Chapter 2

Data Communications Concepts

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Objectives

- Understanding data representation.
- Investigating serial vs. parallel transmission and different transmission protocols.
- Studying modulation and demodulations techniques.
- Studying various multiplexing techniques.
- Packet switching and data switching.

Goal: Thorough understanding of modem communication

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Data Digitization

- Character Encoding: Process of transforming humanly readable characters (letters, numbers, voices, images, etc.) into machine readable code.
- Computer data is encoded into 1s and 0s. These are known as bits. The series of 8-bits is called as byte.
- **ASCII:** American Standard Code for Information Interchange
  - Uses 7 bits ➔ 128 (2^7) different characters
  - 8^{th} bit for parity used for error detection
- **EBCDIC:** Extended Binary Coded Decimal for Interchange Code
  - Uses 8 bits ➔ 256 (2^8) different characters
  - Used in IBM mainframe computers

ASCII Table

			MSB Bit 6	0	0	0	0	1	1	1	1
			Bit 5	0	0	1	1	0	0	1	1
			Bit 4	0	1	0	1	0	1	0	1
LSB											
Bit 0	Bit 1	Bit 2	Bit 3								
0	0	0	0	NUL	DLE	SP	0	@	P	‘	p
1	0	0	0	SOH	DC1	!	1	A	Q	a	q
0	1	0	0	STX	DC2	“	2	B	R	b	r
1	1	0	0	ETX	DC3	#	3	C	S	c	s
0	0	1	0	EOT	DC4	$	4	D	T	d	t
1	0	1	0	ENQ	NAK	%	5	E	U	e	u
0	1	1	0	ACK	SYN	&	6	F	V	f	v
1	1	1	0	BEL	ETB	'	7	G	W	g	w
0	0	0	1	BS	CAN	(	8	H	X	h	x
1	0	0	1	HT	EM	)	9	I	Y	i	y
0	1	0	1	LF	SUB	*	:	J	Z	j	z
1	1	0	1	VT	ESC	+	;	K	[	k	{
0	0	1	1	FF	FS	,	<	L	\	l	|
1	0	1	1	CR	GS	-	=	M	]	m	}
0	1	1	1	SO	RS	.	>	N	^	n	~
1	1	1	1	SI	US	/	?	O	-	o	DEL

EBCDIC Table

			MSB																
			Bit 0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
			Bit 1	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
			Bit 2	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
			Bit 3	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LSB																			
Bit 7	Bit 6	Bit 5	Bit 4																
0	0	0	0	NUL	DLE	DS		SP	&	-									0
1	0	0	0	SOH	DC1	SOS						a	j			A	J		1
0	1	0	0	STX	DC2	FS	SYN					b	k	s		B	K	S	2
1	1	0	0	ETX	DC3							c	l	t		C	L	T	3
0	0	1	0	PF	RES	BYP	PN					d	m	u		D	M	U	4
1	0	1	0	HT	NL	LF	RS					e	n	v		E	N	V	5
0	1	1	0	LC	BS	EOB	UC					f	o	w		F	O	W	6
1	1	1	0	DEL	IL	PRE	EOT					g	p	x		G	P	X	7
0	0	0	1		CAN							h	q	y		H	Q	Y	8
1	0	0	1		EM						\	i	r	z		I	R	Z	9
0	1	0	1	SMM	CC	SM		>>	!		:								
1	1	0	1	VT				.	$	,	#								
0	0	1	1	FF	IFS		DC4	<	*	%	@								
1	0	1	1	CR	IGS	ENQ	NAK	(	)										
0	1	1	1	SO	IRS	ACK		+	;	>	=								
1	1	1	1	SI	IUS	BEL	SUB	|	-	?									

Using ASCII/ EBCDIC Tables

Humanly Readable	**ASCII** B6 … B0	**EBCDIC** B0 … B7
A	**1000001 (= 65)**	**11000001 (=193)**
x	**1111000 (= 120)**	**10100111 (= 167)**
5	**0110101 (= 53)**	**11110101 (= 245)**
LF (Line Feed)	**0001010 (= 10)**	**00100101 (= 37)**

UNICODE and ISO 10646

- Used to support non-Latin characters, e.g., Arabic, Chinese, etc.
- Unicode version 1.1 and ISO 10646 are identical and were released in 1993.
- Unicode is a 16-bit code supporting up to 2^{16} = 65,536 characters.
- It is backward compatible with the ASCII-the first 128 characters are identical to ASCII.
- Windows OS supports Unicode.

Next

Data Transmission Techniques

- Serial/Parallel
- Synchronous/Asynchronous
- Half/Full Duplex
- Modulation/Demodulation
- Data Compression

Parallel Communication

- Multiple data, control wires, etc.
  - One bit per wire
- Typically used when connecting devices on same IC or same circuit board
- High data throughput with short distances
  - Bus must be kept short
    - Long parallel wires result in high capacitance values which requires more time to charge/discharge
    - Data misalignment between wires increases as length increases
- Higher cost, bulky
  - Insulation must be used to prevent noise from each wire from interfering with the other wires.
  - A 32-wire cable connecting two devices together will cost much more than a two-wire cable.

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Serial Communication

- Single data wire, possibly also control wires
- Bytes transmitted one bit at a time
- Higher data throughput with long distances
  - Less average capacitance, so more bits per unit of time
- Cheaper, less bulky
- More complex interfacing logic and communication protocol
  - Sender needs to decompose word into bits
  - Receiver needs to recompose bits into word
  - Control signals often sent on same wire as data (start, stop, parity bits etc.) - increasing protocol complexity

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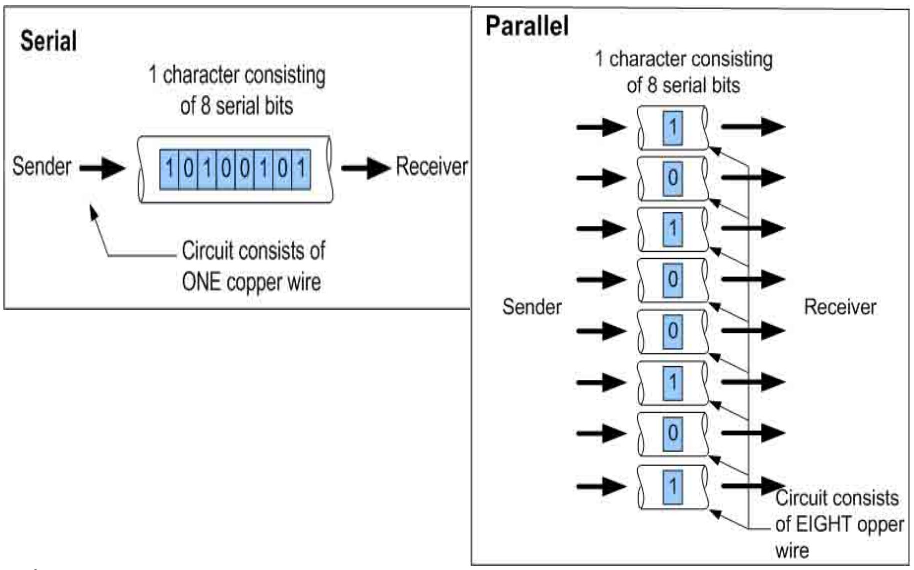
Serial vs. Parallel Transmission



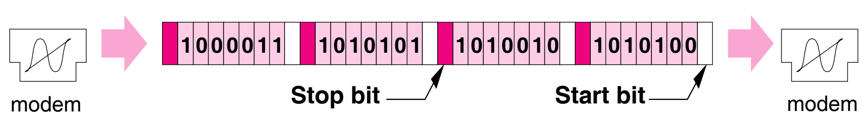
Serial vs. Parallel Transmission

Transmission Characteristics	Serial	Parallel
Transmission Description	Bytes transmitted in a linear fashion, one bit at a time.	Bytes in a single character transmitted simultaneously.
Comparative Speed	Slower	Faster
Distance Limitation	Farther	Shorter
Application	Between two computers, Computer to an external modem, Computer to a slow printer	Within a computer's bus, from computer to parallel high speed printer
Cable Description	All bits travel down a single wire, one bit at a time.	Each bit travels down its own wire, simultaneously with other bits.

Asynchronous vs. Synchronous Transmission

- Data is transmitted serially over medium.
- For receiver to sample incoming bits properly, it must know
  - Arrival time, and
  - Duration of each bit
- To receive bits correctly, transmitter and receiver need to be synchronized.
- Two solutions:
  - Asynchronous
  - Synchronous

Asynchronous Transmission



Characteristics:

- Data is sent one character at a time.
- Each character has a start & stop bit.
- Synchronization is re-established for each character.
- Time (interval) between characters is unsynchronized and of random/ undetermined length.

Efficiency (1000 character transmission)

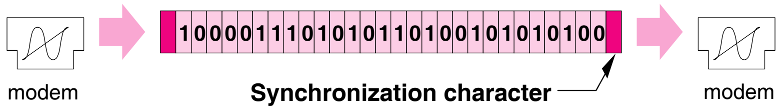
Control / overhead bits: 1 start and 1 stop bits per character.

2 control bits per character x 1000 characters = 2000 control bits

7000 data bits / 9000 total bits = 77.7% efficient

Efficiency is low because 2 bits for 7/8 bits are overhead.

Synchronous Transmission



Characteristics:

- Data is sent as a block of uninterrupted characters.
- Synchronization characters precede and follow the data block.
- The data block may be as large as 1000 uninterrupted characters (or more).
- Synchronization is maintained whether data is actually being transmitted or not. So modems remain synchronized during idle time.

Efficiency (1000 character transmission)

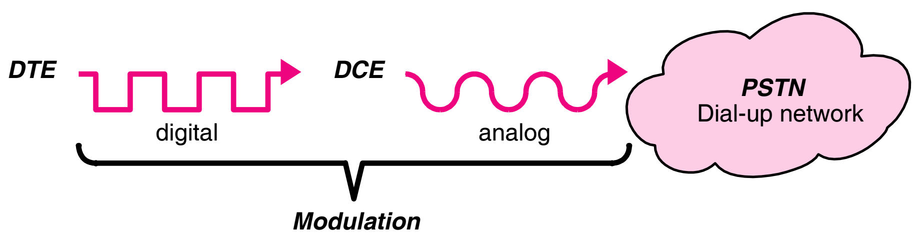
Control / overhead bits: 48 total control bits per block using HDLC **(High-level Data Link Control)** protocol. It embeds information in a data frame.

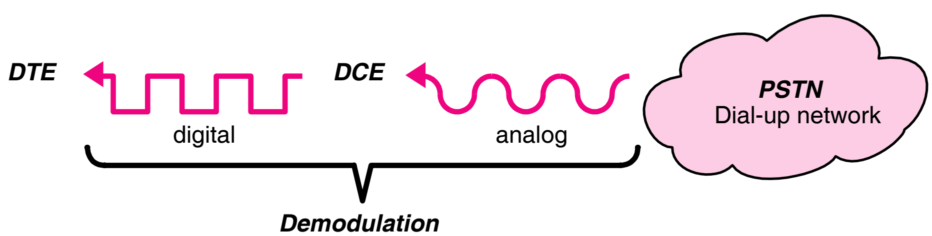
48 control bits per block x 1 block = 48 control bits

7000 data bits / 7048 total bits = 99.3% efficient

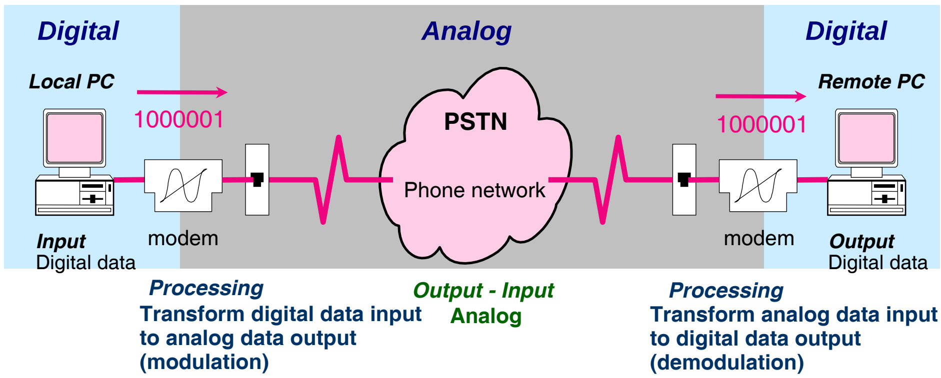
Efficiency is much better than asynchronous.

Modulation vs. Demodulation





Modem Based Communication Channels



- The dial-up modem allows connections through the phone network.

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Half-Duplex vs. Full-Duplex

- Data communications sessions are bi-directional in nature.
- There are two environments available for handling this bi-directional traffic: **full** and **half** duplex.
- In a full duplex communications environment both devices can transmit at the same time.
- In a half duplex environment you can only hear or talk at any given point of time.
- Given the choice of full or half duplex it is usually better to choose full duplex.

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Half-Duplex Mode

- Bidirectional transmissions, but only one direction at a time.
- After initial handshaking only one modem can transmit.
- Modems can reverse their roles.
- Role reversal is known as turn-around time.
- Turn-around time may take 0.2 sec or more.
- Though it is small but may have an impact if done more often.
- E.g., Walkie-Talkie

Full-Duplex Mode

- Data transmissions can take place in both directions simultaneously.
- Usually used in leased line circuits.

- **Simplex Mode:** only unidirectional transmissions are possible.

Frequency, Spectrum and Bandwidth

- Time domain concepts:
  - **Continuous signal:** Varies in a smooth way over time.
  - **Discrete signal:** Maintains a constant level then changes to another constant level.
  - **Periodic signal:** Pattern repeated over time.
  - **Aperiodic signal:** Pattern not repeated over time.

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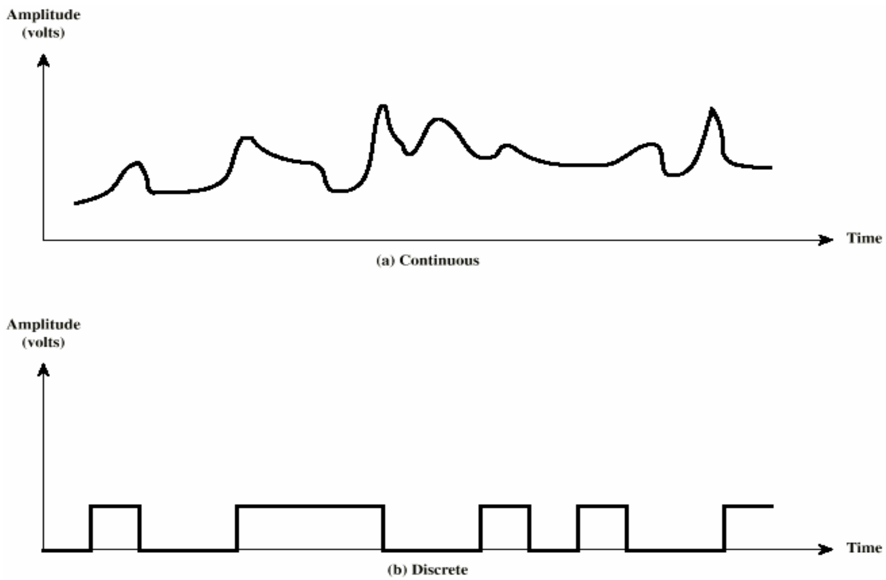
Continuous & Discrete Signals



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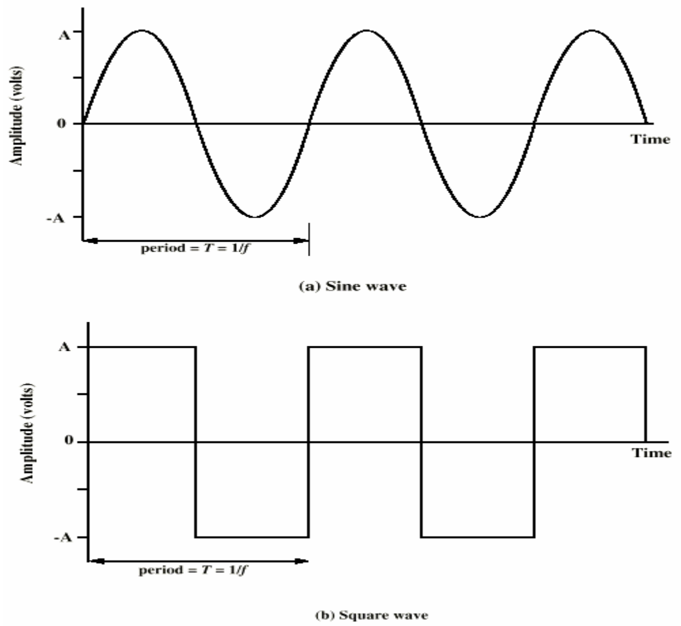
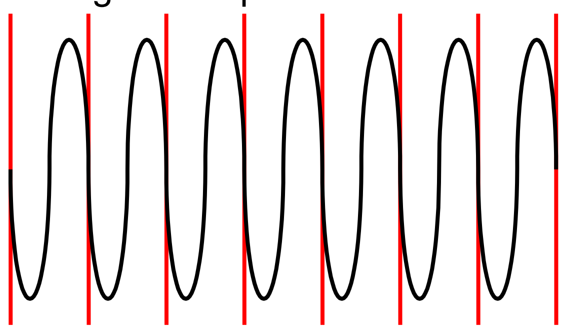
Periodic Signals



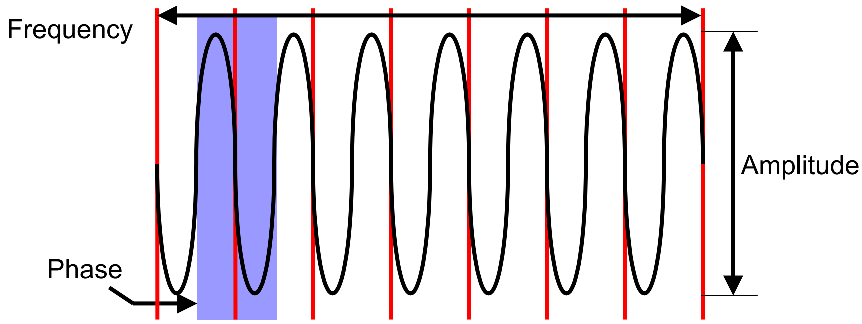
Carrier Waves

- To represent the discrete states 1s & 0s or bits of digitized data on a dial-up phone line, an analog wave must be able to be changed between at least two different states.
- This implies that a normal or neutral wave must exist that can be changed to represent 1s & 0s.



Carrier Waves

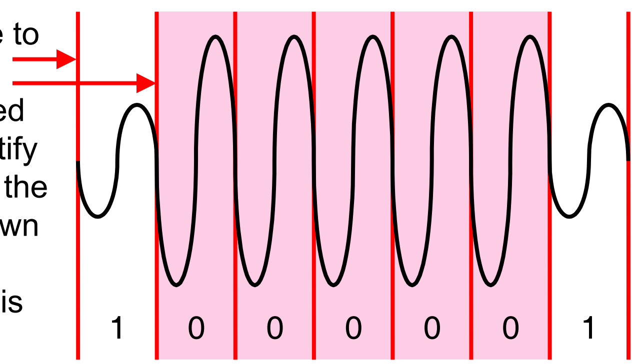
- There are three properties of a wave that can be modulated or altered:
  - Amplitude
  - Frequency
  - Phase.



Amplitude Modulation

(Frequency and Phase constant)

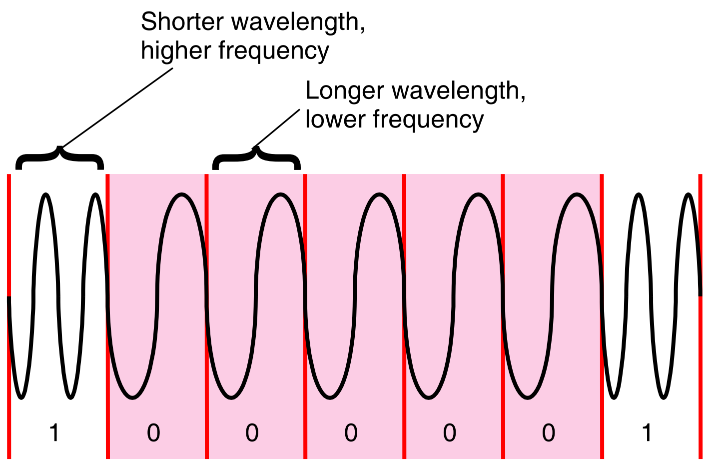
The vertical lines are to identify a 1 or 0 from each other. This timed opportunities to identify 1s & 0s by sampling the carrier wave are known as signaling events. One signaling event is called as **baud**.



ASCII: letter A

Frequency Modulation (FSK)

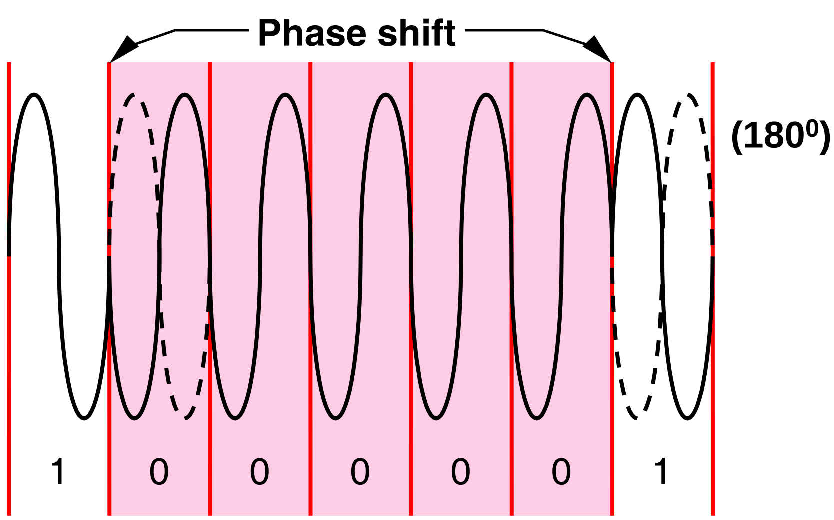
(Amplitude and Phase constant)



ASCII: letter A

Phase Modulation (PSK)

(Amplitude and Frequency constant)



ASCII: letter A

Increasing Transmission Efficiency

- Number of signaling event per second is known as baud rate or bps or transmission rate.
- Two bits per baud - transmission rate measured in bps would be twice the baud rate.
- There are two ways in which a given modem can transmit data faster:
  - increase the signaling events per second, or baud rate.
  - find a way for the modem to interpret more than one bit per baud.

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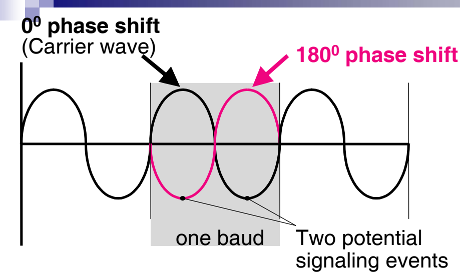
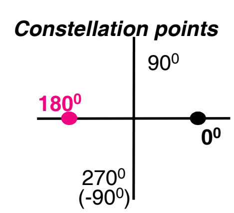
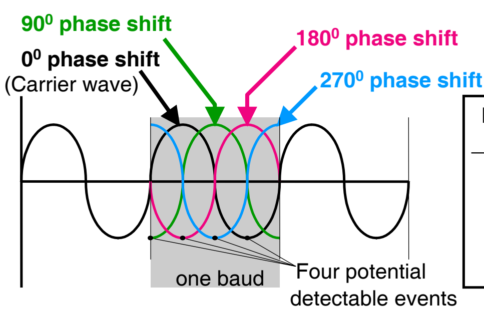


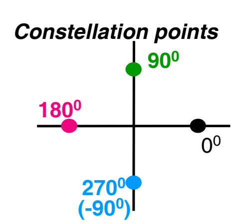
Phase shift	Interpreted bit pattern
0^0	0
180^0	1





Quadrature Phase Shift Keying (QPSK)

Phase shift	Interpreted bit pattern
0^0	00
90^0	01
180^0	10
270^0	11



Relationship Between Number of Phase Shifts and Number of Potential Detectable Events

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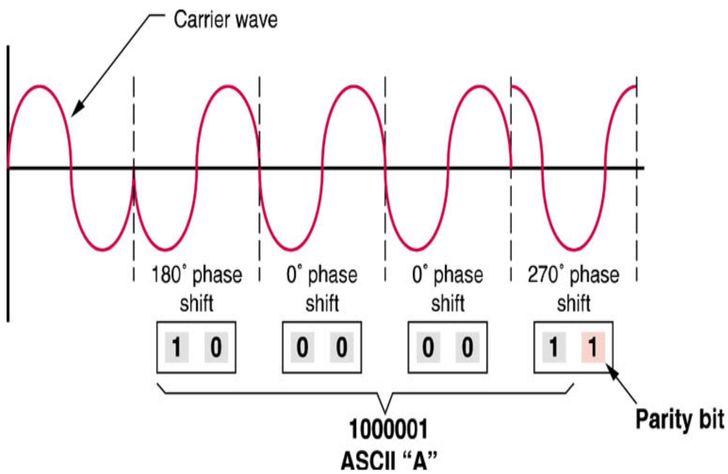
Differential Quadrature Phase Shift Keying

- This technique improves transmission rate by increasing the number of events per baud.



Phase shift	Interpreted bit pattern
0˚	00
90˚	01
180˚	10
270˚	11

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QAM

- How far can we go with increasing the number of phase shift angles? One limiting factor to increasing the bits/baud in phase shift modulation is the quality of the telephone line.
- 16 different phase shifts would require reliable detection of phase shifts of as little as 22.5^0.
- 16 different detectable events can also be produced by varying both phase and amplitude. Modern modems use a modulation technique that varies both phase and amplitude called as **QAM**.

Phase shift	Interpreted bit pattern
0^0	**0000**
22.5^0	**0001**
45^0	**0011**
67.5^0	**0100**
90^0	**0101**
112.5^0	**0110**
135^0	**0111**
.	.
.	.
337.5^0	**1111**

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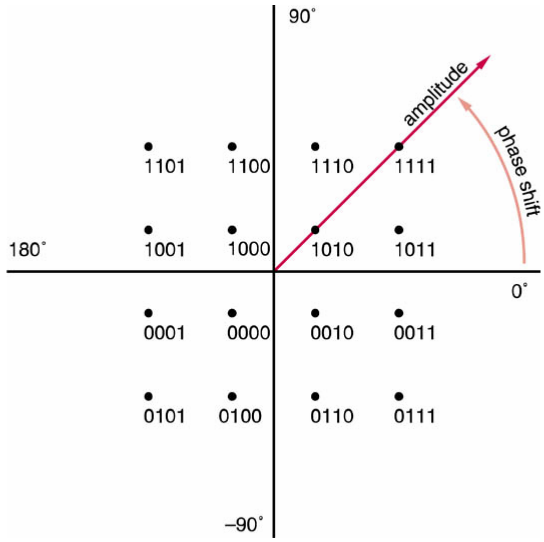
QAM

- Differences in phase are represented in degrees around the center of the diagram, whereas differences in amplitude are represented by linear distance from the center of the diagram.



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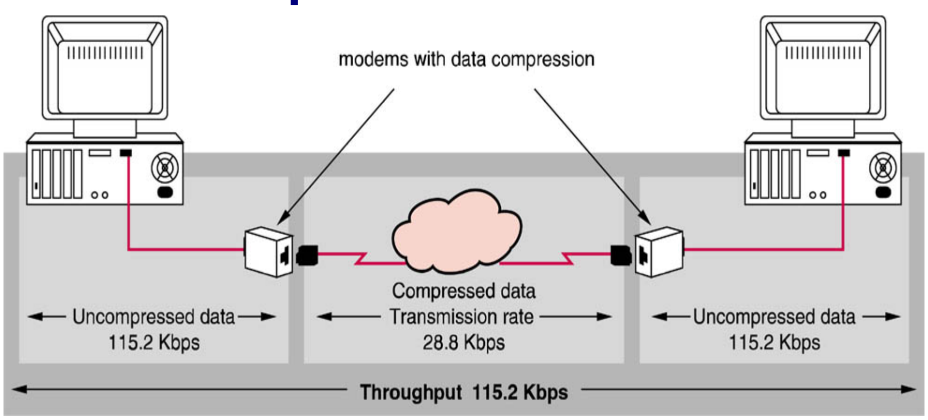
Data Compression



- Data compression techniques improve throughput.
- *Actual* transmission rate is still 28.8Kbps over the phone line.
- Both modems should support the same data compression standard.

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Data Compression

- The sending device replaces strings of repeating character patterns with a special code that represents the pattern.
- The code is significantly smaller than the pattern it represents.
- This results in the increase of amount of data sent between the sending device and the receiving device (also known as throughput).

Next

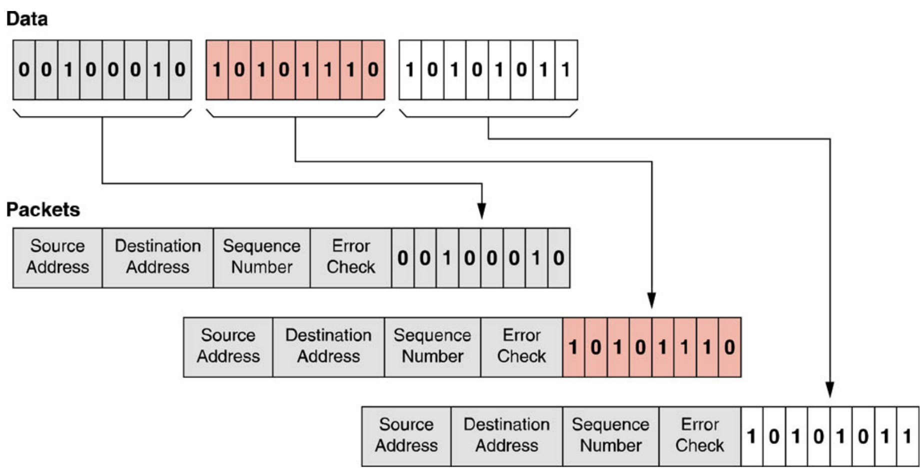
Data Communication Techniques

- Packetization
- Multiplexing
- Switching

Packetization

- The process of dividing the data stream flowing between devices into structured blocks is known as **packetization**.
- A **packet** is a group of data bits organized in a predetermined, structured manner, to which overhead and management data is added to ensure error-free transmission.
- A packet may also be called a frame, cell, block, a data unit, etc…

Packetization



- Data stream is divided into 3 packets (8-bits each).
- Header information is added to the data portion.

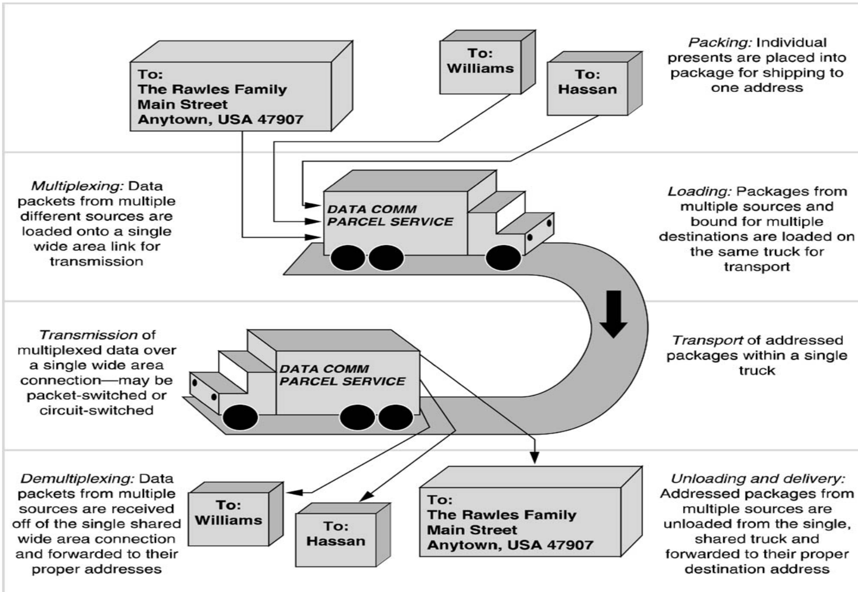
Packetization

- The predetermined structure of a packet is critical.
- Must know the location of every data bit within the packet because it has a specific meaning (i.e. source address, destination address, error check, sequence number, etc…)
- Through the use of standards, devices know the number of bits in each section; the header, data portion and trailer.

Multiplexing

- Combining the packetized data on one shared link.
- Multiplexing is transmitting 2 or more signals over a single channel.
- Three types of multiplexers are commonly used.
  - Frequency Division Multiplexers (FDM)
  - Time Division Multiplexers (TDM)
  - Statistical Time Division Multiplexers (STDM)
- In general, multiplexers from different vendors are not compatible.

Multiplexing



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Frequency Division Multiplexers

- FDMs operate by dividing the available bandwidth into multiple sub-channels.
- Each connected terminal has a **portion of the total bandwidth** available for 100% of the time.
- Guardbands are used to separate these sub-channels, making sure that the channels don't interfere with each other.
- FDMs generally incorporate the modem function within the unit.
- FDMs are difficult to expand.
- They have lost popularity.

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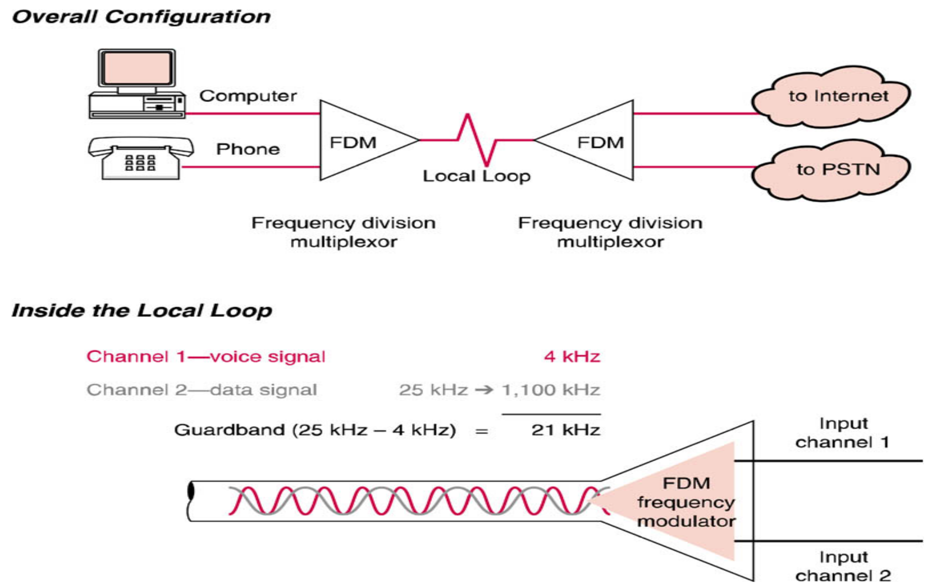
Frequency Division Multiplexing



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Time Division Multiplexers

- A TDM allocates a constant time slice to every device.
- Each connected terminal has 100% of the total bandwidth available for a **portion of the time**.
- A message frame is assembled by the TDM that contains data from each device.
- The TDM at the receiving end will un-assemble the message frame and transmit to the corresponding receiving devices.
- A central clock or timing device gives each input device its allotted time to empty its buffer into an area of TDM where the combined data from all of the input devices is combined into a single message frame.

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Time Division Multiplexers (cont'd)

- No addressing info is required since a terminal's data can be identified by its position in the message frame.
- If a terminal has nothing to send, its allotted space in the message frame is filled with blanks or null characters making inefficient use of the shared circuit connecting the two TDMs.
- The process of checking on each connected terminal to see if any data is ready to be sent is known as **polling**.
- It is possible to use either bit or byte message framing.

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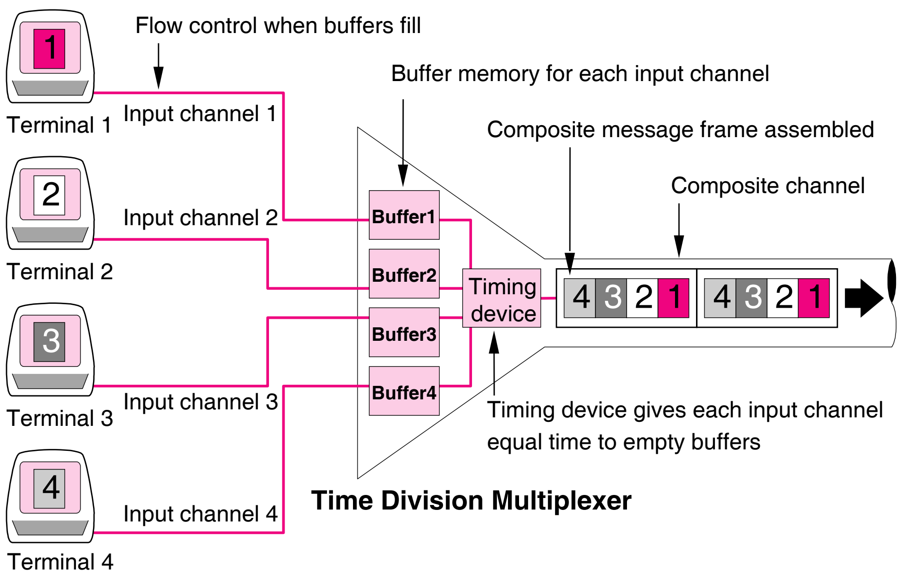
Time Division Multiplexing



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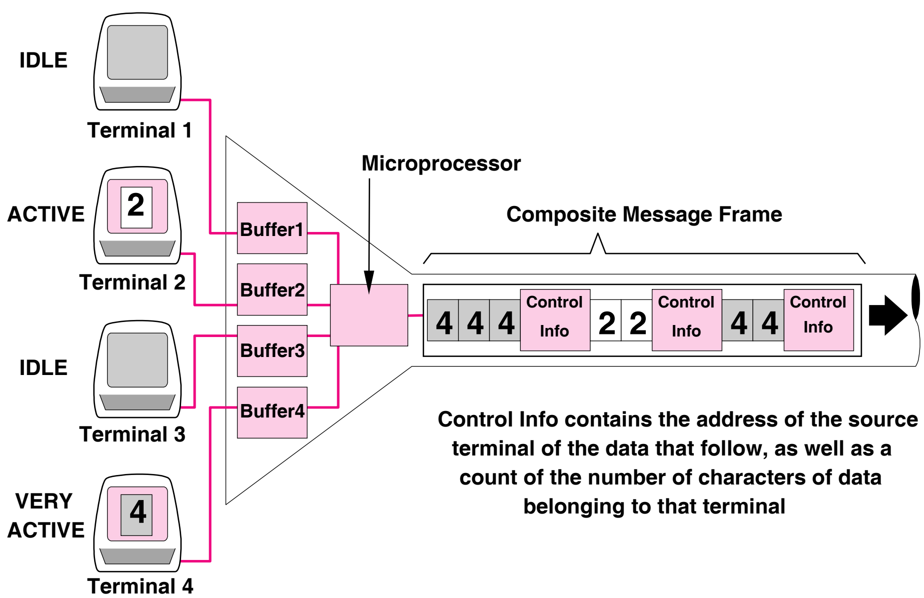
Statistical Time Division Multiplexers

- STDMs eliminate "idle time" allocations to inactive terminals.
- It is possible to allocate more time slices to some terminals.
- It uses dynamic time slot allocation.
- It adds control information to each terminal's data.
- The sum of all the input terminal speeds can exceed that of the actual WAN circuit.
  - this is made possible through buffering and flow control.

STDMs Make Efficient Use of Composite Bandwidth



Statistical Time Division Multiplexers
(cont'd)

- STDM works on the principle that not all of the terminals will want to transmit at the same time.
- This allows full use of the circuit, and generally better performance for the terminals.

WaveLength Division Multiplexing (WDM)

- WDM can be used only on fiber optic circuits
- It works by sending multiple simultaneous bits of information using different wavelengths of light (colors).
- Relatively new!

Switching

- It is simple to establish a direct connection between two devices. Data travel directly across the connection.

- But, if the devices do not have the direct connection?

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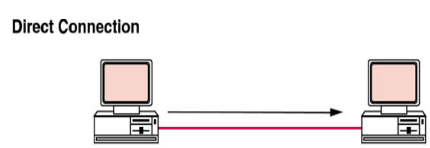
Switching



- Switching allows temporary connections to be established, maintained and terminated between message sources and message destinations.
- There are two primary switching techniques employed: **circuit switching** and **packet switching.**

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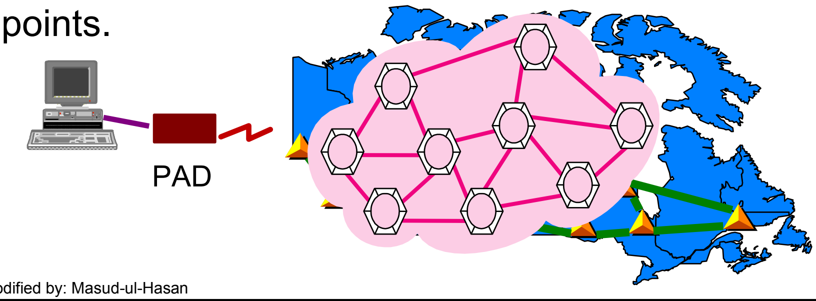
Switched Networks

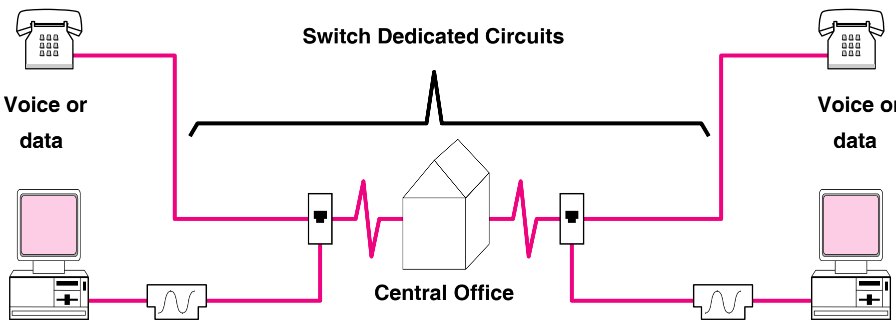
- **Circuit switching** involves establishing a direct (permanent or temporary) connection between two or more points.
- **Packet switching** involves sending a message through a network "cloud" to reach its destination.
- The network "cloud" is a number of interconnected nodes offering multiple connection paths between two points.



Circuit Switching

- The work to create a signal path is done up front; a switch fabric creates a direct path between the source and the destination.
- Communication takes place just as if the temporary circuit were a permanent direct connection.
- The switched dedicated circuit makes it appear to the user of the circuit as if a wire has been run directly between the communicating devices.

Circuit Switching



All data or voice travel from source to destination over the same physical path

- In a **circuit switched network**, a switched dedicated circuit is created to connect the two or more parties, eliminating the need for source and destination address information.

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Packet Switching

- In a **packet switched network**, packets of data travel one at a time from the message source to the message destination.
- The physical path taken by one packet may be different than that taken by other packets in the data stream.
- The path is unknown to the end user.
- A series of **packet switches** pass packets among themselves as they travel from source to destination.

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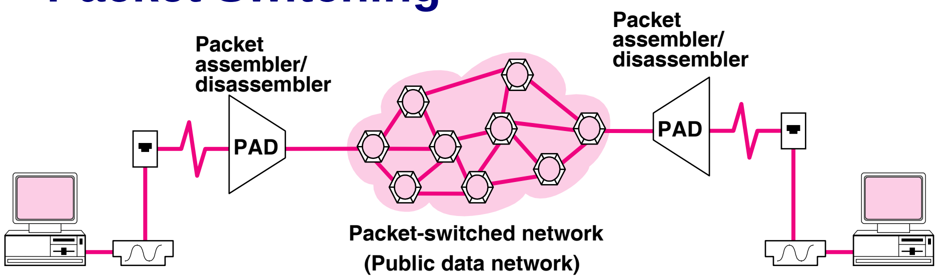
Packet Switching



Data enter the packet-switched network one packet at a time;
packets may take different physical paths within packet-switched networks.

- PDN is a network established and operated by a telecommunications administration, or a recognized private operating agency, for the specific purpose of providing data transmission services for the public. A variety of protocols can be used like frame relay, ATM, IP, etc.

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Packet-Switched Networks (cont'd)

- The user has no control over the route that a packet takes to reach its destination.
- Packets need a sequence number because there is no guarantee that the packets will always choose the same path, and some paths might be faster than others.
- The Packet Assembler-Disassembler (PAD) is responsible for sending/receiving packets.
- Routing decisions are made by the packet switches ().
  - routing is based on available circuits, speed, congestion, etc.

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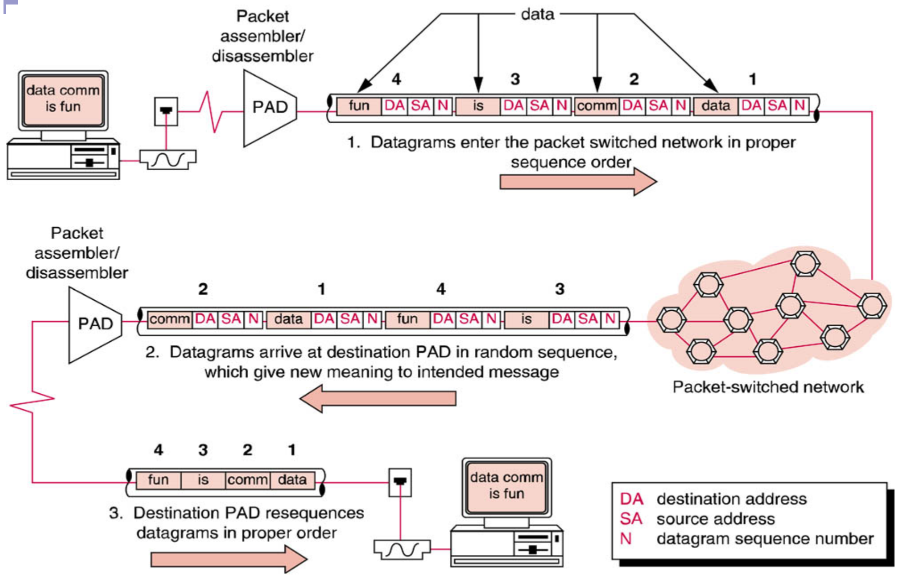
Connectionless vs. Connection-oriented packet switched services

- In order for a switch to process any packet of data, packet address information be included on each packet.
- Each switch reads and processes the packet by making routing decisions based upon the destination address and network conditions.
- The full destination address uniquely identifying the ultimate destination of each packet is known as the **global address**.

Connectionless/Datagrams

- Message pieces may arrive out of order at the destination due to the speed and condition of the alternate paths within the Packet Switched Network.
- The data message must be pieced back together in proper order by the destination PAD before final transmission to the destination address.
- These self-sufficient packets containing full source and destination address information plus a message segment are known as **datagrams**.
- A switching methodology in which each datagram is handled and routed on an individual basis resulting in the possibility of packets traveling over a variety of physical paths on the way to their destination is known as **connectionless** packet network.



- Datagram delivery in a packet Switched Network

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Connection-Oriented

- It establishes virtual circuits enabling the message packets to follow one another in sequence, down the same connection or physical circuit.
- This connection from source to destination is set up by special packets known as **call setup packets**.
- Once they determined the best path and establish the virtual circuit, the message carrying packets follow one another in sequence along the virtual circuit or logical channel.
- Packets do not need the global address instead an **LCN** (Logical Channel Number) included in each.
- Reliable-because check sum & error detection with ACK/NAK is possible.

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Packet-Switched Networks

- There are two types of connections that can be made with packet-switched networks:
  - switched virtual circuits **(SVC):** the virtual circuit is terminated when the complete message has been sent. Similar to phone call.
  - permanent virtual circuit **(PVC):** the virtual connection is permanent, it is similar to a standard leased line (in concept).

Connection-oriented vs. Connectionless Packet Switched Networks

	Overhead	Greatest Strength	Call Set-up	Addressing	Also Known As...	Virtual Circuit	Error Correction	Flow Control
Connectionless	Less	Ability to dynamically reroute data	None	Global	Datagram unreliable	None	Left to end-user devices	Left to end-user devices
Connection-oriented	More	Reliability	Yes	Local logical channel number	Reliable Virtual circuit	Created for each call, virtual circuit table established	By virtual circuit	By virtual circuit

Next

Error Control Techniques

- Error Detection
- Error Prevention

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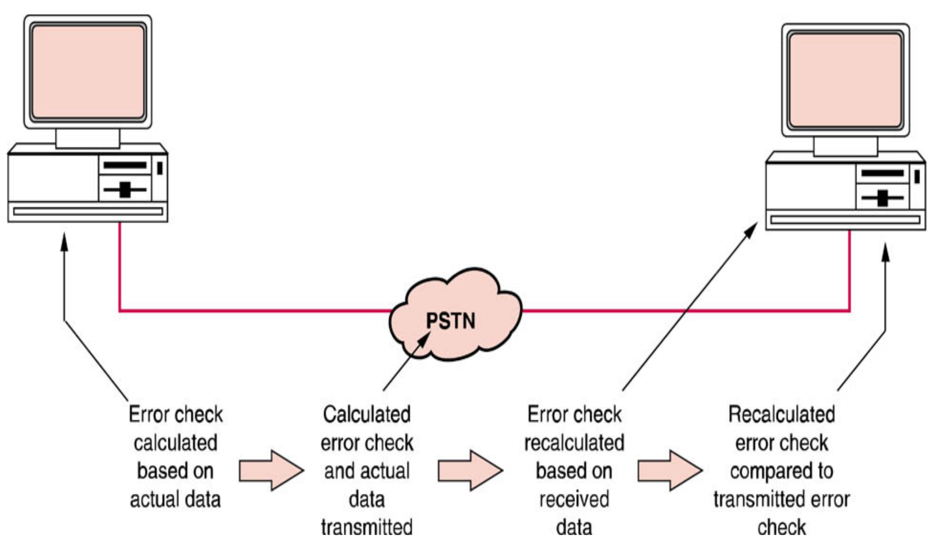
Error Detection Process



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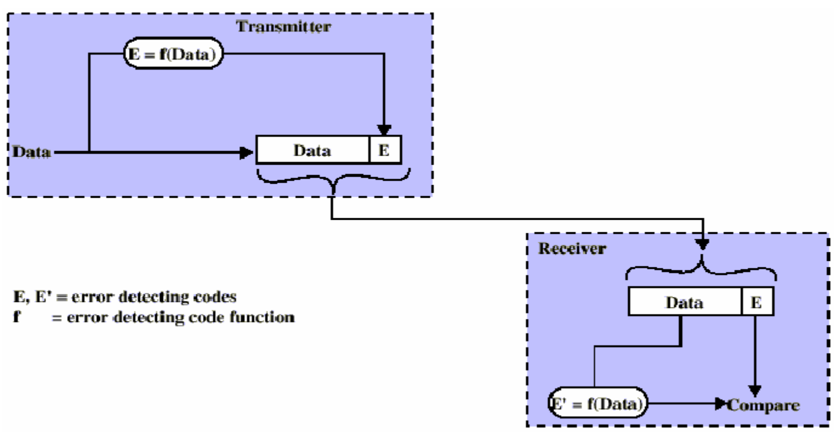
Error Detection Process

- The transmitting and receiving devices agree on how the error check is to be calculated.
- The transmitting device calculates and transmits the error check along with the transmitted data.
- The receiving device re-calculates the error check based on the received data and compares its newly calculated error check to the error check received with the data.
- If the two error checks match, everything is fine. If they do not match, an error has occurred.

Error Detection

- Additional bits (calculated error check) added by transmitter for error detection code.



Next

Error Detection Techniques

- Parity (VRC)
- Longitudinal Redundancy Checks (LRC)
- Checksums
- Cyclic Redundancy Checks (CRC)

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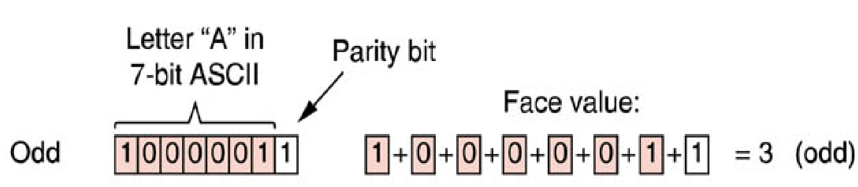
Parity

- **Parity**-also known as Vertical Redundancy Check (VRC), simplest error detection technique. It can be even or odd.
- Parity works by adding an error check bit to each character.

Letter "A" with odd and even parity



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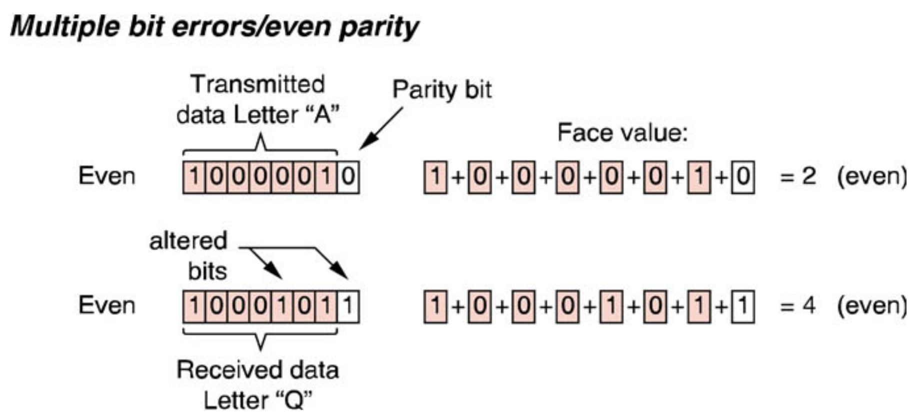
Parity Checking

- Limitation-It can't check even number of errors.



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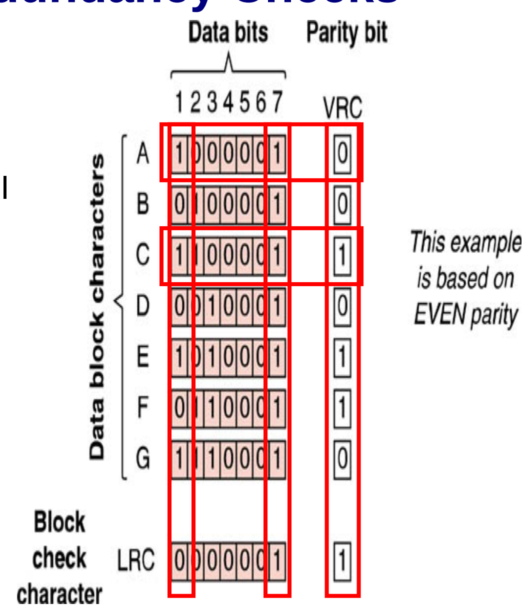
Longitudinal Redundancy Checks

- **Longitudinal Redundancy Checks** (**LRC**) seek to overcome the weakness of simple, bit-oriented one directional parity checking.
- Block oriented error detection.
- LRC adds a second dimension to parity.
- LRC improves parity checking at the cost of extra data transmitted.



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Checksums

- **Checksums** are also block-oriented error detection characters added to a block of data characters.
- A checksum is calculated by adding the decimal face values of all of the characters sent in a given data block and sending only the least significant byte of that sum.
- The receiving modem generates its own checksum and compares the locally calculated checksum with the transmitted checksum.

Cyclic Redundancy Check (CRC)

- More sophisticated
- A sending device applies a 16- or 32-bit polynomial to a block of data that is to be transmitted and appends the resulting cyclic redundancy code to the block.
- The receiving end applies the same polynomial to the data and compares its result with the result appended by the sender.
- A 16- or 32-bit cyclic redundancy code detects all single and double-bit errors and ensures detection of 99.998% of all possible errors.

Error Correction

- The receiving modem has detected an error and requests a re-transmission of the erroneous block of data from the sending modem.
- The transmitting modem retransmits the incorrect data.
- Three main issues:
  - How is retransmission requested?
  - How much data must be retransmitted?
  - How is retransmission time minimized?

Automatic Retransmission Request

- **ARQ** (Automatic Retransmission reQuest) is a general term to describe this process.
- ARQ turns unreliable data link into a reliable one.
- Request for retransmission may occur in different ways:
  1. Discrete ARQ: Stop and Wait
  2. Continuous ARQ: Go Back N
  3. Selective ARQ: Selective Reject

Discrete ARQ

- Also known as: Stop and wait protocol.
- The receiving modem sends an ACK (positive acknowledgment) for every block correctly received. ***Transmitter will then send next block of data.***
- A negative acknowledgment or NAK for *every* erroneous block of data received. ***Transmitter will then send same block of data again.***

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Continuous ARQ

- Eliminates the requirement for transmitting device to wait for an ACK or NAK before transmitting the next block of data. Eliminates a great deal of idle time.
- Also known as: Go-Back N Protocol
- Sliding Window Protocols-a block sequence number is appended to each block of data transmitted.
- ACK signals are sent much less frequently.
- A NAK is sent (along with the block number) if an error occurs.
- Transmitting modem slides its transmission window back to the block number in error and resumes transmission from that point.

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Selective ARQ

- Also known as Selective Reject or Selective retransmission.
- Only rejected blocks are retransmitted rather than the block in error and all subsequent blocks.
- Subsequent blocks are accepted by the receiver and buffered.
- Minimizes number of retransmitted blocks and time.

Flow Control

- Blocks of data are saved in **buffer memory** in sequence order in which it was transmitted.
- The constant storage and retrieval of blocks of data from this finite amount of memory needs some management. This is called as **flow control**.
- The flow control software constantly monitors the amount of free space available in buffer and tells the sending device to stop sending data when there is insufficient storage space.
- When the buffer once again has room the sending device is told to resume transmitting.
- So a **signal** is sent from the receiving device to tell the transmitter to stop or resume the flow of data. Two types:
  - Hardware Flow Control
  - Software Flow Control