Data Communications for a Global Environment

Improving Server Performance

- Software improvements
  - Choose a faster NOS
  - Fine tune network and NOS parameters such as
    - Amount of memory used for disk cache
    - Number of simultaneously open files
    - Amount of buffer space
- Hardware improvements
  - Add a second server
  - Upgrade the server's CPU
  - Increase its memory space
  - Add more hard disks
  - Add a second NIC to the server

6-49

Data Communications for a Global Environment

Improving Disk Drive Performance

- Especially important, since disk reads are the slowest task the server needs to do
- Consider Redundant Array of Inexpensive Disks (RAID)
  - Replacing one large drive with many small ones
  - Can be used to both improve performance and increase reliability
  - Building redundancy into the hard drives so drive failure does not result in any loss of data

6-50

Data Communications for a Global Environment

Improving Circuit Capacity

- Upgrade to a faster protocol
  - Means upgrading the NICs and possible cables
  - Examples:
    - Upgrading the network from 10Base-T to 100Base-T
    - Upgrading the segment to the server from 10Base-T to 100Base-T
- Increase number of segments to server
  - Adding additional NIC cards to the servers
    - Increasing the number of ways to access to server
    - Ideal number of NICs/server = 3
      - More NICs may affect server's processing capacity

6-51

Data Communications for a Global Environment

Network Segmentation

6-52

Data Communications for a Global Environment

Reducing Network Demand

- Move files to client computers
  - Such as heavily used software packages
- Install disk caching software on client machines
  - Reduces the need to access files stored on the server
- Move user demands to off peak times
  - Encourage users to not use the network as heavily during peak usage times such as early morning or after lunch
  - Delay some network intensive jobs to off-peak times, such as run heavy printing jobs at night

6-53

Data Communications for a Global Environment

Improving LAN Performance - Summary

- Increase Server Performance
  - Software: Fine-tune the NOS settings
  - Hardware:
    - Add more servers and spread the network applications across the servers to balance the load
    - Upgrade to a faster computer
    - Increase the server's memory
    - Increase the number and speed of the server's hard disk(s)
    - Upgrade to a faster NIC
- Increase Circuit Capacity
  - Upgrade to a faster circuit
  - Segment the network
- Reduce Network Demand
  - Move files from the server to the client computers
  - Increase the use of disk caching on client computers
  - Change user behavior

6-54

Data Communications for a Global Environment

Lecture 16

1

Chapter 7

Wireless Local Area Networks

7 - 2

Three categories of wireless technologies:
Wi-Fi, WiMAX and BlueTooth

- All Three of these technologies us layer 2 (Data Link) protocols.

Thus these protocols have to be compatible with the layer above it (Network Layer) and the layer below it (The physical layer). These must meet the needs of the wireless protocols.

7 - 3

Wireless LANs (WLANs)

- At the physical layer, WLAN's use radio or infrared frequencies to transmit signals through the air (instead of cables)
- Basic Categories
  - Use of Radio frequencies (FOCUS of this chapter)
    - 802.1x family of standards (aka, Wi-Fi)
  - Use of Infrared frequencies (Optical transmission)

7 - 4

Wireless LANs (WLANs)

- Microwave and Infrared technologies were competing technologies in the early development stages.
  - Advantages of IR
    - o Easily reflected
    - o More secure than MW
    - o equipment is very inexpensive
  - Major drawback of IR
    - o Most rooms have intense IR background radiation.
- Microwave has become the predominant technology

7 - 5

Principal WLANs Technologies

- WI-FI
  - *IEEE 802.11x*
  - *802.11n is the newest standard*
  - *a = 5.0 GHz,*
  - *b = 2.4 GHz, speed = 11 Mbps, d = 328' indoors, 1312' outdoors*
  - *g = 2.4 GHz, speed = 54 Mbps, d = 328' indoors, 1312' outdoors*
  - *n = 2.4 GHZ, speed = 270 Mbps*
- WIMAX
  - IEEE 802.16
  - fixed or mobile
- Bluetooth
  - IEEE 802.15

7 - 6

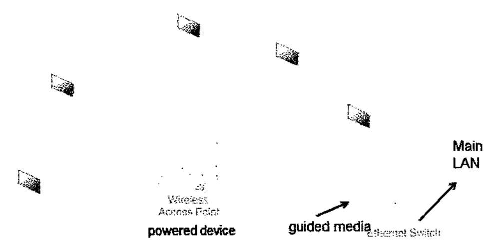
Components of WLANs

- Network Interface Cards
  - Many laptops come with WLAN cards built in
  - Is a radio transceiver transmits and receives over short distances
  - About 100-300 feet max transmission range
- Access Points (APs)
  - Plays the same role as a Hub in a wired Ethernet LAN
  - Connects a WLAN to a wired LAN usually through a 100baseT connection.
  - Requires a separate source of power
    a. via a normal electrical outlet
    b. POE power over Ethernet connection

7-7

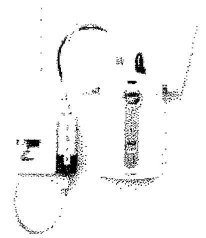
Components of WLANs

Access Points



8

Components of WLANs



Power over Ethernet AP

Advantages

Cheaper cabling — even category 5 cable is cheaper than USB repeaters.

A Gigabit of data per second to every device is possible, which exceeds 2009 USB and the AC powerline networking capabilities.

Global organizations can deploy PoE everywhere without concern for any local variance in AC power standards, outlets, plugs, or reliability.

Direct injection from standard 48 V DC battery power arrays; this enables critical infrastructure to run more easily in outages.

Symmetric distribution is possible. Unlike USB and AC outlets, power can be supplied at either end of the cable or outlet.

7-9

Components of WLANs

- Access Points (APs)
  - *Act as repeater to ensure that all computers within range of the AP hear the signals of all other computers*
  - Wireless NIC's never communicate with each other directly. They always transmit to an AP. This doubles the number of transmissions in an WLAN.
  - **Never place the server on the WLAN.**
  - There are two type of AP antennas: omnidirectional and directional.

7-10

Characteristics of Radio Frequency Transmission

- Most Countries allow WLANS to operate in two frequency ranges: 2.4 GHz and 5.0 GHz. Note that all other unlicensed devices also operate in this same range.
- The frequency range directly affects the data rates that can be transmitted. The higher the frequency the greater the data rate.
- Because radio waves are attenuated as they travel from the AP, the data rate drops off with distance from the AP. The higher the frequency the higher the attenuation rate and the shorter the transmission distance.
- The vendor provided transmission distance is often over-stated. Absorbing barriers such as walls, noise and other factors can substantially reduce the effective transmission distance.

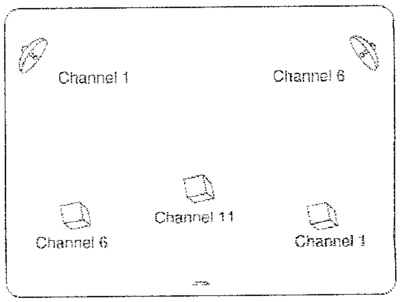
7-11

Characteristics of Radio Frequency Transmission

- Each AP in a LAN is set to transmit at a different frequency (or channel) from any other AP in receiving distance to avoid interfering with each other.
- When a computer on WLAN first starts up the NIC scans all of the channels within the appropriate frequency range and selects the one with the strongest signal strength.
- NIC's may scan for different channels if the user is roaming or the traffic on that channel becomes to busy.

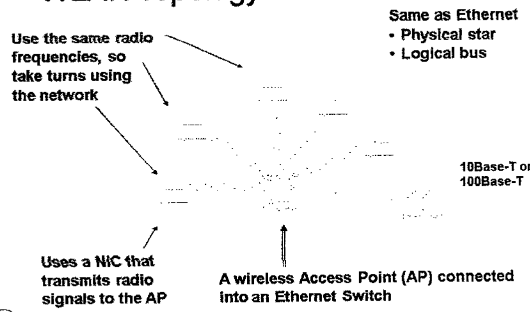
7-12

A WLAN Using Different Channels



7 - 13

WLAN Topology

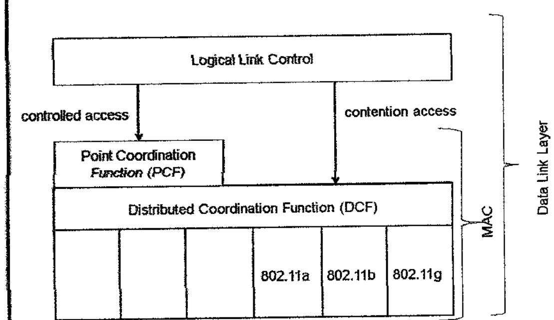


7 - 14

WLAN Media Access Control

- Uses CSMA/CA
  - CA → collision avoidance
  - A station waits until another station is finished transmitting plus an additional random period of time before sending anything
- May use two MAC techniques simultaneously
  - Distributed Coordination Function (DCF)
    - Also called "Physical Carrier Sense Method"
  - Point Coordination Function (PCF)
    - Also called "Virtual Carrier Sense Method"
    - Optional: (can be set as "always", "never", or "just for certain frame sizes")

7 - 15



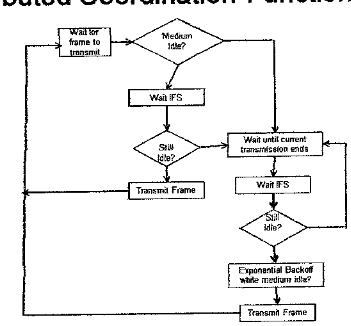
7 - 16

Distributed Coordination Function

- Relies on the ability of computers to physically listen before they transmit
  - When a node wants to send a message:
    - First listens to make sure that the transmitting node has finished, then
    - Waits a period of time longer
- Each frame is sent using stop-and-wait ARQ
  - By waiting, the listening node can detect that the sending node has finished and
  - Can then begin sending its transmission
  - ACK/NAK sent a short time after a frame is received,
  - Message frames are sent a somewhat longer time after (ensuring that no collision will occur)

7 - 17

Distributed Coordination Function



7 - 18

Point Coordination Function (PCF)

- Solves Hidden Node problem
  - Two computers can not detect each other's signals
    - A computer is near the transmission limits of the AP at one end and another computer is near the transmission limits at the other end of the AP's range
  - Physical carrier sense method will not work
- Solution
  - First send a Request To Send (RTS) signal to the AP
    - Request to reserve the circuit and duration
  - AP responds with a Clear To Send (CTS) signal,
    - Also indicates duration that the channel is reserved
  - Computer wishing to send begins transmitting

7 - 19

IEEE 802.11g

- Designed to combine advantages of 802.11a and 802.11b
  - Offers higher data rates (up to 54 Mbps) in 2.4 GHz band (as in .11b) with longer ranges
  - Backward compatible with 802.11b
    - .11b devices can interoperate with .11g APs
    - Price to pay: when an .11g AP detects an .11b device, it prohibits .11g devices from operating at higher speeds
- Uses the same topology as .11b
  - Provides 3-6 channels (depending on configuration)
  - 54 Mbps rate obtained within 50 meter range

7 - 20

IEEE 802.11n

- Is now showing up in production equipment
- Goal to provide high speed wireless networking
- Uses both the 2.4 and 5 GHz frequency ranges simultaneously
- Current drafts propose speeds of 100-200 Mbps

7 - 21

WI-FI as Public Internet Access

- Wi-Fi was intended to be used for indoor mobile wireless access
- Many providers have in airports and malls and other public places
- Political issues, not technical, interfere with the large scale provision of Wi-Fi

7 - 22

WIMAX (Worldwide interoperability for Microwave Acess)

- Commercial name for family of IEEE 802.16 standards
- Two primary types: Fixed and mobile
- Logical and physical topology same as 802.11 and shared Ethernet
- Uses controlled access with a version of 802.11 point coordination function
- Two types:
  - 802.16d (fixed point wireless access)
  - 802.16e (mobile user access)

7 - 23

WIMAX vs. Wi-Fi

Wi-Fi was originally intended to be a wireless extension of wired LAN.

WIMAX was intended for wireless MAN's.
- LOS fixed stations BWA is in the range of 30 Miles vs 300 ft for Wi-Fi.
- The range for mobile stations is 3 – 10 miles.

WIMAX operates on both licensed and unlicensed frequencies in the 2 – 11 GHz range and is less subject to interference than Wi-Fi

WIMAX can support QoS capabilities, and supports both LOS and NLOS capabilities. (to accomplish this Clearwire sets it cellular towers 1.5 miles apart.)

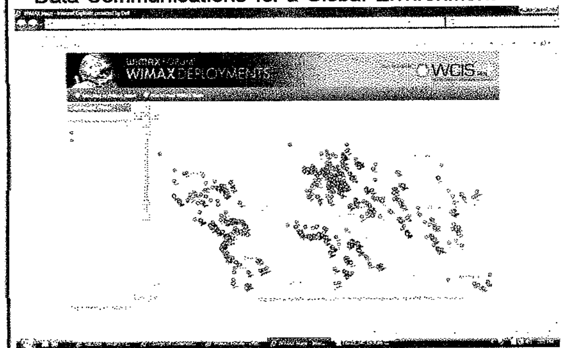
7 - 24

WIMAX vs. Wi-Fi

The 802.16 standard covers the spectrum range 2 GHz – 66 GHz, however the frequency ranges differ somewhat from country to country most Implementations are in the range from 2 GHz – 11 GHz.

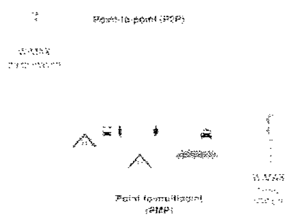
7-25

Data Communications for a Global Environment



26

Data Communications for a Global Environment



27

Data Communications for a Global Environment

Adaptive Antenna System (AAS)

Adaptive Antenna Systems (AAS) use beam-forming technologies to focus the wireless beam between the base station and the subscriber. This reduces the possibility of interference from other broadcasters as the beam runs straight between the two points.

28

Data Communications for a Global Environment

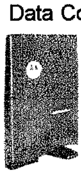


Figure 16: Indoor WiMAX CPE, courtesy Motorola

The most significant advantage of indoor over outdoor CPE is that it is installed by the subscriber. This frees the service provider from the expense of "truck roll" or installation. In addition, it can be sold online or in a retail facility thus sparing the service provider a trip to the customer site. Indoor CPE also allows a certain instant gratification for the subscriber in that there is no wait time for installation by the service provider. Currently, many telephone companies require a one month wait between placement of order and installation of T1 or E1 services. In addition, an instant delivery of service is very appealing to the business subscriber in the event of a network outage by the incumbent service provider.

29

Data Communications for a Global Environment

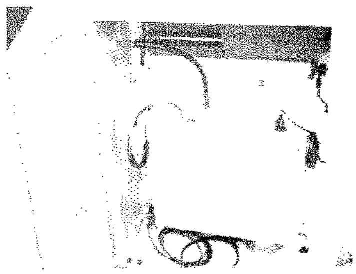
Outdoor CPE

Figure 15: An outdoor CPE device

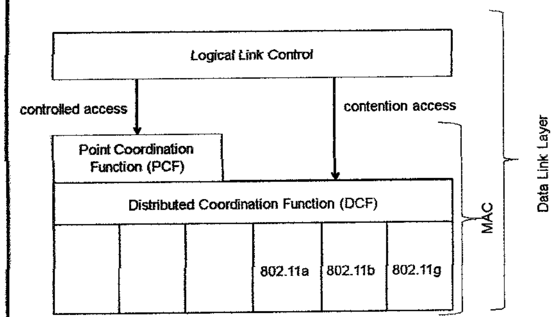
Outdoor CPE, very simply put, offers somewhat better performance over indoor CPE given that WiMAX reception is not impeded by walls of concrete or brick, RF blocking glass or steel in the building's walls. In many cases the subscriber may wish to utilize an outdoor CPE in order to maximize reception via a line of sight connection to the base station not possible with indoor CPE. Outdoor CPE will cost more than indoor CPE due to a number of factors including extra measures necessary to make outdoor CPE weather resistant.

30

Data Communications for a Global Environment



31



7-32

Issues to consider with WIMAX

- WIMAX is a competitor to public access Wi-Fi and cellular phone service
- WIMAX is incompatible with both
- Has an effective range that offers benefits
- Has controlled access, version of PCF
- Considerably more distance covered with WIMAX over Wi-Fi:
  - 802.16d has a maximum real world effective range of 5 miles, 802.16e is 6 miles

7-33

Bluetooth (IEEE 802.15)

- A standard for Wireless Personal Area Network (WPAN)
  - Provides networking in a very small area
    - Up to 10 meters (current generation)
    - Up to 100 meters (next generation)
  - Includes small (1/3 of an inch square) and cheap devices designed to
    - Replace short distance cabling between devices
      - Keyboards, mouse, handsets, PDAs, etc
  - Provides a basic data rate of up to 3 Mbps
    - Can be divided into several voice and data channels

7-34

Bluetooth Topology

- Uses the term "piconet" to refer to a Bluetooth network
  - Consists of 8 devices
    - A "master" device controlling other devices, "slaves"
      - Acts like an AP
      - Selects frequencies and controls access
      - All devices in a piconet share the same frequency range

7-35

Bluetooth Media Access Control

- Uses Frequency Hopping Spread Spectrum (FHSS)
  - Available frequency range (2.4000-2.4835) divided into 79 separate 1-MHz channels
  - A data burst transmitted using one channel, next data burst uses the next channel, and so on.
  - Channels changed based on a sequence and established by the slave and the master prior to the data transfers
    - 1,600 hops or channel changes per second
  - Also used to minimize interference
    - A noisy channel avoided eventually
- Not compatible with 802.11b
  - Potential interference problems (especially if many Bluetooth devices present close to .11b devices)

7-36

Data Communications for a Global Environment

Lecture 12

1

Data Communications for a Global Environment

Chapter 3

Physical Layer

3 - 2

Data Communications for a Global Environment

Physical Layer - Overview

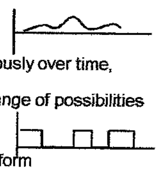
Network Layer
Data Link Layer
Physical Layer

- Includes network hardware and circuits
- Network circuits:
  - physical media (e.g., cables) and
  - special purposes devices (e.g., routers,switches and hubs).
- Types of Circuits
  - Physical circuits connect devices & include actual wires such as twisted pair wires
  - Logical circuits refer to the transmission characteristics of the circuit.
  - Physical and logical circuits may be the same or different. For example, in multiplexing, one physical wire may carry several logical circuits.

3 - 3

Data Communications for a Global Environment

Types of Data Transmitted



- Analog data
  - Produced by telephones
  - Sound waves, which vary continuously over time, *analogous* to one's voice
  - Can take on any value in a wide range of possibilities
- Digital data
  - Produced by computers, in binary form
  - information is represented as code in a series of ones and zeros
  - All digital data is either on or off, 0 or 1

3 - 4

Data Communications for a Global Environment

Types of Transmission

- Analog transmissions
  - Analog data transmitted in analog form
  - Example of analog data being sent using analog transmissions are radio (AM or FM)
- Digital transmissions
  - Made of discrete square waves with a clear beginning and ending
  - Computer networks send digital data using digital transmissions
- Data converted between analog and digital formats
  - Modem (modulator/demodulator): used when digital data is sent as an analog transmission
  - Codec (coder/decoder): used when analog data is sent via digital transmission

3 - 5

Data Communications for a Global Environment

Data Type vs. Transmission Type

	Analog Transmission	Digital Transmission
Analog Data	AM and FM Radio,	Pulse code modulation, MP3, CDs, *iPOD*, cellphones, VoIP
Digital Data	Dial up modem sending email from your house	Codes such as ASCII or EBCDIC run over Ethernet LANs

3 - 6

Data Communications for a Global Environment

Digital Transmission: Advantages

- Produces fewer errors
  - Easier to detect and correct errors, since transmitted data is binary (1s and 0s, only two distinct values)
  - A weak square wave can easily be propagated again in perfect form, allowing more crisp transmission than analog
- Permits higher maximum transmission rates
  - e.g., Optical fiber designed for digital transmission
- More efficient
  - Possible to send more digital data through a given circuit, circuit can be "packed"
- More secure
  - Easier to encrypt digital bit stream
- Simpler to integrate voice, video and data
  - Easier mix and match V, V, D on the same circuit, since all signals made up of 0's and 1's

3-7

Data Communications for a Global Environment

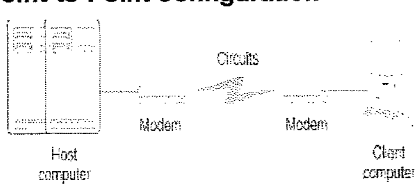
Circuit Configuration

- Basic physical layout of the circuit
- Configuration types:
  - Point-to-Point Configuration
    - Goes from one point to another
    - Sometimes called "dedicated circuits"
  - Multipoint Configuration
    - Many computer connected on the same circuit
    - Sometimes called "shared circuit"

3-8

Data Communications for a Global Environment

Point-to-Point Configuration



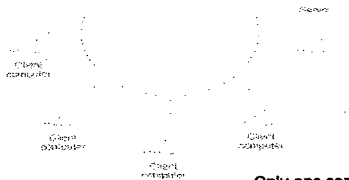
- Used when computers generate enough data to fill the capacity of the circuit
- Each computer has its own circuit to reach the other computer in the network (expensive)

3-9

Data Communications for a Global Environment

Multipoint Configuration

- Used when each computer does not need to continuously use the entire capacity of the circuit



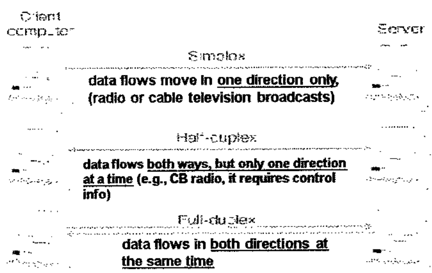
+ Cheaper (not as many wires) and simpler to wire

- Only one computer can use the circuit at a time

3 - 10

Data Communications for a Global Environment

Data Flow (Transmission)



3 - 11

Data Communications for a Global Environment

Selection of Data Flow Method

- Main factor: Application
  - If data required to flow in one direction only
    - Simplex Method
      - e.g., From a remote sensor to a host computer
  - If data required to flow in both directions
    - Terminal-to-host communication (send and wait type communications)
      - Half-Duplex Method
    - Client-server; host-to-host communication (peer-to-peer communications)
      - Full Duplex Method
- Capacity may be a factor too
  - Full-duplex uses half of the capacity for each direction

3 - 12

Data Communications for a Global Environment

Multiplexing

- Breaking up a higher speed circuit into several slower (logical) circuits
  - Several devices can use it at the same time
  - Requires two multiplexer: one to combine; one to separate
- Main advantage: cost
  - Fewer network circuits needed
- Categories of multiplexing:
  - Frequency division multiplexing (FDM)
  - Time division multiplexing (TDM)
  - Statistical time division multiplexing (STDM)
  - Wavelength division multiplexing (WDM)

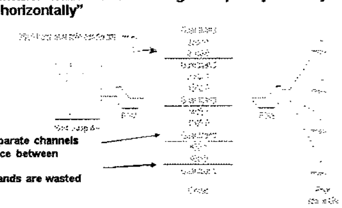
3 - 13

Data Communications for a Global Environment

Frequency Division Multiplexing

Makes a number of smaller channels from a larger frequency band by dividing the circuit "horizontally"

Used mostly by CATV



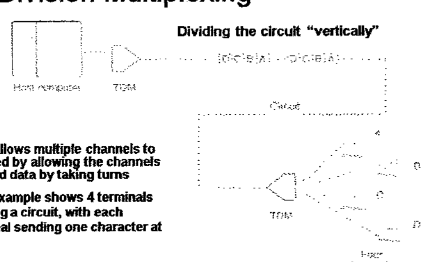
Guardbands needed to separate channels
- **To prevent interference between channels**
- **Unused frequency bands are wasted capacity**

3 - 14

Data Communications for a Global Environment

Time Division Multiplexing

Dividing the circuit "vertically"

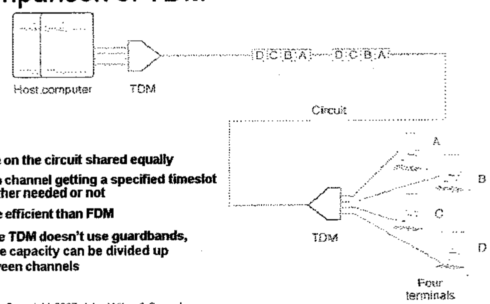


- **TDM allows multiple channels to be used by allowing the channels to send data by taking turns**
- **This example shows 4 terminals sharing a circuit, with each terminal sending one character at a time**

3 - 15

Data Communications for a Global Environment

Comparison of TDM



- **Time on the circuit shared equally**
- **Each channel getting a specified timeslot whether needed or not**
- **More efficient than FDM**
- **Since TDM doesn't use guardbands, entire capacity can be divided up between channels**

3 - 16

Data Communications for a Global Environment

Statistical TDM (STDM)

- Designed to make use of the idle time slots
  - In TDM, when terminals are not using the multiplexed circuit, timeslots for those terminals are idle
- Uses non-dedicated time slots
  - Time slots used as needed by the different terminals
- Complexities of STDM
  - Additional addressing information needed
    - Since source of a data sample is not identified by the time slot it occupies
  - Potential response time delays (when all terminals try to use the multiplexed circuit intensively)
    - Requires memory to store data (in case more data comes in than its outgoing circuit capacity can handle)

3 - 17

Data Communications for a Global Environment

Wavelength Division Multiplexing

- Transmitting data at many different frequencies
  - Lasers or LEDs used to transmit on optical fibers
  - Previously single frequency on single fiber (typical transmission rate being around 622 Mbps)
  - Now multi frequencies on single fiber → n x 622+ Mbps
- Dense WDM (DWDM)
  - Over a hundred channels per fiber
  - Each transmitting at a rate of 10 Gbps
  - Aggregate data rates in the low terabit range (Tbps)
- Future versions of DWDM
  - Both per channel data rates and total number of channels continue to rise
  - Possibility of petabit (Pbps) aggregate rates

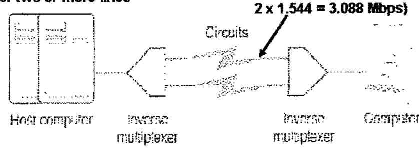
3 - 18

Data Communications for a Global Environment

Inverse Multiplexing (IMUX)

Shares the load by sending data over two or more lines

e.g., two T-1 lines used creating a combined multiplexed capacity of 2 x 1.544 = 3.088 Mbps)



- Bandwidth ON Demand Network Interoperability Group (BONDING) standard
- Commonly used for videoconferencing applications
- Six 64 kbps lines can be combined to create an aggregate line of 384 kbps for transmitting video

3 - 19

Data Communications for a Global Environment

Digital Subscriber Line (DSL)

- Became popular as a way to increase data rates in the local loop.
  - Uses full physical capacity of twisted pair (copper) phone lines (up to 1 MHz) instead of using the 0-4000 KHz voice channel
- 1 MHz capacity split into (FDM):
  - a 4 KHz voice channel
  - an upstream channel
  - a downstream channel
- Requires a pair of DSL modems
  - One at the customer's site; one at the CO site

May be divided further (via TDM) to have one or more logical channels

3 - 20

Data Communications for a Global Environment

xDSL

- Several versions of DSL
  - Depends on how the bandwidth allocated between the upstream and downstream channels
  - A for Asynchronous, H for High speed, etc
- G.Lite - a form of ADSL
  - Provides
    - a 4 Khz voice channel
    - 384 kbps upstream
    - 1.5 Mbps downstream (provided line conditions are optimal).

3 - 21

Data Communications for a Global Environment

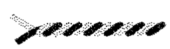
Communications Media

- Physical material that carries transmission
- Guided media:
  - Transmission flows along a physical guide (Media guides the signal across the network)
  - Examples include twisted pair wiring, coaxial cable and fiber optic cable
- Wireless media (radiated media)
  - No wave guide, the transmission flows through the air or space
  - Examples include radio such as microwave and satellite, as well as infrared communications

3 - 22

Data Communications for a Global Environment

Twisted Pair (TP) Wires



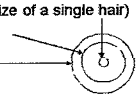
- Commonly used for telephones and LANs
- Reduced electromagnetic interference
  - Via twisting two wires together (Usually several twists per inch)
- TP cables have a number of pairs of wires
  - Telephone lines: two pairs (4 wires, usually only one pair is used by the telephone)
  - LAN cables: 4 pairs (8 wires)
- Also used in telephone trunk lines (up to several thousand pairs)
- Shielded twisted pair also exists, but is more expensive

3 - 23

Data Communications for a Global Environment

Fiber Optic Cable

- Light created by an LED (light-emitting diode) or laser is sent down a thin glass or plastic fiber
- Has extremely high capacity, ideal for broadband
- Works well under harsh environments
  - Not fragile, nor brittle; Not heavy nor bulky
  - More resistant to corrosion, fire, water
  - Highly secure, know when is tapped
- Fiber optic cable structure (from center):
  - Core (v. small, 5-50 microns, ~ the size of a single hair)
  - Cladding, which reflects the signal
  - Protective outer jacket



3 - 24

Data Communications for a Global Environment

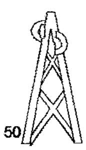
Wireless Media

- Radio
  - Wireless transmission of electrical waves through air
  - Each device has a radio transceiver with a specific frequency
    - Low power transmitters (few miles range)
    - Often attached to portables (Laptops, PDAs, cell phones)
  - Includes
    - AM and FM radios, Cellular phones
    - Wireless LANs (IEEE 802.11) and Bluetooth
    - Microwaves and Satellites, Low Earth Orbiting Satellites
- Infrared
  - "invisible" light waves with frequency below red light spectrum
  - Requires line of sight; generally subject to interference from heavy rain, smog, and fog
  - Used in remote control units such as for controlling the TV

3 - 25

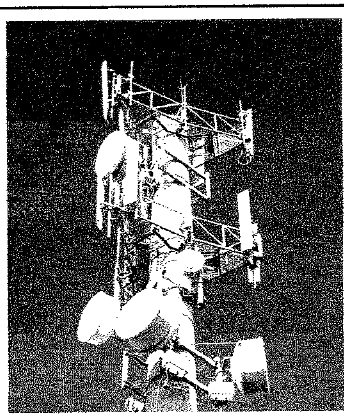
Data Communications for a Global Environment

Microwave Radio



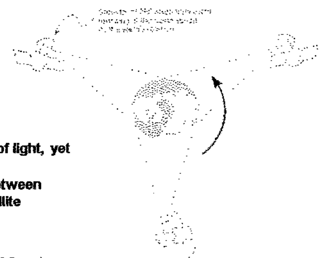
- High frequency form of radio communications
  - Extremely short (*micro*) wavelength (1 cm to 1 m)
  - Requires line-of-sight
- Performs same functions as cables
  - Often used for long distance, terrestrial transmissions (over 50 miles without repeaters)
  - No wiring and digging required
  - Requires large antennas (about 10 ft) and high towers
- Possesses similar properties as light
  - Reflection, Refraction, and focusing
  - Can be focused into narrow powerful beams for long distance
  - Some effect from water, rain and snow

3 - 26



Data Communications for a Global Environment

Satellite Communications



Special form of microwave communications

Signals travel at speed of light, yet long propagation delay due to great distance between ground station and satellite

3 - 28

Data Communications for a Global Environment

Factors Used in Media Selection

- Type of network
  - LAN, WAN, or Backbone
- Cost
  - Always changing; depends on the distance
- Transmission distance
  - Short: up to 300 m; medium: up to 500 m
- Security
  - Wireless media is less secure
- Error rates
  - Wireless media has the highest error rate (interference)
- Transmission speeds
  - Constantly improving; Fiber has the highest

3 - 29

Data Communications for a Global Environment

Media Summary

Guided Media

Media	Network Type	Cost	Transmission Distance	Security	Error Rates	Speed
Twisted Pair	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Coaxial Cable	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fiber Optics	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Radiated Media

Media	Network Type	Cost	Transmission Distance	Security	Error Rates	Speed
Radio	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Infrared	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Microwave	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Satellite	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

3 - 30

Data Communications for a Global Environment

Digital Transmission of Digital Data

- Computers produce binary data
- Standards needed to ensure both sender and receiver understands this data
  - *Codes:* digital combinations of bits making up languages that computers use to represent letters, numbers, and symbols in a message
  - *Signals:* electrical or optical patterns that computers use to represent the coded bits (0 or 1) during transmission across media

3 - 31

Data Communications for a Global Environment

Coding

a character ← is represented by→ a group of bits

Letters (A, B, ..), numbers (1, 2,..), special symbols (#, $, ..) → **1000001**

- ASCII: American Standard Code for Information Interchange
  - Originally used a 7-bit code (128 combinations), but an 8-bit version (256 combinations) is now in use
  - Found on PC computers
- EBCDIC: Extended Binary Coded Decimal Interchange Code
  - An 8-bit code developed by IBM
  - Used mostly in mainframe computer environment

3 - 32

Data Communications for a Global Environment

Character	ASCII
A	01000001
B	01000010
C	01000011
D	01000100
E	01000101
a	01100001
b	01100010
c	01100011
d	01100100
e	01100101
1	00110001
2	00110010
3	00110011
4	00110100
!	00100001
$	00100100

c03f015

Data Communications for a Global Environment

Transmission Modes

- Bits in a message can be sent:
  - A single wire one after another (Serial transmission)
  - Multiple wires simultaneously (Parallel transmission)
- Serial Mode
  - Sends bit by bit over a single wire
  - Serial mode is slower than parallel mode
- Parallel mode
  - Uses several wires, each wire sending one bit at the same time as the others
    - A parallel printer cable sends 8 bits together
    - Computer's processor and motherboard also use parallel busses (8 bits, 16 bits, 32 bits) to move data around

3 - 34

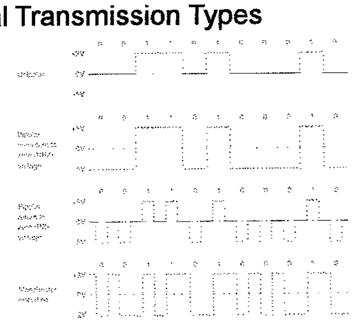
Signaling of Bits

- Digital Transmission
  - Signals sent as a series of "square waves" of either positive or negative voltage
  - Voltages vary between +3/-3 and +24/-24 depending on the circuit
- Signaling (encoding)
  - Defines how the voltage levels will correspond to the bit values of 0 or 1
  - Examples:
    - Unipolar, Bipolar
    - RTZ, NRZ, Manchester
  - Data rate: describes how often the sender can transmit data
    - 64 Kbps → once every 1/64000 of a second

3 - 35

Data Communications for a Global Environment

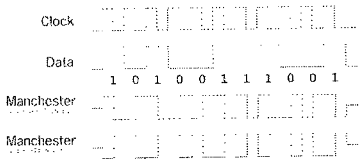
Digital Transmission Types



3 - 36

Data Communications for a Global Environment

Manchester Encoding



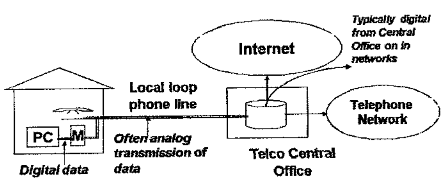
original data = clock XOR
Manchester value 0 0 0
0 1 1
1 0 1
1 1 0

3 - 37

Data Communications for a Global Environment

Analog Transmission of Digital Data

- A well known example using phone lines to connect PCs to Internet
  - PCs generate digital data
  - Local loop phone lines use analog transmission technology
  - Modems translate digital data into analog signals

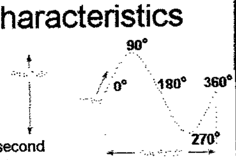


3 - 38

Data Communications for a Global Environment

Sound Waves and Characteristics

- Amplitude
  - Height (loudness) of the wave
  - Measured in decibels (dB)
- Frequency:
  - Number of waves that pass in a second
  - Measured in Hertz (cycles/second)
  - Wavelength, the length of the wave from crest to crest, is related to frequency
- Phase:
  - Refers to the point in each wave cycle at which the wave begins (measured in degrees)
  - (For example, changing a wave's cycle from crest to trough corresponds to a 180 degree phase shift).

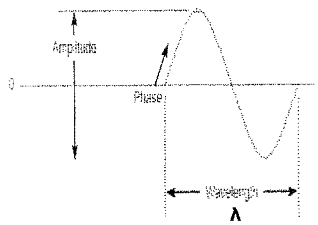


3 - 39

Data Communications for a Global Environment

Wavelength vs. Frequency

speed = frequency * wavelength



$\boxed{v = f\lambda}$

$v = 3 \times 10^8$ m/s
$= 300{,}000$ km/s
$= 186{,}000$ miles/s

Example:
if $f = 900$ MHz
$\lambda = 3 \times 10^8 / 900 \times 10^3$
$= 3/9 = 0.3$ meters

3 - 40

Data Communications for a Global Environment

Modulation

- Modification of a carrier wave's fundamental characteristics in order to encode information
  - Carrier wave: Basic electronic wave transmitted through the circuit (provides a base which we can deviate)
- Basic ways to modulate a *carrier wave:*
  - Amplitude Modulation (AM)
    - Also known as Amplitude Shift Keying (ASK)
  - Frequency Modulation (FM)
    - Also known as Frequency Shift Keying (FSK)
  - Phase Modulation (PM)
    - Also known as Phase Shift Keying (PSK)

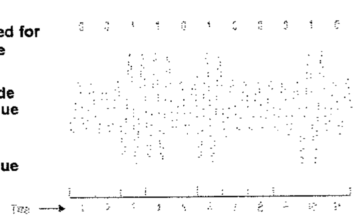
3 - 41

Data Communications for a Global Environment

Amplitude Modulation (AM)

- **Changing the height of the wave to encode data**

- **One bit is encoded for each carrier wave change**
  - **A high amplitude means a bit value of 1**
  - **Low amplitude means a bit value of 0**



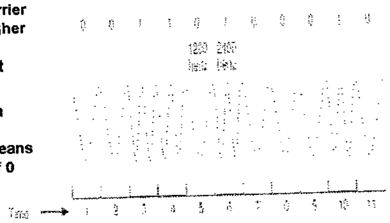
- **More susceptible noise than the other modulation methods**

3 - 42

Data Communications for a Global Environment

Frequency Modulation (FM)

- **Changing the frequency of carrier wave to encode data**
- **One bit is encoded for each carrier wave change**
  - **Changing carrier wave to a higher frequency encodes a bit value of 1**
  - **No change in carrier wave frequency means a bit value of 0**

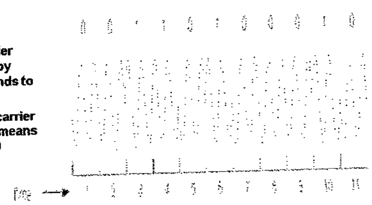


3 - 43

Data Communications for a Global Environment

Phase Modulation (PM)

- **Changing the phase of the carrier wave to encode data**
- **One bit is encoded for each carrier wave change**
  - **Changing carrier wave's phase by 180° corresponds to a bit value of 1**
  - **No change in carrier wave's phase means a bit value of 0**



3 - 44

Data Communications for a Global Environment

Sending Multiple Bits Simultaneously

Concept of Symbol

- Symbol: The number of bits encoded per wave. The number of bits b require 2^n different amplitudes.

Example:

Sending one bit of information at a time

One bit encoded for each symbol (carrier wave change) → 1 bit per symbol requires two amplitudes

Sending 2 bits simultaneously

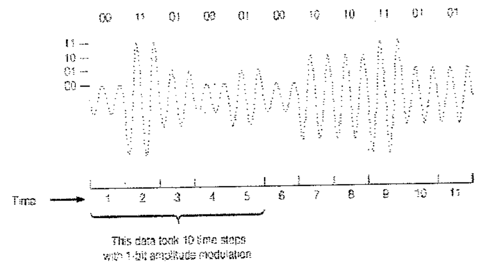
2 bits encoded for each symbol (carrier wave change) → 2 bits per symbol requires 4 amplitudes,

3 - 45

Data Communications for a Global Environment

Example: Two-bit AM

4 symbols



Data Communications for a Global Environment

Sending Multiple Bits per Symbol

- Possible number of symbols must be increased
  - 1 bit of information → 2 symbols
  - 2 bits of information → 4 symbols
  - 3 bits of information 8 → symbols
  - 4 bits of information → 16 symbols
  - n bits of information → 2^n symbols
- Multiple bits per symbol might be encoded using amplitude, frequency, and phase modulation
  - e.g., PM: phase shifts of 0°, 90°, 180°, and 270°
- Subject to limitations: As the number of symbols increases, it becomes harder to detect differences and is more prone to error

Data Communications for a Global Environment

Bit Rate vs. Baud Rate or Symbol Rate

- Bit: a unit of information
- Baud: a unit of signaling speed
- Bit rate (or data rate): b
  - Number of bits transmitted per second
- Baud rate or symbol rate: s
  - number of symbols transmitted per second
- General formula:

$$b = s \times n$$

where

b = Data Rate (bits/second)
s = Symbol Rate (symbols/sec.)
n = Number of bits per symbol

Example: AM
n = 1
→ b = s

Example: 16-QAM
n = 4
→ b = 4 x s

Data Communications for a Global Environment

Bandwidth of a Voice Circuit

- Difference between the highest and lowest frequencies in a band or set if frequencies
- Human hearing frequency range: 20 Hz to 14 kHz
  - Bandwidth = 14,000 – 20 = 13,080 Hz
- Voice circuit frequency range: 0 Hz to 4 kHz
  - Designed for most commonly used range of human voice
- Phone lines transmission capacity is much bigger
  - 1 MHz for lines up to 2 miles from a telephone exchange
  - 300 kHz for lines 2-3 miles away

3 - 49

Data Communications for a Global Environment

Data Capacity of a Voice Circuit

- Fastest rate at which you can send your data over the circuit (in bits per second)
  - Calculated as the bit rate: b = s x n
    - Depends on modulation (symbol rate)
    - Max. Symbol rate = bandwidth (if no noise)
- Maximum voice circuit capacity:
  - Using QAM with 4 bits per symbol (n = 4)
  - Max. voice channel carrier wave frequency: 4000 Hz = max. symbol rate (under perfect conditions)
    →Data rate = 4 * 4000 → 16,000 bps
  - A circuit with a 10 MHz bandwidth using 64-QAM could provide up to 60 Mbps.

3 - 50

Data Communications for a Global Environment

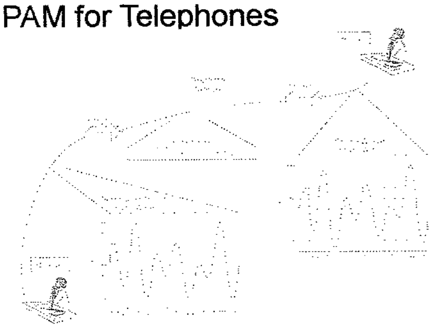
Digital Transmission of Analog Data

- Analog voice data sent over digital network using digital transmission
- Requires a pair of special devices called Codec - Coder/decoder
  - A device that converts an analog voice signal into digital form
  - Converts it back to analog data at the receiving end
  - Used by the phone system
- Modem is reverse device than Codec, and this word stands for Modulate/Demodulate. Modems are used for analog transmission of digital data.

3 - 51

Data Communications for a Global Environment

PAM for Telephones



3 - 52

Data Communications for a Global Environment

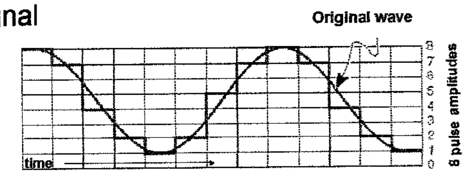
Analog to Digital Conversion

- Analog data must be translated into a series of bits before transmission onto a digital circuit
- Done by a technique called Pulse Amplitude Modulation (PAM) involving 4 steps:
  1. Take samples of the continuously varying analog signal across time
  2. Measure the amplitude of each signal sample
  3. Encode the amplitude measurement of the signal as binary data that is representative of the sample
  4. Send the discrete, digital data stream of 0's and 1's that approximates the original analog signal
- Creates a rough (digitized) approximation of original signal
  - Quantizing error: difference between the original analog signal and the replicated but approximated, digital signal
  - The more samples taken in time, the less quantizing error

3 - 53

Data Communications for a Global Environment

PAM – Measuring Signal

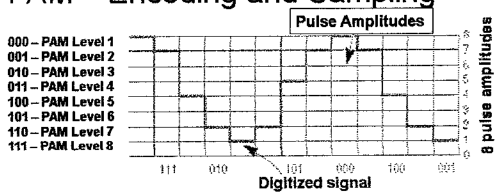


- **Sample analog waveform across time and measure amplitude of signal**
- **In this example, quantize the samples using only 8 pulse amplitudes or levels for simplicity**
- **Our 8 levels or amplitudes can be depicted digitally by using 0's and 1's in a 3-bit code, yielding 2^3 possible amplitudes**

3 - 54

Data Communications for a Global Environment

PAM – Encoding and Sampling



- For digitizing a voice signal, it is typically 8,000 samples per second and 8 bits per sample
- 8,000 samples x 8 bits per sample → 64,000 bps transmission rate needed
- 8,000 samples then transmitted as a serial stream of 0s and 1s

3 - 55

Data Communications for a Global Environment

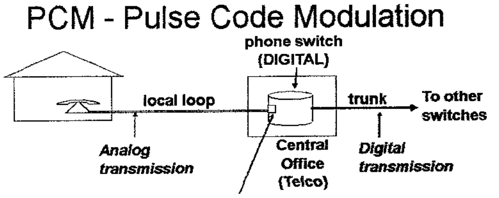
Minimize Quantizing Errors

- Increase number of amplitude levels
  - Difference between levels minimized → smoother signal
  - Requires more bits to represent levels → more data to transmit
  - Adequate human voice: 7 bits → 128 levels
  - Music: at least 16 bits → 65,536 levels
- Sample more frequently
  - Will reduce the length of each step → smoother signal
  - Adequate Voice signal: twice the highest possible frequency (4Khz x 2 = 8000 samples / second) Nyquist theorem.
  - RealNetworks: 48,000 samples / second

3 - 56

Data Communications for a Global Environment

PCM - Pulse Code Modulation



convert analog signals to digital data using PCM (similar to PAM)

- DS-0 is the basic digital communications unit used by phone network
- DS-0 corresponds to 1 digital voice signal

- 8000 samples per second and 8 bits per sample (7 bits for sample + 1 bit for control)

→ 64 Kb/s (DS-0 rate)

3 - 57

Data Communications for a Global Environment

Lecture 10

1

Data Communications for a Global Environment

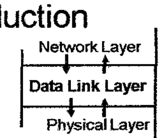
Chapter 4

Data Link Layer

4-2

Data Communications for a Global Environment

Data Link Layer - Introduction



- **Major functions of a data link layer protocol**
  - Media Access Control
    - Controlling when computers transmit
  - Error Control
    - Detecting and correcting transmission errors
  - Message Delineation
    - Identifying the beginning and end of a message

4-3

Data Communications for a Global Environment

Media Access Control (MAC)

- Controlling when and what computers transmit
  - Important when more than one computer wants to send data at the same time over the same, shared circuit
    - Point-to-point half duplex links
      - computers take turns
    - Multipoint configurations
      - Ensure that no two computers attempt to transmit data at the same time
- Two possible approaches
  - Controlled access
  - Contention based access

4-4

Data Communications for a Global Environment

Controlled Access

- Controlling access to shared resources
  - Acts like a stop light
- Commonly used by mainframes (or its front end processor)
  - Determines which circuits have access to mainframe at a given time
- Also used by some LAN protocols
  - Token ring, FDDI
- Major controlled access methods
  - X-ON/X-OFF and Polling

4-5

Data Communications for a Global Environment

Polling

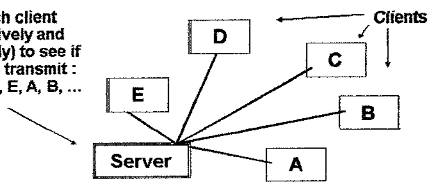
- Process of transmitting to a client only if asked and/or permitted
  - Client stores the information to be transmitted
  - Server (periodically) polls the client if it has data to send
  - Client, if it has any, sends the data
  - If no data to send, client responds negatively, and server asks the next client
- Types of polling
  - Roll call polling
  - Hub polling (also called token passing)

4-6

Data Communications for a Global Environment

Roll Call Polling

Check each client (consecutively and periodically) to see if it wants to transmit : A, B, C, D, E, A, B, ...



Clients can also be prioritized so that they are polled more frequently: A, B, A, C, A, D, A, E, A, B, ..

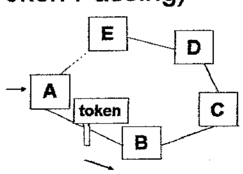
- Involves waiting: Poll and wait for a response
- Needs a timer to prevent lock-up (by client not answering)

4-7

Data Communications for a Global Environment

Hub Polling (Token Passing)

One computer starts the poll:
- sends message (if if any) then
- passes the token on to the next computer
- Token is a unique series of bits



Continues in sequence until the token reaches the first computer, which starts the polling cycle all over again

4-8

Data Communications for a Global Environment

Contention Methods

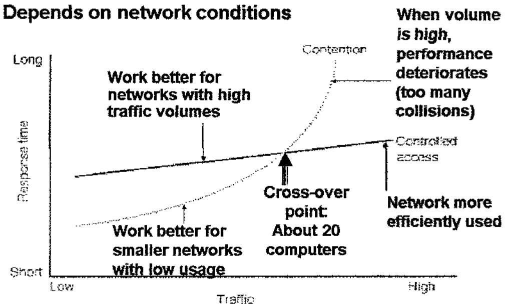
- Transmit whenever the circuit is free
- Collisions
  - Occurs when more than one computer transmitting at the same time
  - Need to determine which computer is allowed to transmit first after the collision
- Used commonly in Ethernet LANs
- Problematic in heavy usage networks

4-9

Data Communications for a Global Environment

Relative Performance

Depends on network conditions



4 - 10 Copyright 2007 John Wiley & Sons, Inc

Data Communications for a Global Environment

Error Control

- Handling of network errors caused by problems in transmission
  - Network errors
    - Can be a changing a bit value during transmission
    - Controlled by network hardware and software
  - Human errors:
    - Can be a mistake in typing a number
    - Controlled by application programs

    We cannot correct for these errors in the communication software
- Categories of Network Errors
  - Corrupted (data is changed from what it is)
  - Lost data (cannot find the data at all)

4 - 11 Copyright 2007 John Wiley & Sons, Inc

Data Communications for a Global Environment

Error Control (Cont.)

- Error Rate
  - 1 bit error in n bits transmitted, e.g., 1 in 500,000
- Burst error
  - Many bits are corrupted at the same time
  - Errors not uniformly distributed
    - e.g., 100 in 50,000,000 → 1 in 500,000
- Major functions
  - Preventing errors
  - Detecting errors
  - Correcting errors

4 - 12 Copyright 2007 John Wiley & Sons, Inc

Data Communications for a Global Environment

Sources of Errors

- Line noise and distortion – major cause
  - More likely on electrical media
  - Undesirable electrical signal
  - Introduced by equipment and natural disturbances
- Degrades performance of a circuit
- Manifestation
  - Extra bits
  - "flipped" bits
  - Missing bits

4 - 13

Data Communications for a Global Environment

Sources of Errors and Prevention

Source of Error	What causes it	How to prevent it
Line Outages	Faulty equipment, Storms, Accidents (circuit fails)	
White Noise	Movement of electrons (thermal energy)	Increase signal strength (increase SNR)
Impulse Noise	Sudden increases in electricity (e.g., lightning, power surges)	Shield or move the wires
Cross-talk	Multiplexer guard bands are too small or wires too close together	Increase the guard bands, or move or shield the wires
Echo	Poor connections (causing signal to be reflected back to the source)	Fix the connections, or tune equipment
Attenuation	Gradual decrease in signal over distance (weakening of a signal)	Use repeaters or amplifiers
Intermodulation Noise	Signals from several circuits combine	Move or shield the wires
Jitter	Analog signals change (small changes in amp., freq., and phase)	Tune equipment
Harmonic Distortion	Amplifier changes phase (does not correctly amplify its input signal)	Tune equipment

More important

mostly on analog

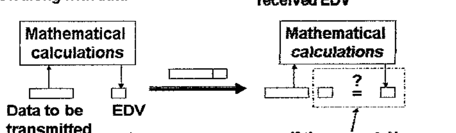
4 - 14

Data Communications for a Global Environment

Error Detection

Sender calculates an Error Detection Value (EDV) and transmits it along with data

Receiver recalculates EDV and checks it against the received EDV



Larger the size, better error detection (but lower efficiency)

- If the same → No errors in transmission
- If different → Error(s) in transmission

4 - 15

Data Communications for a Global Environment

Error Detection Techniques

- Parity checks
- Checksum
- Cyclic Redundancy Check (CRC)

4 - 16

Data Communications for a Global Environment

Parity Checking

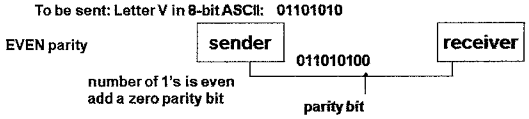
- One of the oldest and simplest
- A single bit added to each character
  - Even parity: number of 1's remains even
  - Odd parity: number of 1's remains odd
- Receiving end recalculates parity bit
  - If one bit has been transmitted in error the received parity bit will differ from the recalculated one
- Simple, but doesn't catch all errors
  - If two (or an even number of) bits have been transmitted in error at the same time, the parity check appears to be correct
  - Detects about 50% of errors

4 - 17

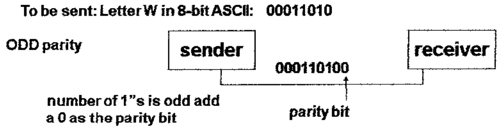
Data Communications for a Global Environment

Examples of Using Parity

To be sent: Letter V in 8-bit ASCII: 01101010



To be sent: Letter W in 8-bit ASCII: 00011010



4 - 18

Data Communications for a Global Environment

Checksum

- A checksum (usually 1 byte) is added to the end of the message
- It is 95% effective
- Method:
  - Add decimal values of each character in the message
  - Divide the sum by 255
  - The remainder is the checksum value

4 - 19

Data Communications for a Global Environment

Cyclic Redundancy Check (CRC)

$$P / G = Q + R / G$$

Message (treated as one long binary number)

A fixed number (determines the length of the R)

Quotient (whole number)

Remainder:
- –added to the message as EDV
- –could be 8 bits, 16 bits, 24 bits, or 32 bits long
- –CRC16 has R of 16 bits

Example:
P = 58
G = 8
Q = 7
R = 2

- – Most powerful and most common
- – Detects 100% of errors (if number of errors <= size of R)
  - –Otherwise: CRC-16 (99.998%) and CRC-32 (99.9999%)

4 - 20

Data Communications for a Global Environment

Error Correction

- Once detected, the error must be corrected
- Error correction techniques
  - Retransmission (or, backward error correction)
    - Simplest, most effective, least expensive, most commonly used
    - Corrected by retransmission of the data
      - Receiver, when detecting an error, asks the sender to retransmit the message
    - Often called Automatic Repeat Request (ARQ)
  - Forward Error Correction
    - Receiving device can correct incoming messages itself

4 - 21

Data Communications for a Global Environment

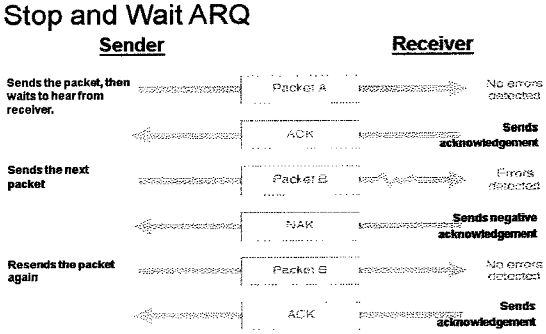
Automatic Repeat Request (ARQ)

- Process of requesting that a data transmission be resent
- Main ARQ protocols
  - Stop and Wait ARQ (A half duplex technique)
    - Sender sends a message and waits for acknowledgment, then sends the next message
    - Receiver receives the message and sends an acknowledgement, then waits for the next message
  - Continuous ARQ (A full duplex technique)
    - Sender continues sending packets without waiting for the receiver to acknowledge
    - Receiver continues receiving messages without acknowledging them right away

4 - 22

Data Communications for a Global Environment

Stop and Wait ARQ



4 - 23

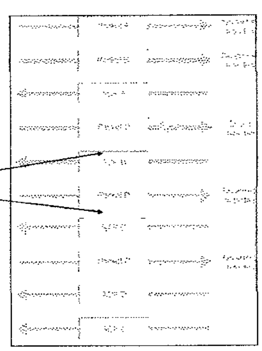
Data Communications for a Global Environment

Continuous ARQ

Sender sends packets continuously without waiting for receiver to acknowledge

Notice that acknowledgments now identify the packet being acknowledged.

Receiver sends back a NAK for a specific packet to be resent.



4 - 24

Data Communications for a Global Environment

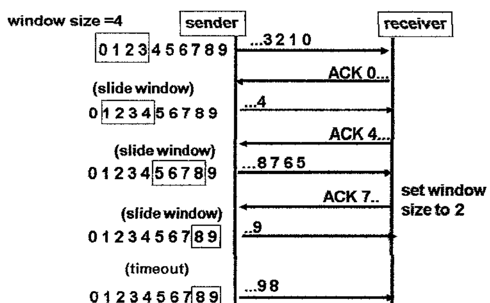
Flow Control with ARQ

- Ensuring that sender is not transmitting too quickly for the receiver
  - Stop-and-wait ARQ
    - Receiver sends an ACK or NAK when it is ready to receive more packets
  - Continuous ARQ:
    - Both sides agree on the size of the "sliding window"
      - Number of messages that can be handled by the receiver without causing significant delays

4 - 25

Data Communications for a Global Environment

Flow Control Example



4 - 26

Data Communications for a Global Environment

Forward Error Correction (FEC)

- Receiving device can correct incoming messages itself (without retransmission)
- Requires extra corrective information
  - Sent along with the data
  - Allows data to be checked and corrected by the receiver
  - Amount of extra information: usually 50-100% of the data
- Useful for satellite transmission
  - One way transmissions (retransmission not possible)
  - Transmission times are very long (retransmission will take a long time)
  - In this situation, relatively insignificant cost of FEC

4 - 27