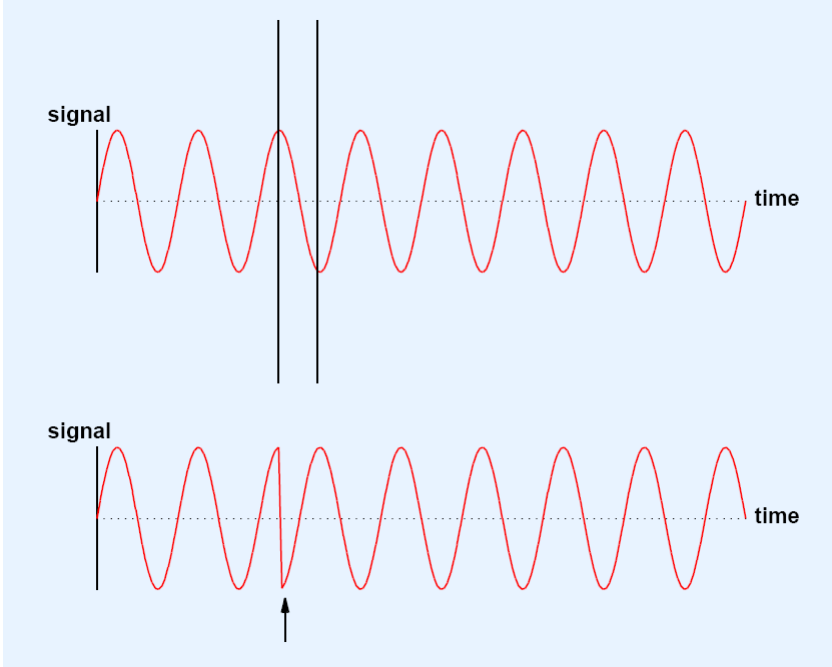
Phase-Shift Example

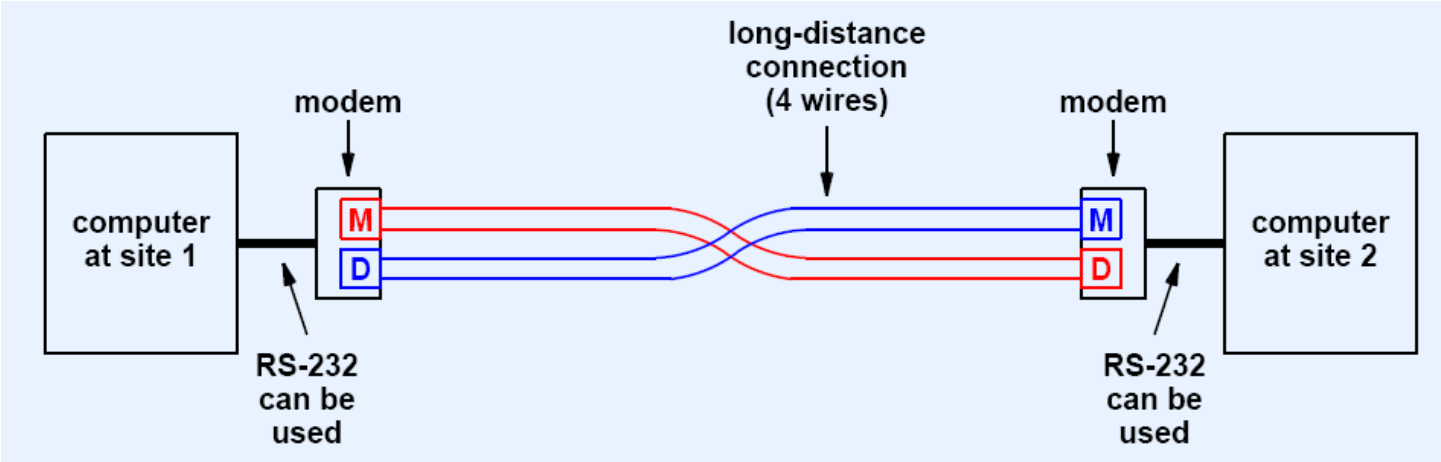
- Section of wave is omitted at phase shift
- Data bits determine size of omitted section



Modem

- Hardware device
- Used for long-distance communication
- Contains separate circuitry for
  - Modulation of outgoing signal
  - Demodulation of incoming signal
- Name abbreviates *mo*dulator/*demo*dulator

Illustration Of Modems Used Over A Long Distance



- One modem at each end
- Separate wires carry signals in each direction
- Modulator on one modem connects to demodulator on other

Types Of Modems

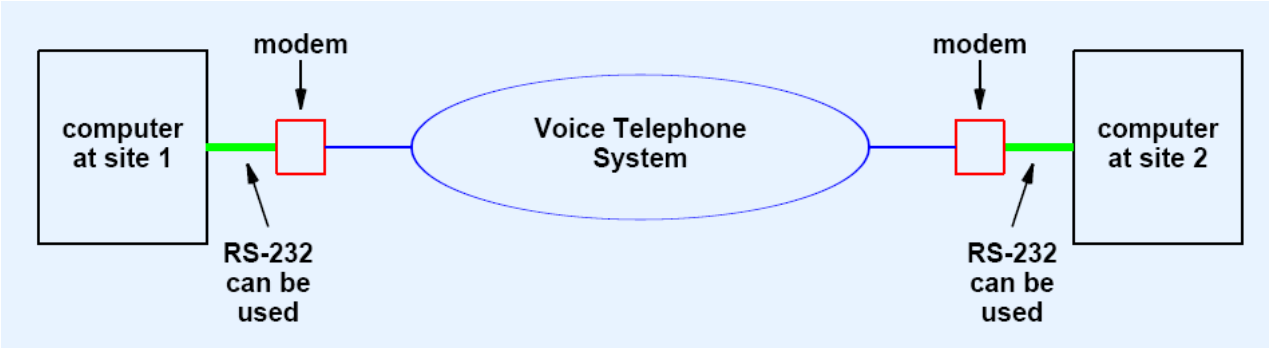
- Conventional
  - Use four wires
  - Transmit modulated electrical wave
- Optical
  - Use glass fibers
  - Transmit modulated light
- Wireless
  - Use air/space
  - Transmit modulated RF wave

Types Of Modems (continued)

- Dialup
  - Use voice telephone system
  - Transmit modulated audio tone

- Note: in practice, a dialup modem uses multiple tones simultaneously

Illustration Of Dialup Modem



- Modem can
  - Dial
  - Answer
- Carrier is audio tone

Modem Terminology

- *Full-duplex modem*
  - Provides 2-way communication
  - Allows simultaneous transmission
  - Uses four wires
- *Half-duplex modem*
  - Provides 2-way communication
  - Transmits in one direction at any time
  - Uses two wires

Recall

- *Propagation delay*
  - Determined by physics
  - Time required for signal to travel across medium
- *Bandwidth*
  - Electrical property of physical transmission system
  - Maximum times per second signal can change

Fundamental Measures Of A Digital Transmission System

- *Delay*
  - The amount of time required for a bit of data to travel from one end to the other
  - Usually the same as the propagation delay in underlying hardware
- *Throughput*
  - The number of bits per second that can be transmitted
  - Related to underlying hardware bandwidth

Relationship Between Digital Throughput And Bandwidth

- Given by Nyquist's theorem:

$$D = 2B\log_2 K$$

where

- D is maximum data rate
- B is hardware bandwidth
- K is number of values used to encode data

Applications Of Nyquist's Theorem

For RS-232

- *K* is 2 because RS-232 uses two values, +15 or -15 volts, to encode data bits
- *D* is *2B log22 = 2B*

- For phase-shift encoding
  - Suppose *K* is 8 (possible shifts)
  - *D* is *2Blog28 = 2B* * *3 = 6B*

More Bad News

- Physics tells us that real systems emit and absorb energy (e.g., thermal)
- Engineers call unwanted energy *noise*
- Nyquist's theorem
  - Assumes a noise-free system
  - Only works in theory
- Shannon's theorem corrects for noise

Shannon's Theorem

- Gives capacity in presence of noise:

$$C = B\log_2(1 + S/N)$$

where
  - C is the effective channel capacity in bits per second
  - B is hardware bandwidth
  - S is the average power (*signal*)
  - N is the *noise*
- S/N is *signal-to-noise ratio*

Application Of Shannon's Theorem

- Conventional telephone system
  - Engineered for voice
  - Bandwidth is *3000 Hz*
  - Signal-to-noise ratio is approximately *1000*
  - Effective capacity is

    3000log2(1 + 1000) = ~30000 bps
- Conclusion: dialup modems have little hope of exceeding *28.8* Kbps

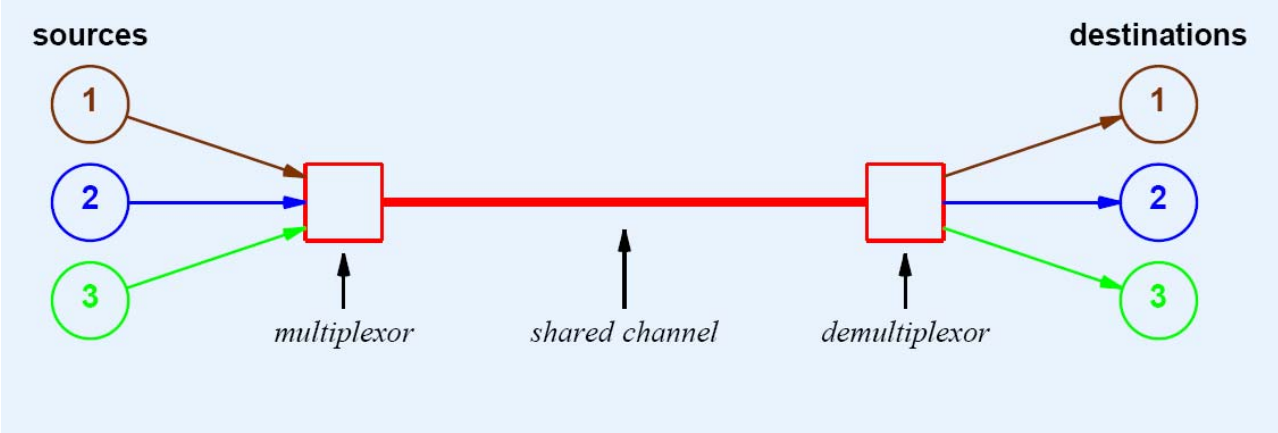
The Bottom Line

- Nyquist's theorem means finding a way to encode more bits per cycle improves the data rate
- Shannon's theorem means that no amount of clever engineering can overcome the fundamental physical limits of a real transmission system

Multiplexing

- Fundamental to networking
- General concept
- Used in
  - Lowest level of transmission systems
  - Higher levels of network hardware
  - Protocol software
  - Applications

The General Concept Of Multiplexing



- Separate pairs of communications travel across sharedchannel
- Multiplexing prevents interference
- Each destination receives only data sent by corresponding source

Two Basic Types Of Multiplexing

- *Time Division Multiplexing (TDM)*
  - Only one item at a time on shared channel
  - Item marked to identify source
  - Demultiplexor uses identifying mark to know where to deliver
- *Frequency Division Multiplexing (FDM)*
  - Multiple items transmitted simultaneously
  - Uses multiple “channels”

Transmission Schemes

- *Baseband transmission*
  - Uses only low frequencies
  - Encodes data directly
- *Broadband transmission*
  - Uses multiple carriers
  - Can use higher frequencies
  - Achieves higher throughput
  - Hardware more complex and expensive

Scientific Principle Behind Frequency Division Multiplexing

Two or more signals that use different carrier frequencies can be transmitted over a single medium simultaneously without interference.

Note: this is the same principle that allows a cable TV company to send multiple television signals across a single cable.

Wave Division Multiplexing

- Facts
  - FDM can be used with any electromagnetic radiation
  - Light is electromagnetic radiation
- When applied to light, FDM is called *wave division multiplexing*
  - Informally called *color division multiplexing*

Summary

- Various transmission schemes and media available
  - Electrical current over copper
  - Light over glass
  - Electromagnetic waves
- Digital encoding used for data
- Asynchronous communication
  - Used for keyboards and serial ports
  - RS-232 is standard
  - Sender and receiver agree on baud rate

Summary (continued)

- Modems
  - Used for long-distance communication
  - Available for copper, optical fiber, dialup
  - Transmit modulated carrier
    - * Phase-shift modulation popular
  - Classified as full- or half- duplex
- Two measures of digital communication system
  - Delay
  - Throughput

Summary (continued)

- Nyquist's theorem
  - Relates throughput to bandwidth
  - Encourages engineers to use complex encoding
- Shannon's theorem
  - Adjusts for noise
  - Specifies limits on real transmission systems

Summary (continued)

- Multiplexing
  - Fundamental concept
  - Used at many levels
  - Applied in both hardware and software
  - Two basic types
    - Time-division multiplexing (TDM)
    - Frequency-division multiplexing (FDM)
- When applied to light, FDM is called wave-division multiplexing

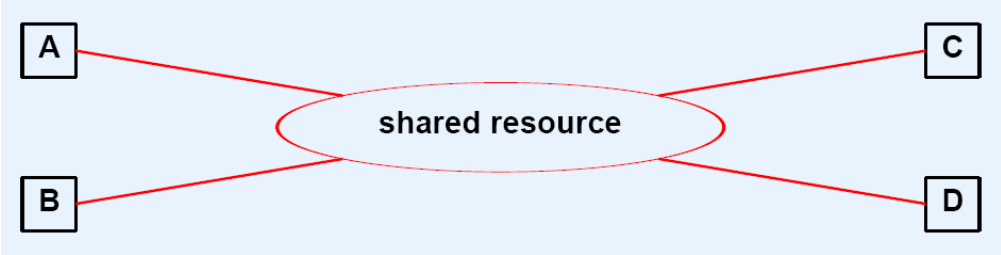
PART III

Packets, Frames, Parity, Checksums, and CRCs

The Problem

- Cannot afford individual network connection per pair of computers
- Reasons
  - Installing wires consumes time and money
  - Maintaining wires consumes money (esp. long-distance connections)

Solution



- Network has
  - Shared central core
  - Many attached stations

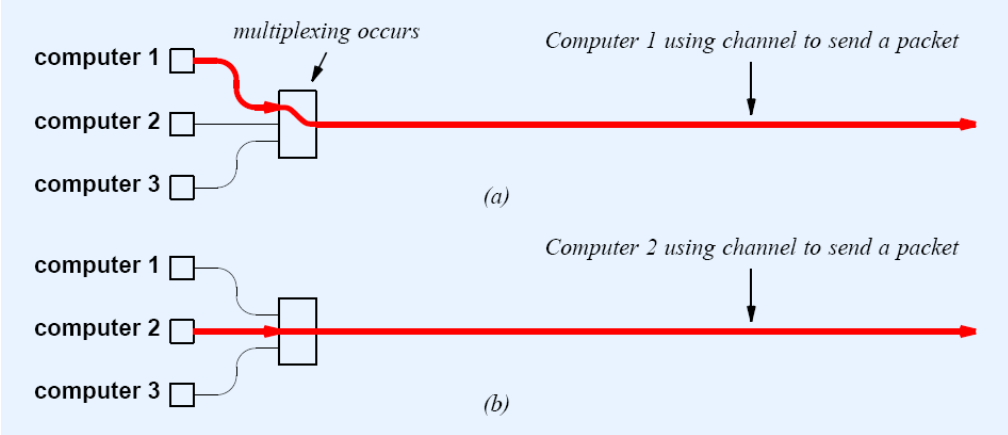
The Problem With Sharing

- Demand high
- Some applications have large transfers
- Some applications cannot wait
- Need mechanism for fairness

Packet Switching Principle

- Solution for fairness
  - Divide data into small units called *packets*
  - Allow each station opportunity to send a packet before any station sends another
- Form of time-division multiplexing

Illustration Of Packet Switching

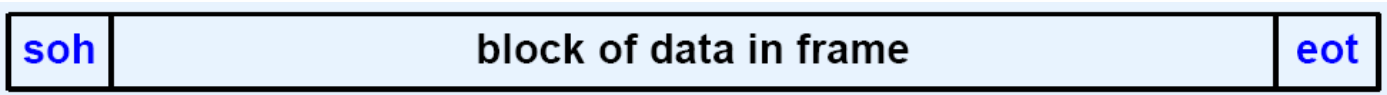


- Acquire shared medium
- Send one packet
- Allow other stations opportunity to send before sending again

Packet Details

- Depend on underlying network
  - Minimum/maximum size
  - Format
- Hardware packet called a *frame*

Example Frame Format Used With RS-232



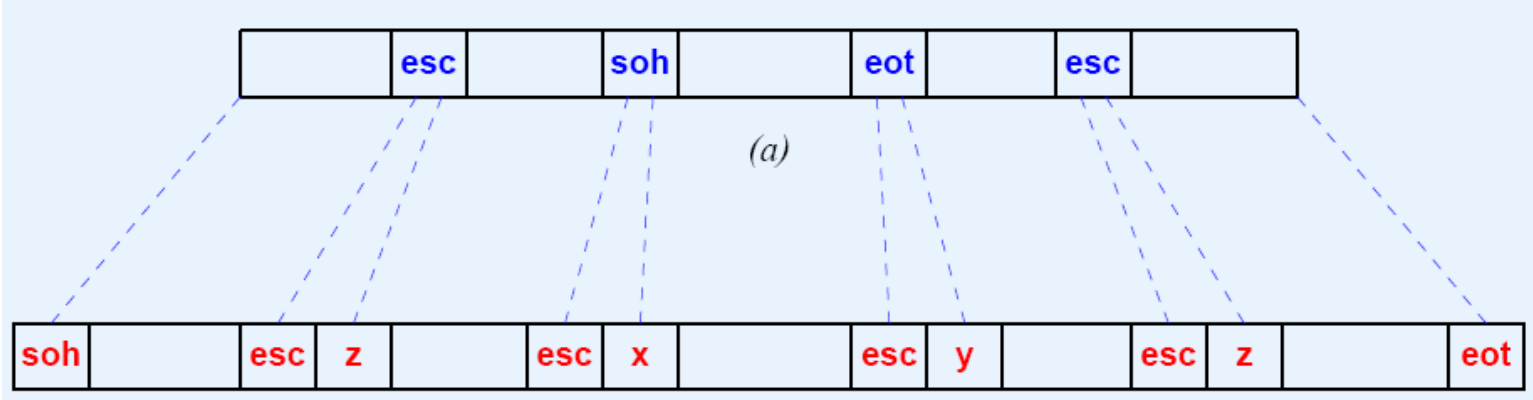
- RS-232 is character-oriented
- Special characters
  - Start of header (*soh*)
  - End of text (*eot*)

When Data Contains Special Characters

- Translate to alternative form
- Called *byte stuffing*
- Example

Character In Data	Characters Sent
soh	esc x
eot	esc y
esc	esc z

Illustration Of Frame With Byte Stuffing



- Stuffed frame longer than original
- Necessary evil

Handling Errors

- Data can be corrupted during transmission
  - Bits lost
  - Bit values changed
- Frame includes additional information to detect/correct error
  - Set by sender
  - Checked by receiver
- Statistical guarantee

Error Detection And Recovery Techniques

- Parity bit
  - One additional bit per character
  - Can use
    - *Even parity*
    - *Odd parity*
  - Cannot handle error that changes two bits

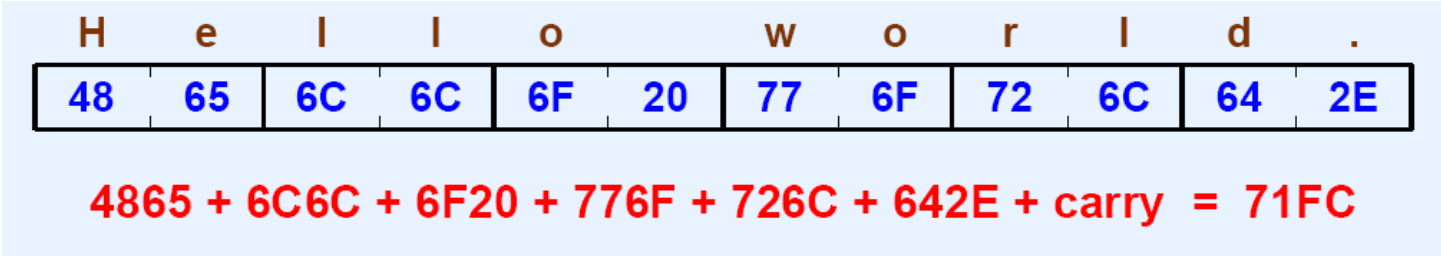
Error Detection And Recovery Techniques (continued)

- Checksum
  - Treat data as sequence of integers
  - Compute and send arithmetic sum
  - Handles multiple bit errors
  - Cannot handle all errors

Error Detection And Recovery Techniques (continued)

- Cyclic Redundancy Check (*CRC*)
  - Mathematical function for data
  - More complex to compute
  - Handles more errors

Example Checksum Computation



- Checksum computed over data
- Checksum appended to frame

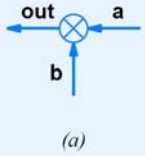
Illustration Of Errors A Checksum Fails To Detect

Data Item In Binary	Checksum Value	Data Item In Binary	Checksum Value
0001	1	0011	3
0010	2	0000	0
0011	3	0001	1
0001	1	0011	3
totals	7		7

- Second bit reversed in each item
- Checksum is the same

Building Blocks For CRC

- Exclusive or

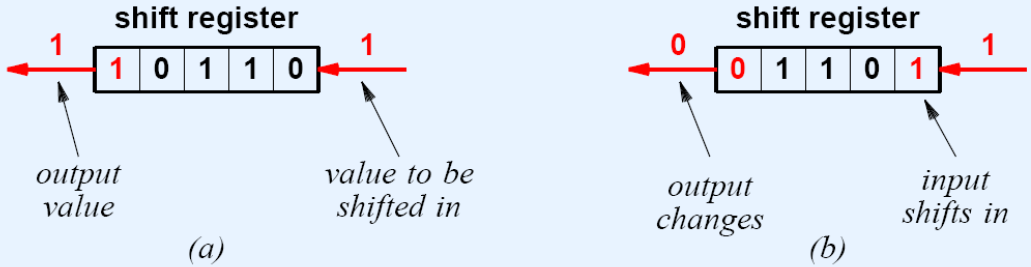


(a)

a	b	out
0	0	0
0	1	1
1	0	1
1	1	0

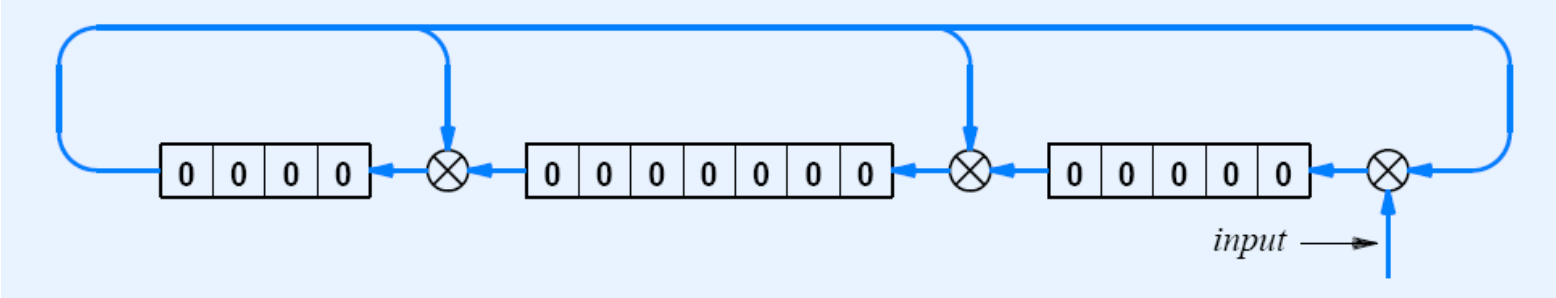
(b)

- Shift register



– *a* shows status before shift
– *b* shows status after shift
– Output same as top bit

Example Of CRC Hardware



- Computes 16-bit CRC
- Registers initialized to zero
- Bits of message shifted in
- CRC found in registers

Example CRC Computation

- Input data is all *1* bits
- CRC shown after 15, 16, and 17 bits shifted
- Feedback introduces zeroes in CRC

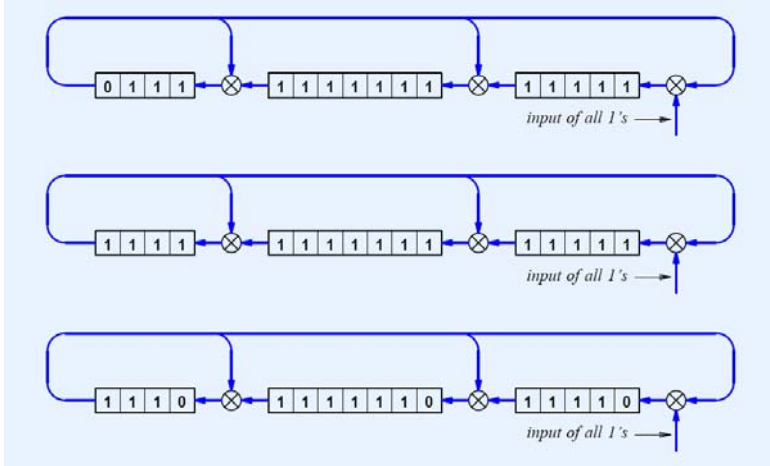
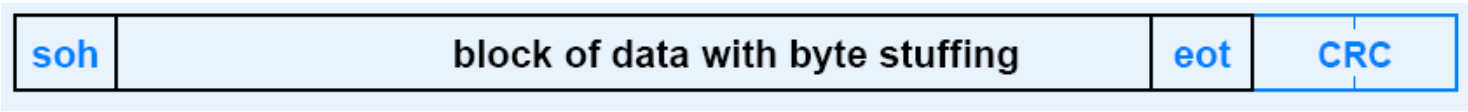


Illustration Of Frame Using CRC



- CRC covers data only

Summary

- Packet technology
  - Invented to provide fair access in shared network
  - Sender divides data into small packets
- Hardware packets called frames
- Can use packet-switching with RS-232
  - Special characters delimit beginning and end of frame
  - Byte-stuffing needed when special characters appear in data

Summary (continued)

- To detect data corruption
  - Sender adds information to packet
  - Receiver checks
- Techniques
  - Parity bit
  - Checksum
  - Cyclic Redundancy Check (CRC)
  - Provide statistical guarantees

PART IV

Local Area Networks
(LANs)

Classification Terminology

- Network technologies classified into three broad categories
- *Local Area Network (LAN)*
- *Metropolitan Area Network (MAN)*
- *Wide Area Network (WAN)*
- LAN and WAN most widely deployed

The Local Area Network (LAN)

- Engineering classification
- Extremely popular (most networks are LANs)
- Many LAN technologies exist