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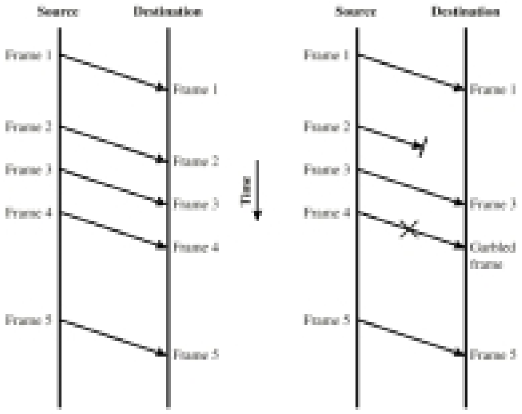
Data and Computer Communications

Chapter 7
Data Link Control

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

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

Stop and Wait Link Utilization

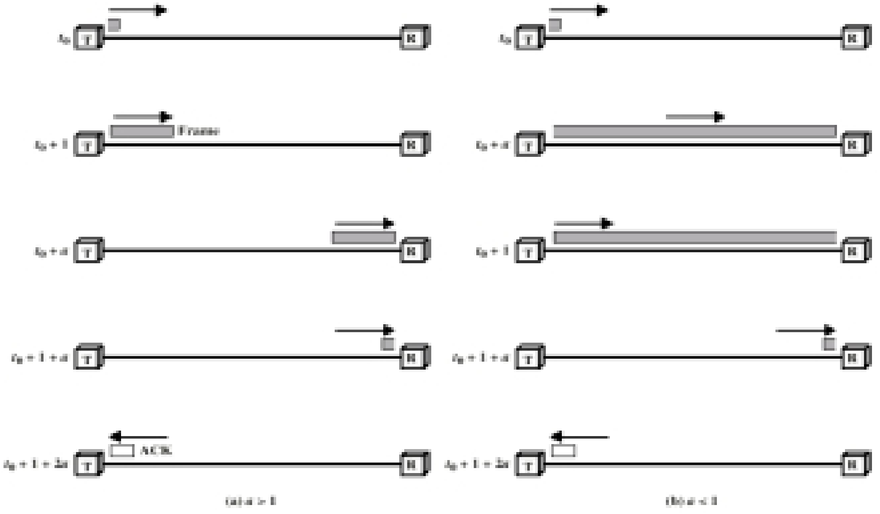
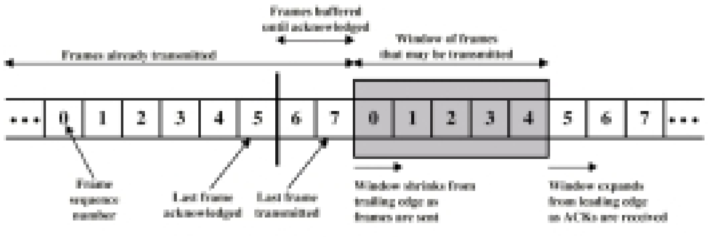


Figure 7.2 Stop-and-Wait Link Utilization (transmission time = 1; propagation time = a)

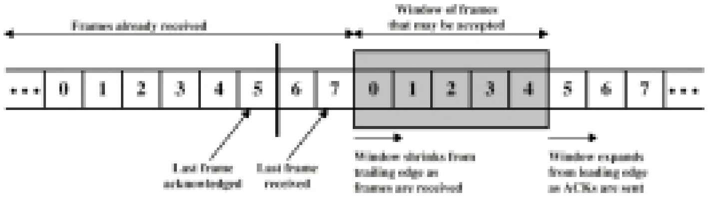
Sliding Windows Flow Control

- Allow multiple frames to be in transit
- Receiver has buffer W long
- 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

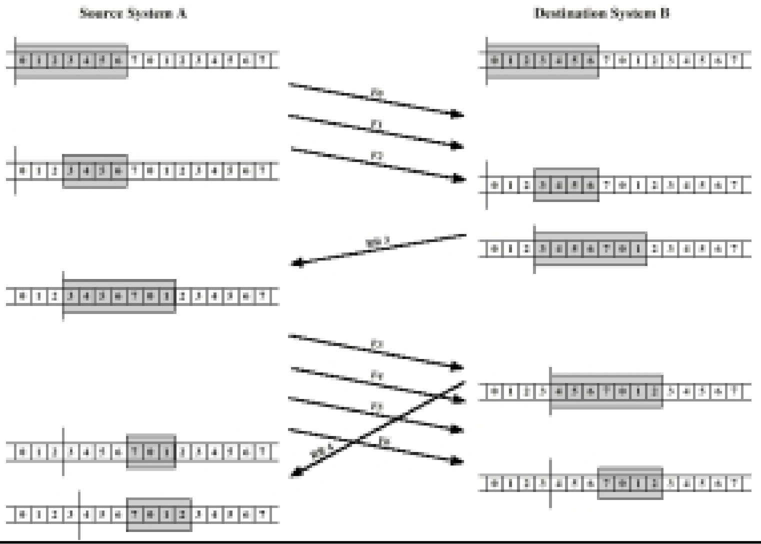


(a) Sender's perspective



(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
  - Acknowledgment is sent with data in same frame
  - 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 Detection

- Transmission system results in errors
- P_b: Probability of a single bit error (BER)
- P_1: Probability that a frame arrives with no bit errors
- P_f: Probability that a frame arrives with one or more bit errors; $P_f=1- P_1$
- $P_{fd:}$ Probability that a faulty frame is detected
- P_2: Probability that a frame arrives with one or more undetected bit errors; $P_2= P_f \text{ x } (1- P_{fd})$
- P_3: Probability that a frame arrives with one or more detected bit errors but no undetected bit errors; $P_3= P_f \text{ x } P_{fd}$
- With no error detection $P_3=0$

Error Detection

- Assuming P_b is constant and independent of bit position and error detection is not employed
  - $P_1=(1- P_b)^F$; F is number of bits in a frame
  - $P_2=1- P_1$
- Objective for ISDN connections is that BER on a 64 Kbps channel < 10^{-6} on at least 90% of observed 1-minute interval
- Assume frame length=1000 bits, 64 Kbps channel, one frame with undetected bit error per day
  - Number of transmitted frames in a day=$5.529\text{x}10^6$
  - Desired frame error rate $P_2=1/(5.529\text{x}10^6)=0.18\text{x}10^{-6}$
  - Assume $P_b= 10^{-6}$, $P_1=(1- 0.000001)^{1000}=0.999$; $P_2= 10^{-3}$
- Error detection techniques are necessary

Error Detection

- Additional bits added by transmitter for error detection code

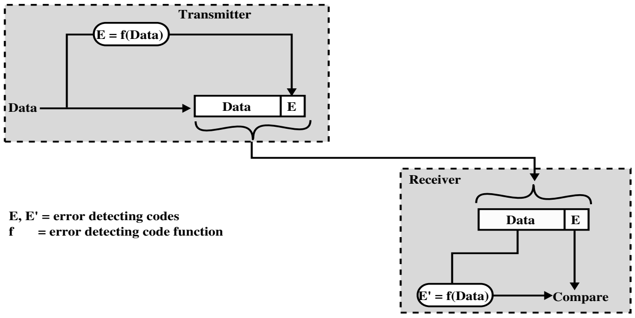


Figure 7.5 Error Detection

Error Detection

- Parity
  - Value of parity bit is such that character has even (even parity) or odd (odd parity) number of ones
  - Even number of bit errors goes undetected
- Cyclic Redundancy Check
  - For a block of *k* bits, transmitter generates *n* bit sequence called frame check sequence (FCS)
  - Transmit *k+n* bits which is exactly divisible by some number
  - Receive divides frame by that number
    - If no remainder, assume no error

Cyclic Redundancy Check

- M= K-bit message
- F=n-bit FCS
- T=(K+n)-bit frame to be transmitted, n<K
- P=pattern of n+1 bits; predetermined divisor
- Requirement is that T/P has no remainder

$$T = 2^n M + F \qquad \frac{2^n M}{P} = Q + \frac{R}{P} \qquad T = 2^n M + R$$

$$\frac{T}{P} = \frac{2^n M + R}{P} = Q + \frac{R}{P} + \frac{R}{P} = Q$$

Cyclic Redundancy Check - Example

- Message M = 1010001101 (10 bits)
- Pattern P = 110101 (6 bits)
- FCS R = 01110 (5 bits)

$$\frac{2^n M}{P} = \frac{1010001101\ 00000}{110101} = 1101010110 + \frac{01110}{110101}$$

$$\frac{2^n M + R}{P} = \frac{1010001101\ 01110}{110101} = 1101010110$$

Cyclic Redundancy Check - Polynomials

- Values expressed as polynomials in a dummy variable X with binary coefficients
  - For M=110011, M(X)=X^5+X^4+X+1
  - For P=11001, P(X)=X^4+X^3+1
- CRC process:

$$\frac{X^n M(X)}{P(X)} = Q(X) + \frac{R(X)}{P(X)}$$

$$T(X) = X^n M(X) + R(X)$$

Cyclic Redundancy Check – Error Detection

- Errors in an (n+k)-bit frame represented by an (n+k)-bit field with 1’s in each error position
- T=Transmitted frame
- E=Error pattern with 1’s in error positions
- T_r=Received frame

$$T_r = T \oplus E$$

- Error is not detected by receiver iff T_r is divisible by P, => E is divisible by P

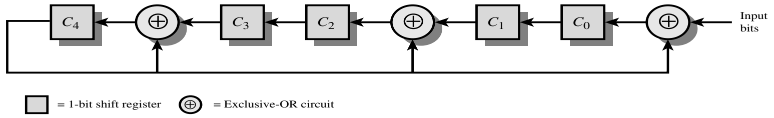
Cyclic Redundancy Check – Error Detection

- The following errors are not divisible by a suitably chosen $p(x)$ & are detectable:
  - All single bit errors
  - All double bit errors, as long as $P(X)$ has at least three 1’s
  - Any odd number of errors as long as $P(X)$ contains a factor of $(1+X)$
  - Any burst error with a length < length of $P(X)$
  - Most larger burst errors

Cyclic Redundancy Check – Error Detection

- Assuming r=length of FCS
- For a burst error of length $r+1$, probability of an undetected error$=1/2^{r-1}$
- For longer burst, probability of an undetected error$=1/2^{r}$
- Four versions of $P(X)$ are widely used
  - CRC-12: $=X^{12}+X^{11}+X^{3}+X^{2}+X+1$
  - CRC-16: $=X^{16}+X^{15}+X^{2}+1$
  - CRC-CCITT: $=X^{16}+X^{12}+X^{5}+1$
  - CRC-32: $=X^{32}+X^{26}+X^{23}+X^{22}+X^{16}+X^{12}+X^{11}+X^{10}+X^{8}+X^{7}+X^{5}+X^{4}+X^{2}+X+1$

Polynomial Division Example



(a) Shift-register implementation

	C_4	C_3	C_2	C_1	C_0	$C_4 \oplus C_3$	$C_4 \oplus C_1$	$C_4 \oplus$ input	input	
Initial	0	0	0	0	0	0	0	1	1	Message to be sent
Step1	0	0	0	0	1	0	0	0	0	
Step2	0	0	0	1	0	0	1	1	1	
Step3	0	0	1	0	1	0	0	0	0	
Step4	0	1	0	1	0	1	1	0	0	
Step5	1	0	1	0	0	1	1	1	0	
Step6	1	1	1	0	1	0	1	0	1	
Step7	0	1	1	1	0	1	1	1	1	
Step8	1	1	1	0	1	0	1	1	0	
Step9	0	1	1	1	1	1	1	1	1	
Step10	1	1	1	1	1	0	0	1	0	Five zeros added
Step11	0	1	0	1	1	1	1	0	0	
Step12	1	0	1	1	0	1	0	1	0	
Step13	1	1	0	0	1	0	1	1	0	
Step14	0	0	1	1	1	0	1	0	0	
Step15	0	1	1	1	0	1	1	0	—	

(b) Example with input of 1010001101

Figure 7.6 Circuit with Shift Registers for Dividing by the Polynomial $X^5 + X^4 + X^2 + 1$

General CRC Architecture

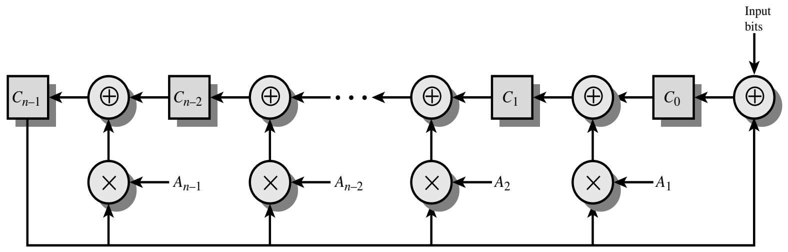


Figure 7.7 General CRC Architecture to Implement Divisor $1 + A_1X + A_2X^2 + \ldots + A_{n-1}X^{n-1} + X^n$

Error Control

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

Automatic Repeat Request (ARQ)

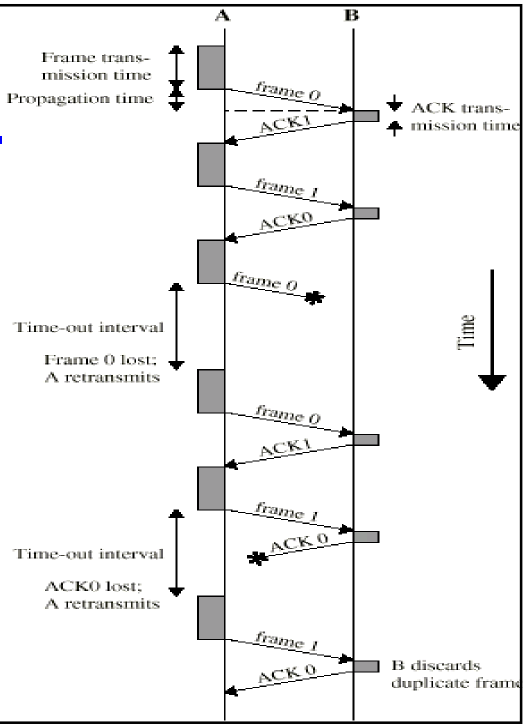
- ARQ turns unreliable data link into a reliable one
- Standardized ARQ versions
  - Stop and wait
  - Go back N
  - Selective reject (selective retransmission)

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

- Simple
- Inefficient



Go Back N

- 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 and all subsequent frames

Go Back N - Damaged Frame

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

Go Back N - Lost Frame: Case1

- Frame *i* 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: Case2

- 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*

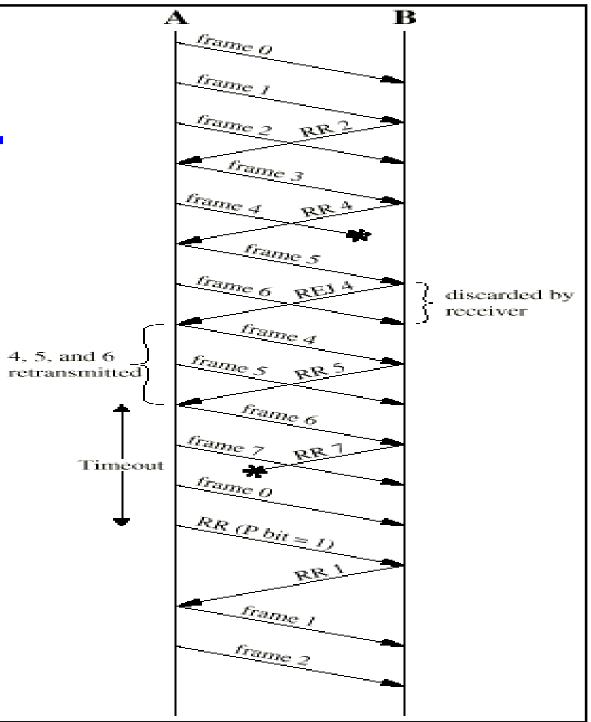
Go Back N - Damaged Acknowledgement

- Receiver gets frame i and send ACK ($i+1$) which is lost
- Acknowledgements are cumulative, so next ACK ($i+n$) 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

- Receiver sends Reject i that is lost
- 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

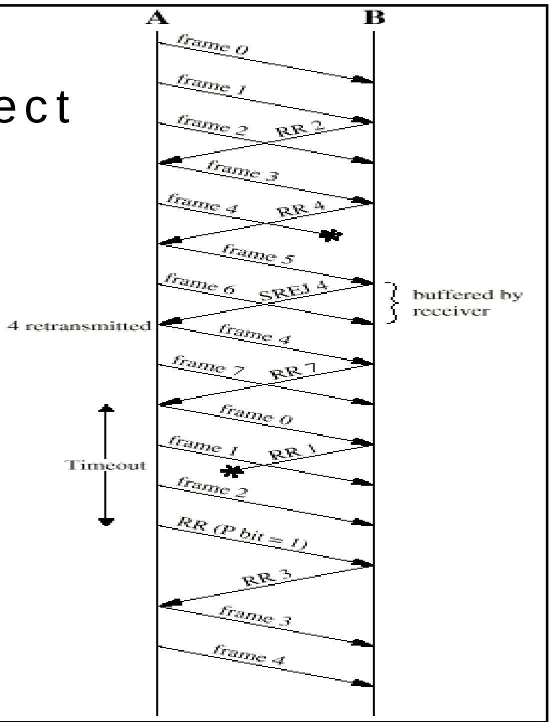
Go Back N



Selective Reject

- Also called selective retransmission
- Only rejected frames are retransmitted
- Subsequent frames are accepted by the receiver and buffered
- Minimizes retransmission
- More complex login in transmitter & receiver

Selective Reject



Maximum Window Size

- **For a k-bit sequence with 2^k sequence numbers, maximum window size is 2^k-1.**
- Data is being exchanged in both directions
  - Station B sends piggybacked acknowledgement with data frames sent to A
- Assume a 3-bit sequence number
- Station A sends frame 0 and gets back an RR 1
- Station A then sends frames 1,2,3,4,5,6,7,0 and gets another RR 1
- This could mean either
  - All eight frames received correctly and acknowledged by RR1
  - All eight frames were damaged or lost and receiver is repeating its previous RR 1.

Stop-and-Wait Performance

- Let T be the time to send a frame and receive an acknowledgment
- $T = t_{frame} + t_{prop} + t_{proc} + t_{ack} + t_{prop} + t_{proc}$
- Assume t_{proc} is negligible and t_{ack} is very small compared to t_{frame}
- $T = t_{frame} + 2t_{prop}$
- Utilization or efficiency of line

$$\mu = \frac{t_{frame}}{2t_{prop} + t_{frame}} = \frac{1}{1+2a}$$

$$a = \frac{t_{prop}}{t_{frame}}$$

Stop-and-Wait Performance

- Let d be the distance link, V the velocity of propagation, L the frame length, and R the data rate

$$a = \frac{t_{prop}}{t_{frame}} = \frac{d\ /\ V}{L\ /\ R} = \frac{Rd}{VL} = \frac{R \times \frac{d}{V}}{L}$$

- V is the speed of light
  - For unguided media V=3x10^8 m/s
  - For optical fiber and copper media V= 2x10^8 m/s

Stop-and-Wait Performance Examples

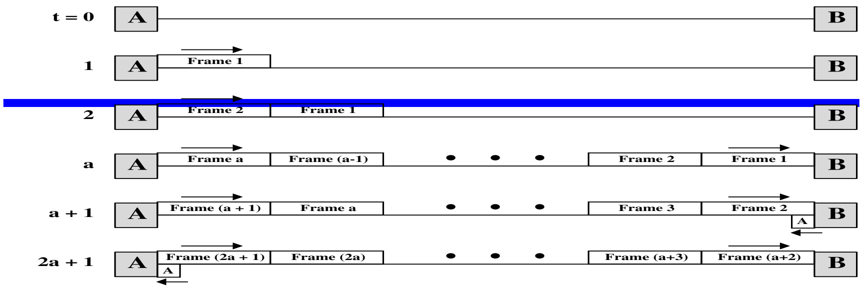
- Consider a WAN using ATM with two stations 1000 Km apart
- In ATM, frame size is 53 bytes (424 bits)
- Assume data rate of 155.52 Mbps
- Transmission time=$424/(155.52\text{x}10^{6})=2.7\text{x}10^{-6}$
- Assuming optical fiber link, propagation time=$(10^{6}$ meters$)/(2\text{x}10^{8}$ m/s$)=0.5\text{x}10^{-2}$
- $a=(0.5\text{x}10^{-2})/(2.7\text{x}10^{-6})=1851$
- Efficiency=$1/3703=0.00027$

Stop-and-Wait Performance Examples

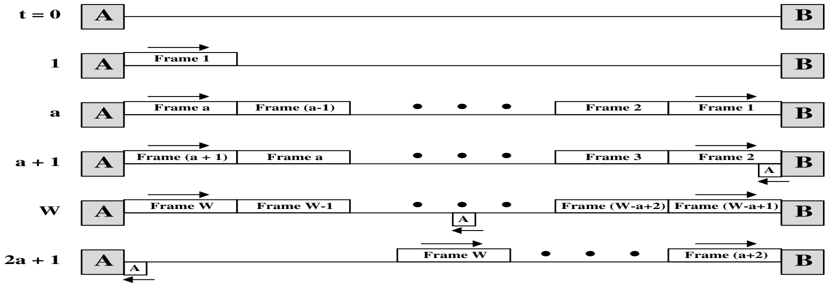
- Assume a LAN with a frame size of 1000 bits, and data rate of 10 Mbps
- For distance of 0.1 km
  - propagation time=$(10^{2}$ meters$)/(2\text{x}10^{8}$ m/s$)=0.5\text{x}10^{-6}$
  - Transmission time=$1000/(10^{7})=10^{-4}$
  - $a=(0.5\text{x}10^{-6})/(10^{-4})=0.005$
  - Efficiency=$1/1.01=0.99$
- For distance of 10 km
  - propagation time=$(10^{4}$ meters$)/(2\text{x}10^{8}$ m/s$)=0.5\text{x}10^{-4}$
  - Transmission time=$1000/(10^{7})=10^{-4}$
  - $a=(0.5\text{x}10^{-4})/(10^{-4})=0.\ 5$
  - Efficiency=$1/2=0.5$

Stop-and-Wait Performance Examples

- Consider digital data transmission via modem over a voice-grade line with data rate equal to 56 kbps.
- Consider a 1000-bit frame.
- The link distance can range from a few tens of meters to thousands of kilometers.
- For a short distance d = 1000 m, then a = (1000 m / 2 x 10^8 m/s) /(1000 bit / 56,000 bps) = 2.8 x 10^{-4}, and utilization is effectively 1.0.
- For a long distance d=5000 km, (5x10^6 m / 2 x 10^8 m/s) /(1000 bit / 56,000 bps) = 1.4, and utilization is 0.26.



(a) W 2a + 1



(b) W < 2a + 1

Figure 7.15 Timing of Sliding-Window Protocol

Error-Free Sliding Window Flow Control Performance

- Case 1: w >= 2a+1
  - Acknowledgment for frame 1 reaches A before A has exhausted its window
  - A can transmit continuously with no pause, and efficiency =1.
- Case 1: w < 2a+1
  - A exhausts its window at t=W and cannot send additional frames until t=2a+1

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

Sliding Window Utilization

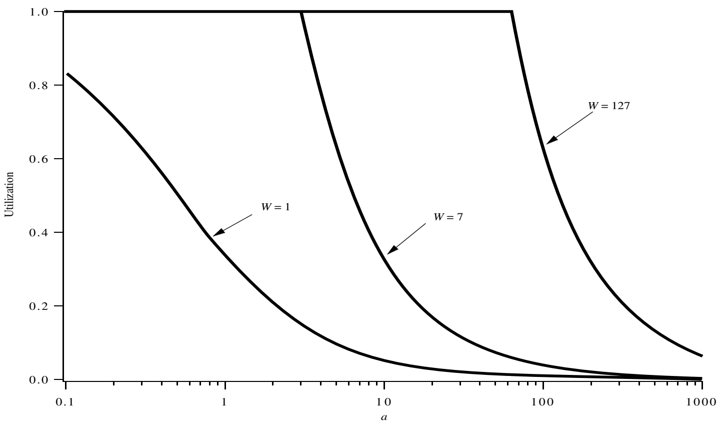


Figure 7.16 Sliding-Window Utilization as a function of *a*

Stop-and-Wait ARQ

- For error-free link

$$\mu = \frac{T_f}{T_t} = \frac{T_f}{T_f + 2T_p} = \frac{1}{1+2a}$$

$$a = \frac{t_p}{t_f}$$

- In the presence of errors
  - N_r is the expected number of transmissions of a frame
  - P is the probability that a single frame is in error

$$\mu = \frac{T_f}{N_r T_t} = \frac{1}{N_r(1+2a)}$$

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

$$N_r = E[transmissions] = \sum_{i=1}^{\infty}\left(i \times \Pr[i\ \ transmissions]\right) = \sum_{i=1}^{\infty}\left(iP^{i-1}(1-P)\right) = \frac{1}{1-P}$$

Selective Reject ARQ Performance

- For error-free link

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

- In presence of errors

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

Go-Back-N ARQ Performance

- ⌘ Each error generates a requirement to retransmit K frames rather than just one frame
- ⌘ *f(i)* is total number of frames transmitted if the original frame must be transmitted i times

$$f(i) = 1 + (i-1)K = (1-K) + iK$$

$$N_r = E[\mathit{number\ of\ transmitted\ frames\ to\ successfully\ transmit\ one\ frame}]$$

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

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

Go-Back-N ARQ Performance

- ⌘ For W>=2a+1, K is approximately equal to (2a+1)
- ⌘ For W<2a+1, K=W

$$\mu = \begin{cases} \dfrac{1\text{-}P}{1+2aP} & W \geq 2a+1 \\[2ex] \dfrac{W(1-P)}{(2a+1)(1-P+WP)} & W < 2a+1 \end{cases}$$

ARQ Utilization

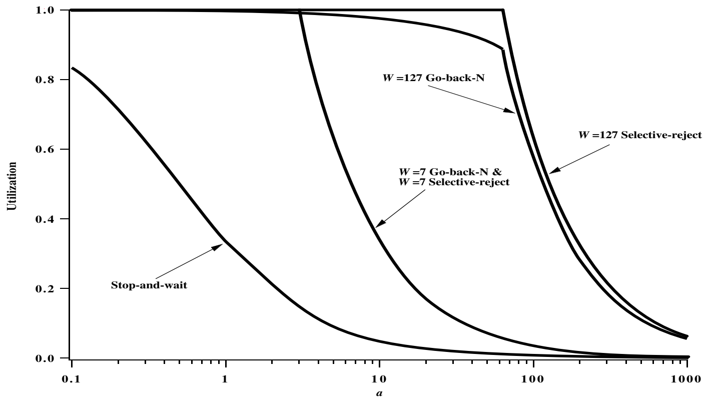


Figure 7.17 ARQ Utilization as a Function of *a* ($P = 10^{-3}$)

High Level Data Link Control

- HDLC is most important data link protocol
- ISO 33009, ISO 4335
- Widely used and basis for many other important data link protocols

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

- 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 as primary
  - Terminals as secondary

HDLC Transfer Modes

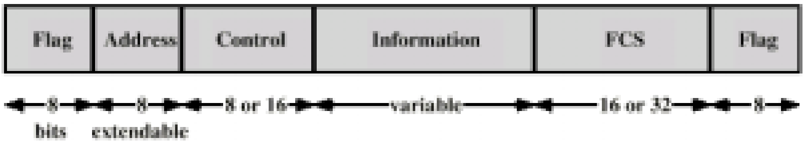
- Asynchronous Balanced Mode (ABM)
  - Balanced configuration
  - Either station may initiate transmission without receiving permission
  - Most widely used
  - No polling overhead

HDLC Transfer Modes

- 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

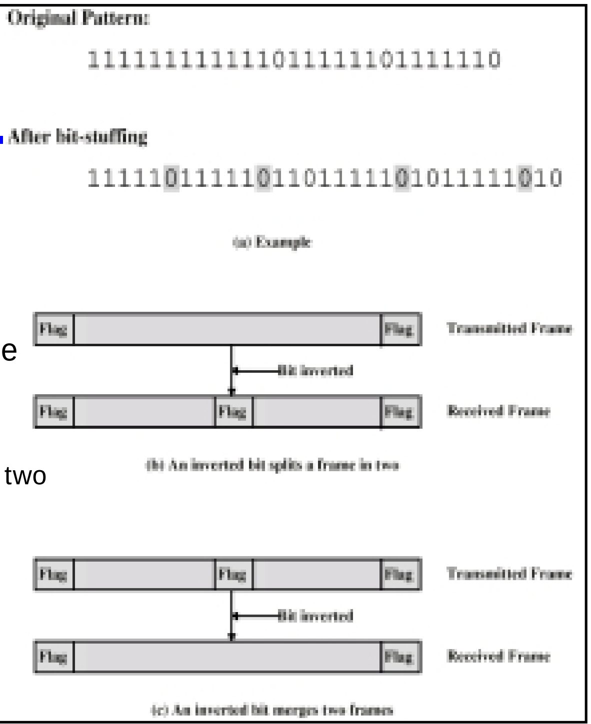


Flag Fields

- 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
- When a flag is used as both ending and starting flag, a single bit error may
  - Merge two frames
  - Split one frame into two



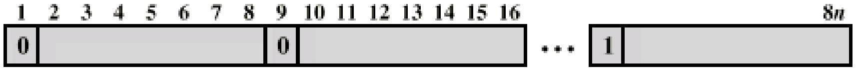
(a) Example

(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

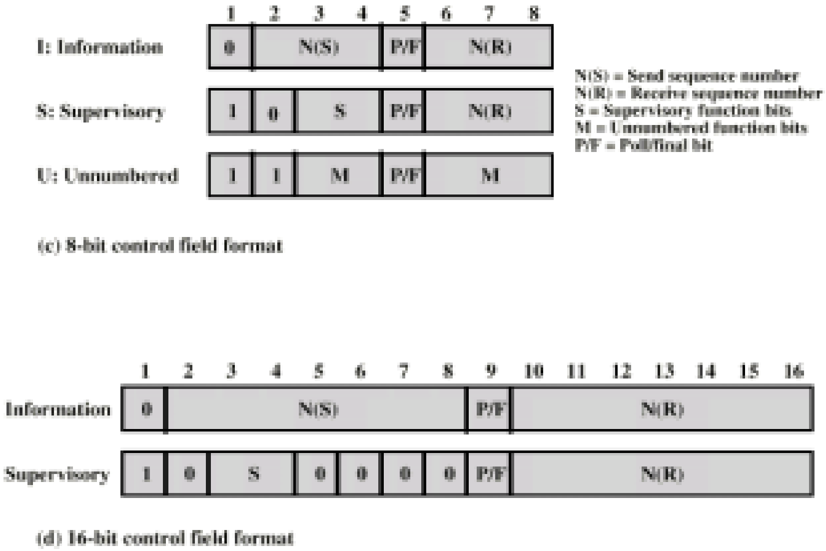


(b) Extended Address Field

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

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

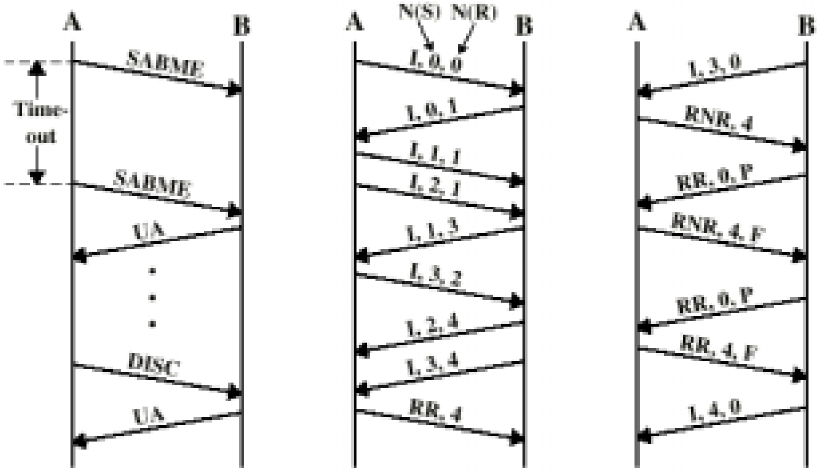
Table 7.1 HDLC Commands and Responses

Name	Command/ Response	Description
Information (I)	C/R	Exchange user data
Supervisory (S)		
Receive ready (RR)	C/R	Positive acknowledgment; ready to receive I-frame
Receive not ready (RNR)	C/R	Positive acknowledgment; not ready to receive
Reject (REJ)	C/R	Negative acknowledgment; go back N
Selective reject (SREJ)	C/R	Negative acknowledgment; selective reject
Unnumbered (U)		
Set normal response/extended mode (SNRM/SNRME)	C	Set mode; extended = 7-bit sequence numbers
Set asynchronous response/extended mode (SARM/SARME)	C	Set mode; extended = 7-bit sequence numbers
Set asynchronous balanced/extended mode (SABM, SABME)	C	Set mode; extended = 7-bit sequence numbers
Set initialization mode (SIM)	C	Initialize link control functions in addressed station
Disconnect (DISC)	C	Terminate logical link connection
Unnumbered Acknowledgment (UA)	R	Acknowledge acceptance of one of the set-mode commands
Disconnected mode (DM)	R	Responder is in disconnected mode
Request disconnect (RD)	R	Request for DISC command
Request initialization mode (RIM)	R	Initialization needed; request for SIM command
Unnumbered information (UI)	C/R	Used to exchange control information
Unnumbered poll (UP)	C	Used to solicit control information
Reset (RSET)	C	Used for recovery; resets N(R), N(S)
Exchange identification (XID)	C/R	Used to request/report status
Test (TEST)	C/R	Exchange identical information fields for testing
Frame reject (FRMR)	R	Report receipt of unacceptable frame

HDLC Operation

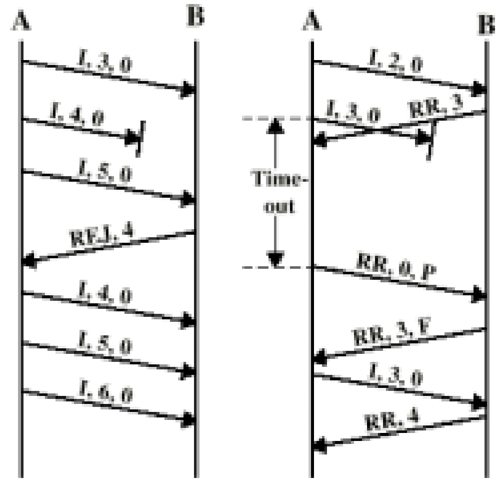
- Exchange of information, supervisory and unnumbered frames
- Three phases
  - Initialization
  - Data transfer
  - Disconnect

Examples of Operation



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

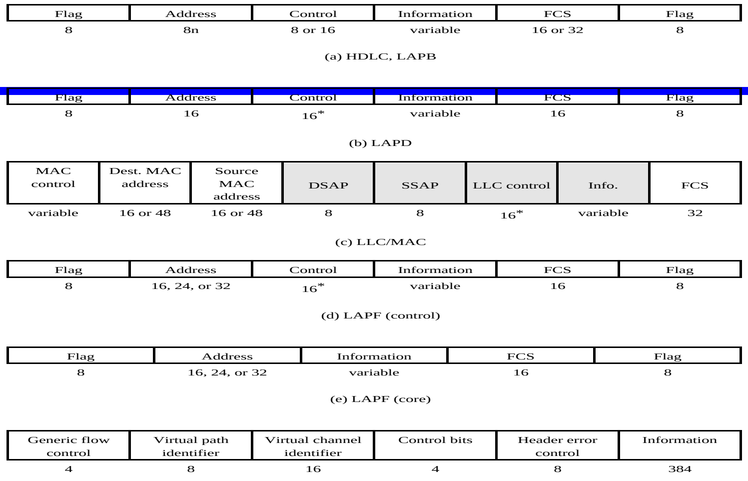
Examples of Operation



(d) Reject recovery (e) Timeout recovery

Other DLC Protocols (LAPB,LAPD)

- Link Access Procedure, Balanced (LAPB)
  - Part of X.25 (ITU-T)
  - Subset of HDLC - ABM
  - Point to point link between system and packet switching network node
- Link Access Procedure, D-Channel
  - ISDN (ITU-D)
  - ABM
  - Always 7-bit sequence numbers (no 3-bit)
  - 16 bit address field contains two sub-addresses
    - One for device and one for user (next layer up)



Flag	Address	Control	Information	FCS	Flag
8	8n	8 or 16	variable	16 or 32	8

(a) HDLC, LAPB

Flag	Address	Control	Information	FCS	Flag
8	16	16*	variable	16	8

(b) LAPD

MAC control	Dest. MAC address	Source MAC address	DSAP	SSAP	LLC control	Info.	FCS
variable	16 or 48	16 or 48	8	8	16*	variable	32

(c) LLC/MAC

Flag	Address	Control	Information	FCS	Flag
8	16, 24, or 32	16*	variable	16	8

(d) LAPF (control)

Flag	Address	Information	FCS	Flag
8	16, 24, or 32	variable	16	8

(e) LAPF (core)

Generic flow control	Virtual path identifier	Virtual channel identifier	Control bits	Header error control	Information
4	8	16	4	8	384

(f) ATM

* = 16-bit control field (7-bit sequence numbers) for I- and S- frames; 8 bits for U-frames

Figure 7.13 Data Link Control Frame Formats

Other DLC Protocols (LLC)

- Logical Link Control (LLC)
  - IEEE 802
  - Different frame format
  - Link control split between medium access layer (MAC) and LLC (on top of MAC)
  - No primary and secondary - all stations are peers
  - Two addresses needed
    - Sender and receiver
  - Error detection at MAC layer
    - 32 bit CRC
  - Destination and source access points (DSAP, SSAP)

Other DLC Protocols (Frame Relay)

- Streamlined capability over high speed packet witched networks
- Used in place of X.25
- Uses Link Access Procedure for Frame-Mode Bearer Services (LAPF)
- Two protocols
  - Control - similar to HDLC
  - Core - subset of control

Other DLC Protocols (Frame Relay)

- ABM
- 7-bit sequence numbers
- 16 bit CRC
- 2, 3 or 4 octet address field
  - Data link connection identifier (DLCI)
  - Identifies logical connection

Other DLC Protocols (ATM)

- Asynchronous Transfer Mode
- Streamlined capability across high speed networks
- Not HDLC based
- Frame format called “cell”
- Fixed 53 octet (424 bit)