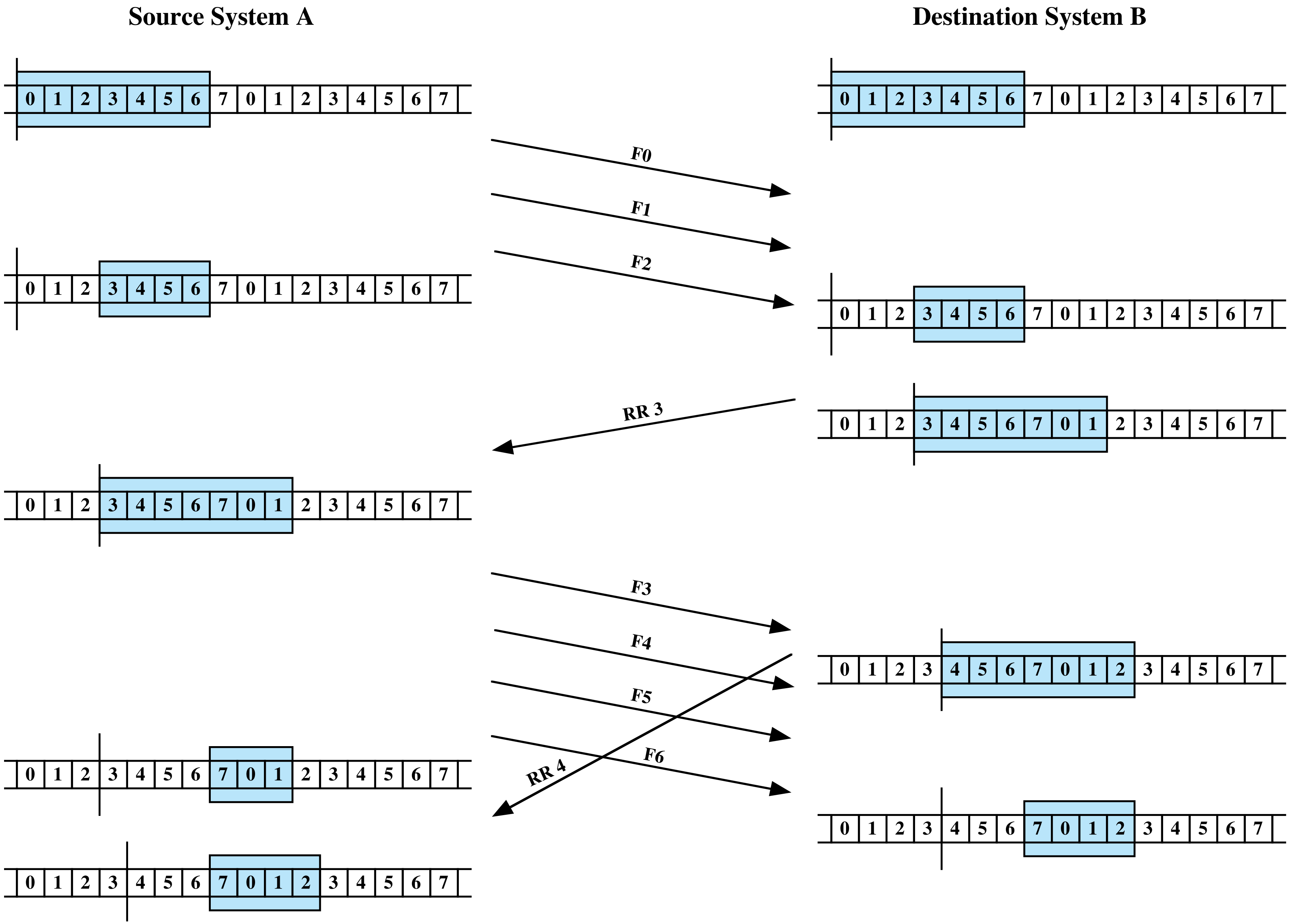


(a) Sender's perspective



(b) Receiver's perspective

Example Sliding Window



Sliding Window Enhancements

- Receiver can acknowledge frames without permitting further transmission (Receive Not Ready)
- Must send a normal acknowledge to resume
- If duplex, use piggybacking
  - —If no data to send, use acknowledgement frame
  - —If data but no acknowledgement to send, send last acknowledgement number again, or have ACK valid flag (TCP)

Error Control

- Detection and correction of errors
- Lost frames
- Damaged frames
- Automatic repeat request
  - Error detection
  - Positive acknowledgment
  - Retransmission after timeout
  - Negative acknowledgement and retransmission

Automatic Repeat Request (ARQ)

Three common approaches:

1. Stop and wait
2. Go back N
3. Selective reject (selective retransmission)

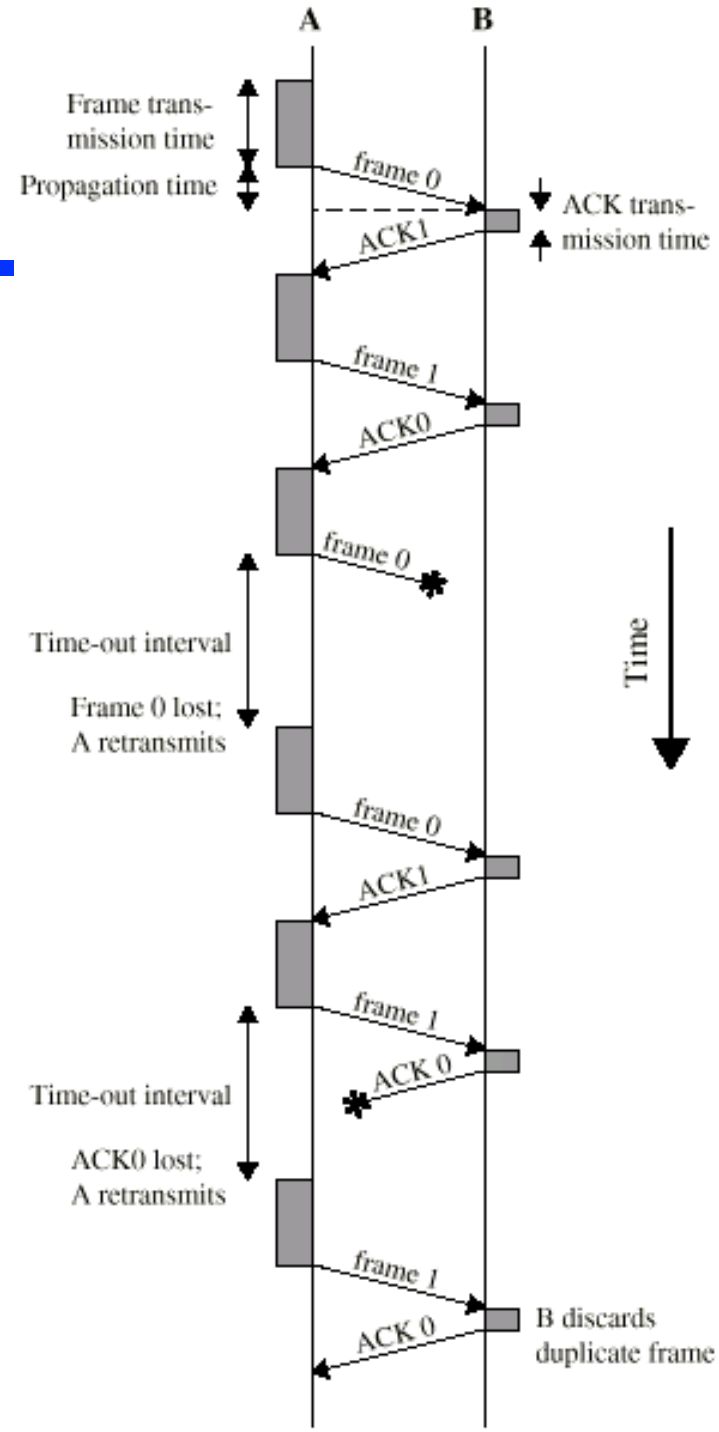
Stop and Wait

- Source transmits single frame
- Wait for ACK
- If received frame damaged, discard it
  - Transmitter has timeout
  - If no ACK within timeout, retransmit
- If ACK damaged,transmitter will not recognize it
  - Transmitter will retransmit
  - Receive gets two copies of frame
  - Use ACK0 and ACK1

Stop and Wait - Diagram

Frame numbers alternate between 0 and 1

Stop and Wait is:
+ simple
- inefficient



Go Back N (1)

- Based on sliding window
- If no error, ACK as usual with next frame expected
- Use window to control number of outstanding frames
- If error, reply with rejection
  - Discard that frame and all future frames until error frame received correctly
  - Transmitter must go back and retransmit that frame <u>and all subsequent frames</u>

Go Back N - Damaged Frame

- Receiver detects error in frame *i*
- Receiver sends rejection-*i*
- Transmitter gets rejection-*i*
- Transmitter retransmits frame *i* and all subsequent frames

Go Back N - Lost Frame (1)

- Frame *i* is lost
- Transmitter sends *i+1*
- Receiver gets frame *i+1* out of sequence
- Receiver send reject *i*
- Transmitter goes back to frame *i* and retransmits

Go Back N - Lost Frame (2)

- Frame *i* lost **and** no additional frame sent
  - Receiver gets nothing and returns neither acknowledgement nor rejection
  - Transmitter times out and sends acknowledgement frame with *P* bit set to 1
  - Receiver interprets this as command which it acknowledges with the number of the next frame it expects (frame *i*)
  - Transmitter then retransmits frame *i*

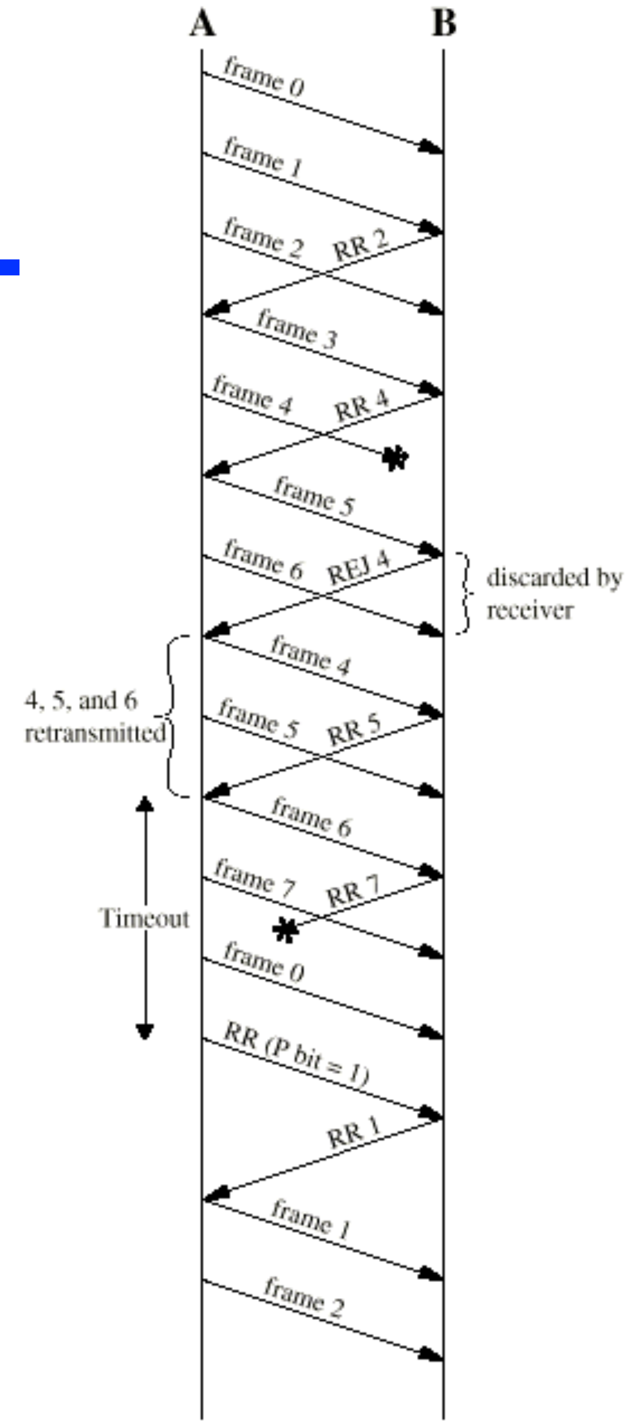
Go Back N - Damaged Acknowledgement

- Receiver gets frame *i* and send acknowledgement (*i+1*) which is lost
  - Acknowledgements are cumulative, so next acknowledgement (*i+n*) may arrive before transmitter times out on frame *i*
  - If transmitter times out, it sends acknowledgement with *P* bit set as before
  - This can be repeated a number of times before a reset procedure is initiated

Go Back N - Damaged Rejection

- As for lost frame (2)

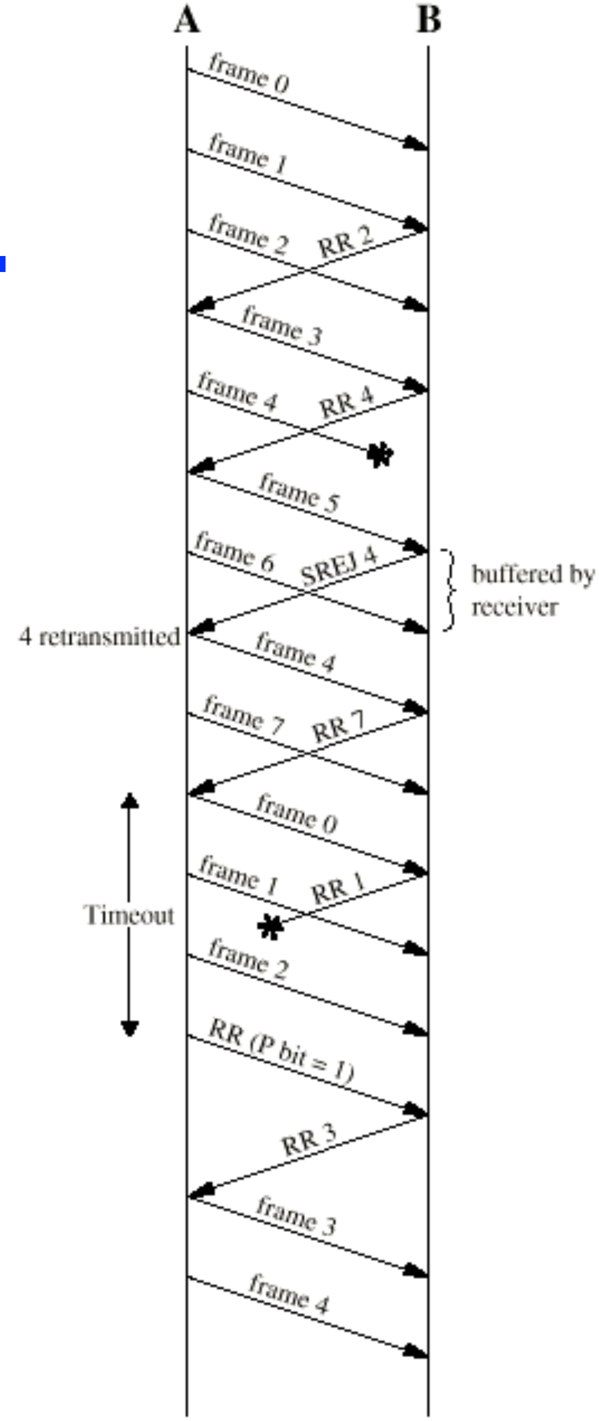
Go Back N - Diagram



Selective Reject

- Also called selective retransmission
- Only rejected frames are retransmitted
- Subsequent frames are accepted by the receiver and buffered
- Minimizes retransmission
- Receiver must maintain large enough buffer
- More complex login in transmitter

Selective Reject - Diagram



Data Link Basics

Performance: Stop & Wait ARQ

- note that utilization U = T_f/T_t where:
  - T_f = time for transmitter to emit a single frame
  - T_t = total time line is engaged in transmission of 1 frame
- for error free Stop & Wait:

$$U = \frac{T_f}{T_f + 2T_p}, \quad \text{if } a = \frac{T_p}{T_f} \text{ then } U = \frac{1}{1+2a}$$

- for errors, $U = T_f/(N_r T_t)$, where N_r is the expected number of transmissions of a particular frame

$$U = \frac{1}{N_r(1+2a)}$$

Data Link Basics

- Assume P = probability a single frame is in error.
- Further assume ACKs and NAKs are never in error.
- The probability that we have i transmissions of a frame is:

$$P^{i-1}(1-P)$$

- Therefore:

$$N_r = \sum_{i=1}^{\infty} iP^{i-1}(1-P) = \frac{1}{1-P}$$

- For Stop & Wait then:

$$U = \frac{1-P}{1+2a}$$

Data Link Basics

- For Sliding Window:

$$U = \begin{cases} 1 & N \geq 2a+1 \\ \dfrac{N}{2a+1} & N < 2a+1 \end{cases}$$

- For Selective Repeat we have:

$$U = \begin{cases} 1-P & N \geq 2a+1 \\ \dfrac{N(1-P)}{2a+1} & N < 2a+1 \end{cases}$$

- For Go-Back-N we have to consider all retransmitted:

$$U = \begin{cases} \dfrac{1-P}{1+2aP} & N \geq 2a+1 \\ \dfrac{N(1-P)}{(1+2a)(1-P+NP)} & N < 2a+1 \end{cases}$$

Data Link Basics

- For Go-Back-N we have to consider all retransmissions. Then N_r is the expected number of transmitted frames to successfully transmit one frame. Each error generates requirement to retransmit K frames.

$$N_r = \sum_{i=1}^{\infty} f(i) P^{i-1}(1-P)$$

with $f(i) = 1 + (i-1)K = (1-K) + Ki$

Total # frames transmitted if original frame must be transmitted i times

then

$$N_r = (1-K)\sum_{i=1}^{\infty} P^{i-1}(1-P) + K\sum_{i=1}^{\infty} iP^{i-1}(1-P)$$

with $\sum_{i=0}^{\infty} r^i = \sum_{i=1}^{\infty} r^{i-1} = \frac{1}{1-r}$ and $\sum_{i=1}^{\infty} ir^{i-1} = \frac{1}{(1-r)^2}$

we get

$$N_r = 1 - K + \frac{K}{1-P} = \frac{1-P+KP}{1-P}$$

High Level Data Link Control

- HDLC
- ISO 33009, ISO 4335

HDLC Station Types

- Primary station
  - —Controls operation of link
  - —Frames issued are called commands
  - —Maintains separate logical link to each secondary station
- Secondary station
  - —Under control of primary station
  - —Frames issued called responses
- Combined station
  - —May issue commands and responses

HDLC Link Configurations

- Unbalanced
  - One primary and one or more secondary stations
  - Supports full duplex and half duplex
- Balanced
  - Two combined stations
  - Supports full duplex and half duplex

HDLC Transfer Modes (1)

- Normal Response Mode (NRM)
  - Unbalanced configuration
  - Primary initiates transfer to secondary
  - Secondary may only transmit data in response to command from primary
  - Used on multi-drop lines
  - Host computer is primary
  - Terminals is secondary

HDLC Transfer Modes (2)

- Asynchronous Balanced Mode (ABM)
  - Balanced configuration
  - Either station may initiate transmission without receiving permission
  - Most widely used
  - No polling overhead

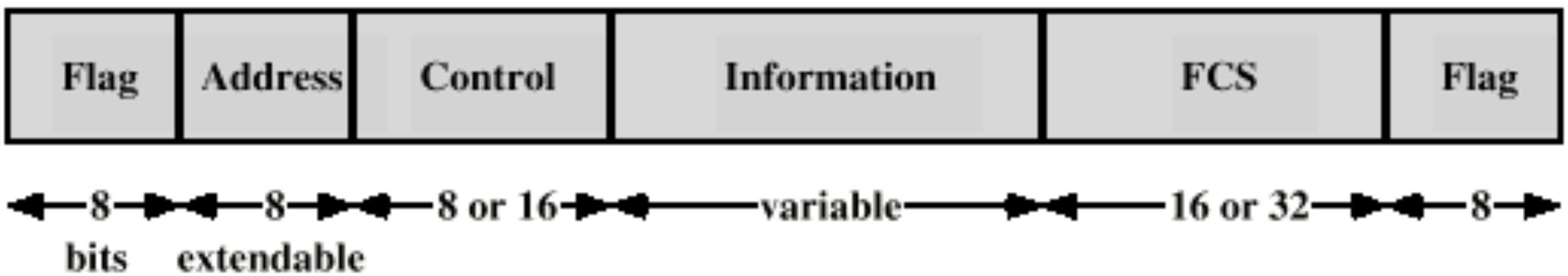
HDLC Transfer Modes (3)

- Asynchronous Response Mode (ARM)
  - Unbalanced configuration
  - Secondary may initiate transmission without permission form primary
  - Primary responsible for line
  - rarely used

Frame Structure

- Synchronous transmission
- All transmissions in frames
- Single frame format for all data and control exchanges

Frame Structure



(a) Frame format

Flag Fields

- Delimit frame at both ends
- 01111110
- May close one frame and open another
- Receiver hunts for flag sequence to synchronize
- Bit stuffing used to avoid confusion with data containing 01111110
  - 0 inserted after every sequence of five 1s
  - If receiver detects five 1s it checks next bit
  - If 0, it is deleted
  - If 1 and seventh bit is 0, accept as flag
  - If sixth and seventh bits 1, sender is indicating abort

Bit Stuffing

- Example with possible errors

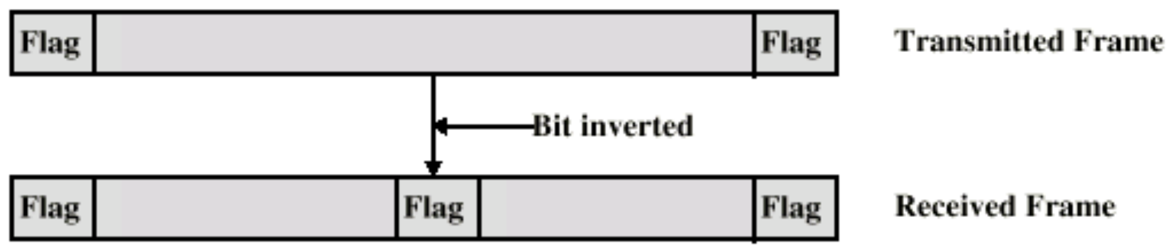
Original Pattern:

111111111111011111101111110

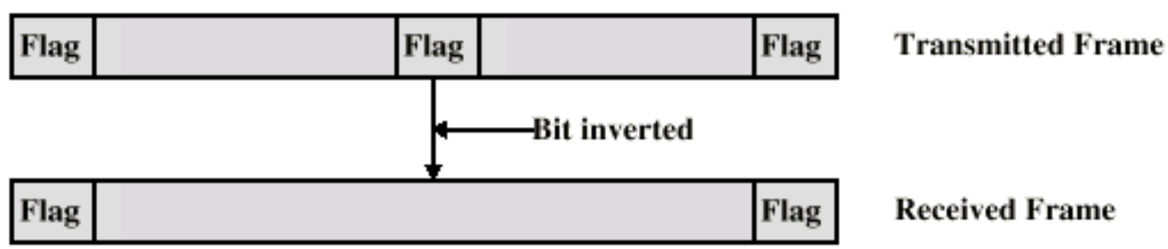
After bit-stuffing

1111101111101101111101011111010

(a) Example



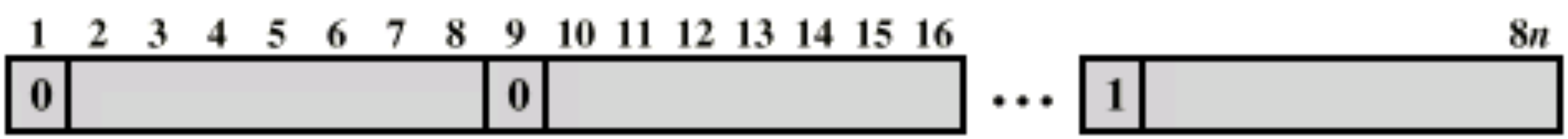
(b) An inverted bit splits a frame in two



(c) An inverted bit merges two frames

Address Field

- Identifies secondary station that sent or will receive frame
- Usually 8 bits long
- May be extended to multiples of 7 bits
  - LSB of each octet indicates that it is the last octet (1) or not (0)
- All ones (11111111) is broadcast

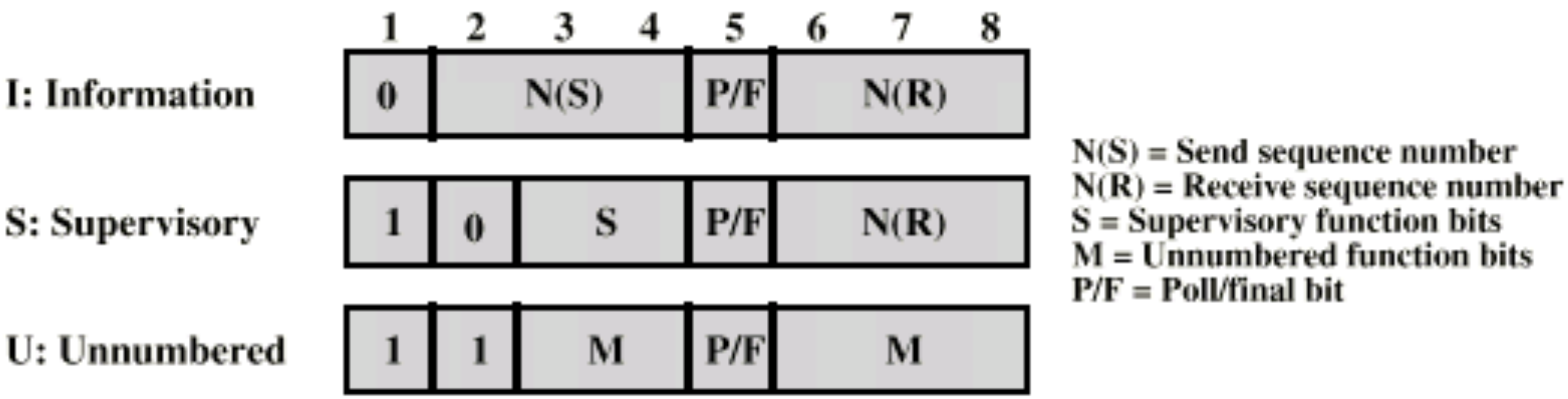


(b) Extended Address Field

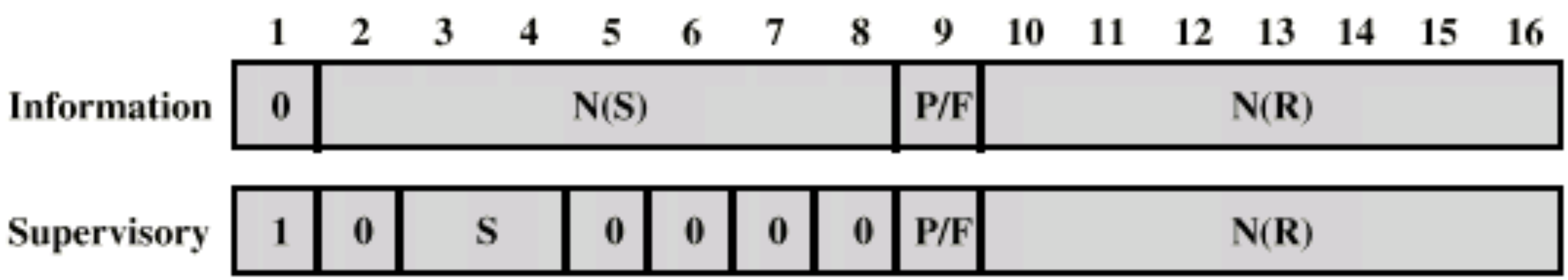
Control Field

- Different for different frame type
  - —Information - data to be transmitted to user (next layer up)
    - Flow and error control piggybacked on information frames
  - —Supervisory - ARQ when piggyback not used
  - —Unnumbered - supplementary link control
- First one or two bits of control filed identify frame type
- Remaining bits explained later

Control Field Diagram



(c) 8-bit control field format



(d) 16-bit control field format

Poll/Final Bit

- Use depends on context
- Command frame
  - P bit
  - 1 to solicit (poll) response from peer
- Response frame
  - F bit
  - 1 indicates response to soliciting command

Information Field

- Only in information and some unnumbered frames
- Must contain integral number of octets
- Variable length

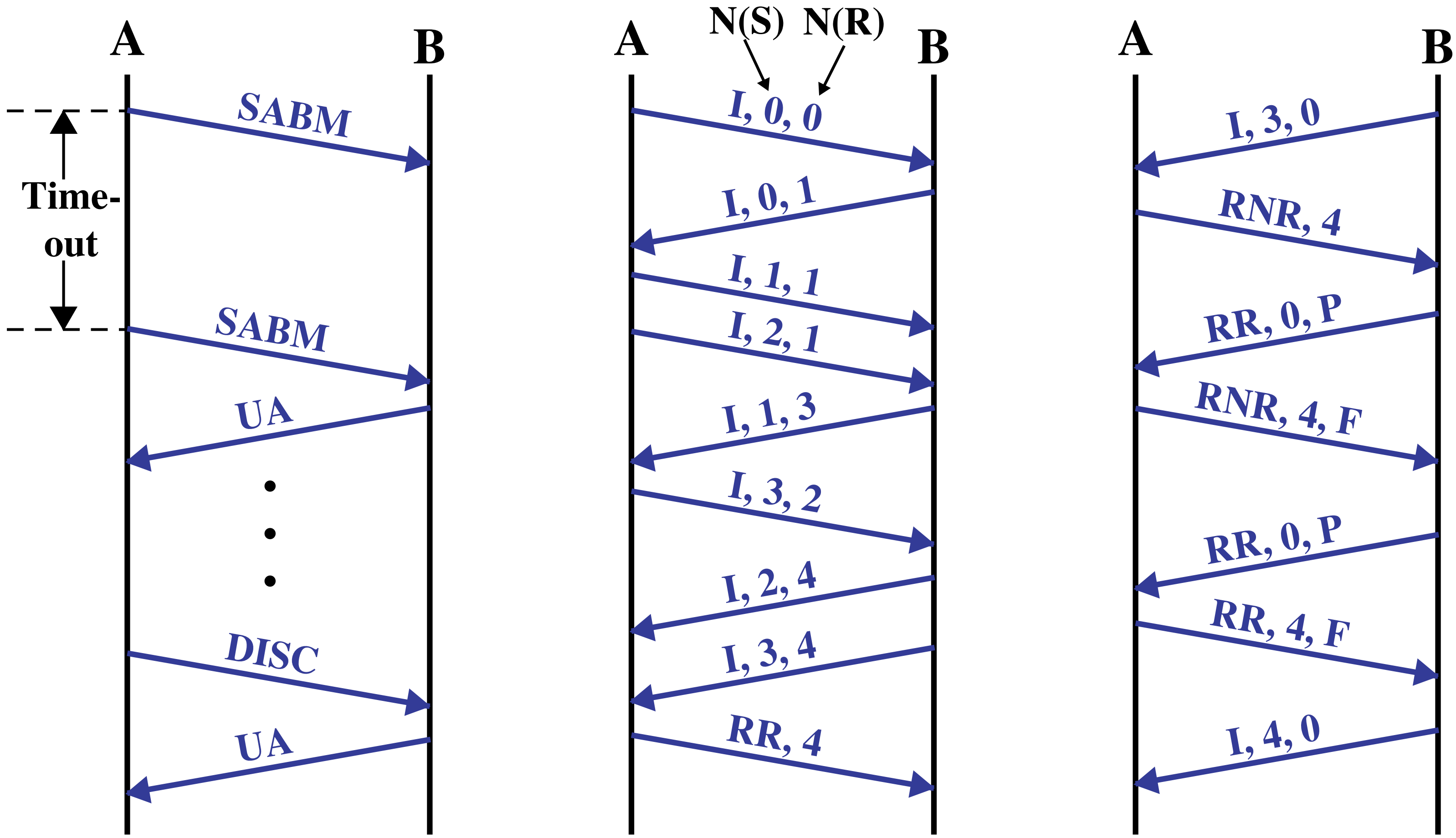
Frame Check Sequence Field

- FCS
- Error detection
- 16 bit CRC
- Optional 32 bit CRC

HDLC Operation

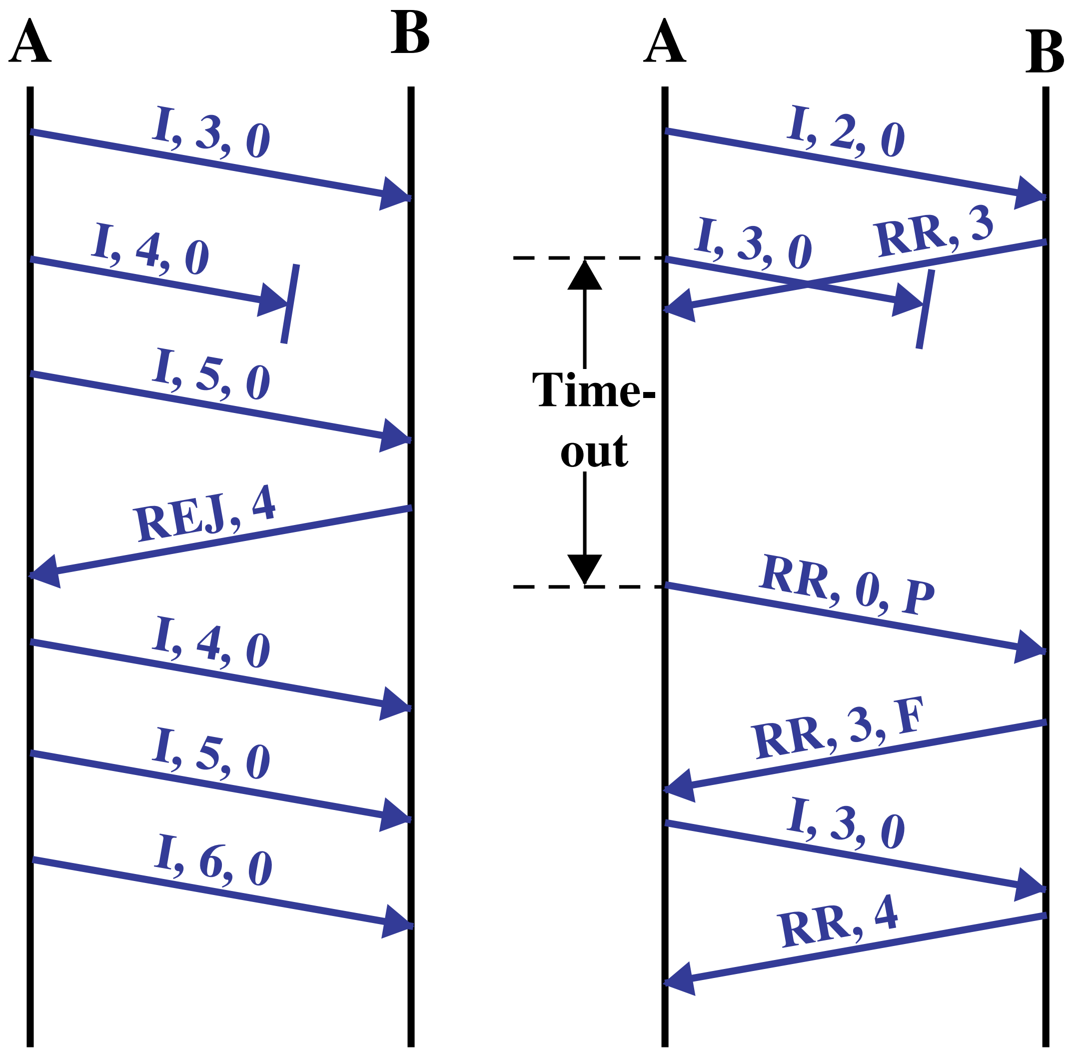
- Exchange of information, supervisory and unnumbered frames
- Three phases
  - Initialization
  - Data transfer
  - Disconnect

Examples of Operation (1)



(a) Link setup and disconnect (b) Two-way data exchange (c) Busy condition

Examples of Operation (2)



(d) Reject recovery (e) Timeout recovery

Summary

- introduced need for data link protocols
  - which included background on *interfacing*
- flow control
- error control
- HDLC