Data Link Layer

Major functions
- Media access control
- Error Control
- Message Delineation

MAC
- controll when and what computers transmit
- two approaches
  - controlled access
  - contention based access
- listens for voltages
- Ethernet is contention - based
- smaller the number trying to communicate, the better

- Rate - Call Policy
- Token Ring (common)

2/22/2011

Data Link layer
- ~~data~~ link layer looks a subnet mask
  - if on same ~~subnet~~ subnet then sent to computer otherwise go to ~~other~~ router

Controlled Access
- acts like a stop light (take turns listening)
- used by mainframes
- Token Ring

- Polling
  - roll call polling (done by central machine)
  - involves waiting: poll and wait for response
  - needs a timer to prevent lock-up
  - ~~Use~~ sequence based on amount of data to transfer

- ~~Hub~~ Polling (Token Ring)
  - goes in order
  - can ~~only~~ only talk if holding "token"

- Contention Method (transmits when circuit is free)
  - data collisions cause voltage spike
  - used by Ethernet LANs (start listening)
  - problematic in heavy network

- Error Control
  - Network errors
  - Human errors (can be corrected by network)

  - Corrupted
  - Lost

  - most errors occurs in bursts
  - Major Functions
    - preventing
    - detecting
    - correcting

Error Sources
- noise/static
- "flipped flipped bit
- missing bits

Error Detection
- ~~parity~~ Parity Checking
- mathematical portion is the only thing that will vary
- Parity
  - oldest and simplest form of checking
    - doesn't check all errors
    - detects 50% of errors

- Checksum
  - 95% effective

- CRC — Cyclic Redundancy Check
  - detects 100% of errors

Error Correction
- retransmission
- forward error correction

- hamming code
  - sending multiple parity bits

ARQ ~ Automatic Repeat Request
- Stop and wait ARQ (half duplex)
- Continuous ARQ (full duplex)

2/24/2011

Error Detection Techniques
- parity checks
- checksum
- CRC (use polynomial calculation)

Steps of Error Checking
- Prevention
- detection
- correction (retransmit or correct)

- half duplex ~ can't send at the same time, but over the same wire

- full duplex - send and receive concurrently; possible to over the receiver; is not concurrent

- ACK - acknowledged
- NAK - not "

- Hamming Code

- ECC memory
  - Error Correction Code
  - used by Raid level drives

- Ethernet (IEEE 802.3) standard
  - IEEE standard
  - Digital (greatest contributor), Intel, Xerox ~ developers
  - contention based media access control

Physical Layer
[ethernet[IP[TCP[HTTP [MSG]]]]]

Data transmission
- analog (analogious)
- digital

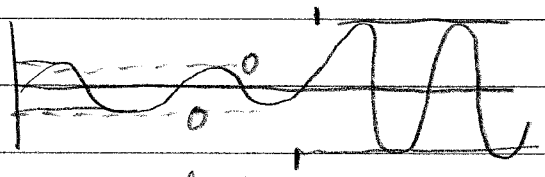
- Point-to-Point (cable modem)
- Multipoint configuration

- multiplexing
  - Frequency Division Multiplexing (FDM)
    - guardbands to seperate channels
    - smaller channels to make a larger channel
  - Time Division Multiplexing
    - terminals send/receive in order,
    - Statistical time division requires a label

3/1/2011

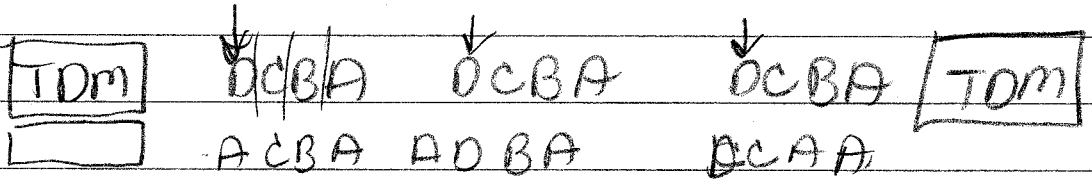
Exam 2 - March 29th?

Multiplexing
- fewer circuits needed
- FDM - most common method



- use a higher frequency for each circuit
- guardband = lost capacity; frequencies not used
- Citrix server

TDM



TDM

Statistical

- for Statistical, identifier must be used; not Timing-based; multiple receivers/senders

- DSL modem is example of FDM
- FDM is cheaper

- Wavelength Division Multiplexing

- Inverse Multiplexing (IMUX)
  - the individual lines and combining them
    (multiple)

- DSL (Digital Subscriber Line)
  - FDM, 1 MHz
  - 4 KHz voice channel
  - upstream "
  - downstream "
  - requires two modems - one at customer site, one at office

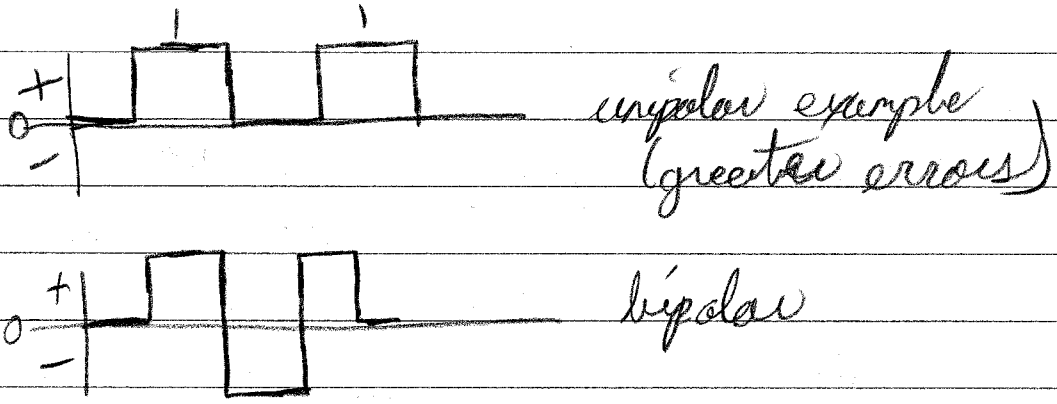
- Guided Media
  - uses wires - copper, fiber optics, twisted pair (cat 5)

- Wireless Media (radiated media)
  - goes through the air or space
  - more prone to errors
  - less secure
  - cost efficient

Coding
- ASCII
- EBCDIC

Transmission Modes
- Serial

Signaling of Bits
- between 3V and 24V depending on the circuit
- voltage level of 0 or 1



- RTZ - Return To Zero
- NRZ - Non-Return To Zero

$v = f \lambda$

speed = frequency * wavelength

three form of modulation
- AM
- FM
- PM (Phase Modulation)

March 3, 2011

- phone signal utilizes analog signal
- analog to digital conversion requires a modem (cable, DSL, etc)
- modulation - the process of converting analog ⇔ digital

$\frac{1 \text{ bit}}{\text{symbol}}$ = 2 amplitude levels

March 3, 2011

2 bits/symbol = 4 amplitude levels

- 00
- 01
- 10
- 11

3 amp level x bits = 2^x amp levels

8 { 000, 001, 010, ... }

@ 8 levels begin to ~~peak~~ push the limit

Bit Rate is not Baud Rate (Symbol Rate)
- not the same unless there is only one bit

$b = s \times n$

b – data rate (bits/sec)
s = symbol rate (symbols/sec)
n = number of bits per symbol

- voice circuit frequency range 0 Hz to 4kHz
- human hearing " " 20Hz to 14kHz
  Bandwidth = 14000 - 20 = 13,080 Hz

- a 10 MHz bandwidth using 64-QAM could provide 60 Mbps
- QAM

- max symbol rate = bandwidth (if no noise)

- Codec = Coder / Decoder
- Modem = Modulate / demodulate

PAM - pulse amplitude modulation levels (horizontal)
sampling frequency (vertical)

greater coordinates of both provides greater analysis of curve

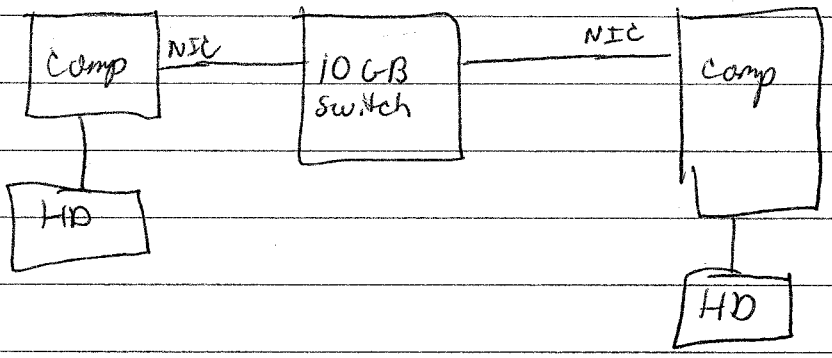
Sampling rate = 2 * bandwidth
SR = 2 x 4000 Hz 8000 Hz

- Phone ~~contains~~ contains a codec
- greater sampling = greater ~~amount~~ amount of data to send

- always a slight difference in the analog curve and the digital curve.

- Quantizing error -

-



3-8-2011

- sampling rate - # of vertical cuts
- reduced quantizing error by increasing sampling rate

N_{yquist} = sampling rate × $Bandwidth_{max}$

↑ sampling rate
↑ bits/symbol ↑ PAM

LAN - Local Area Networks

Reasons/ Purpose of LAN -
- info sharing
- resource sharing
- make better decisions and reduced cost

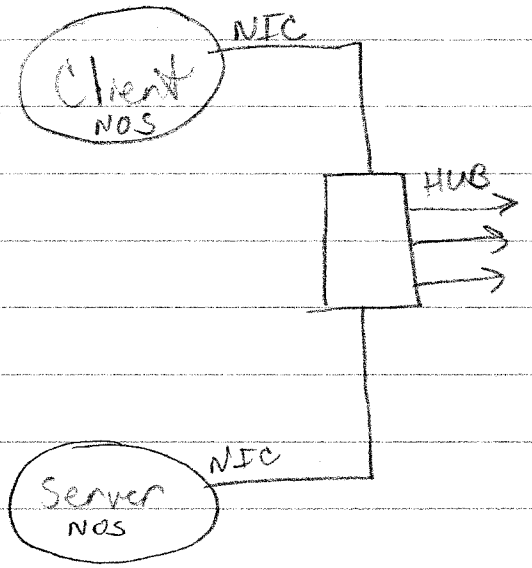
- Sharing COTS (Commercial off the shelf) software
  - paid on per user basis
  - run on server for everyone to use
  - reduced cost, easier maintenance

- 40% of software used is illegal

Network Types
- dedicated server network
- peer to peer

- server can perform specialized certain tasks

- Network cables
  - UTP - unshielded twisted pair
    - 4 sets of pairs
    - tighter the twists, greater capacity



- Hub is a multipoint device

- switch costs more than a hub

NOS - Network Operating System

critical - needs to keep resources
- what users have access to (Active Directory)

domain → forest → tree

each plant — ACME Company — Northern Division, Southern

March 10, 2011

- Parts of NOS
  - Server version of NOS
  - Client " " "
  - Directory Service
  - Network Profiles

- NOS Software (server)
  - handles all network functions
  - acts as the application software
- MS Windows
- Linux

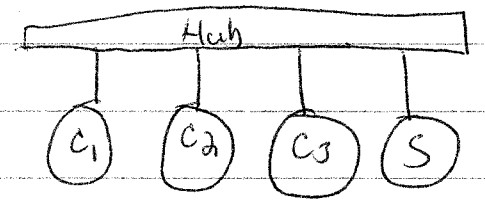
- NOS Directory Service
  - i.e. Active Directory Service (ADS) by Microsoft
  - Categories
  - resources
  - Security principles

Forest
- Tree
- Domain

- can't have duplicate names within a domain

Trusts
- one way
- two way

Topology (land and physical)



CSMA/CD

[Value 1] Base/Broad [-Value 2] ethernet media format

Switched Ethernet topology
- hub sends to all ports; switch only sends to destination address

- switch only reads MAC address then sends

- switch for greater performance

March 22 2011

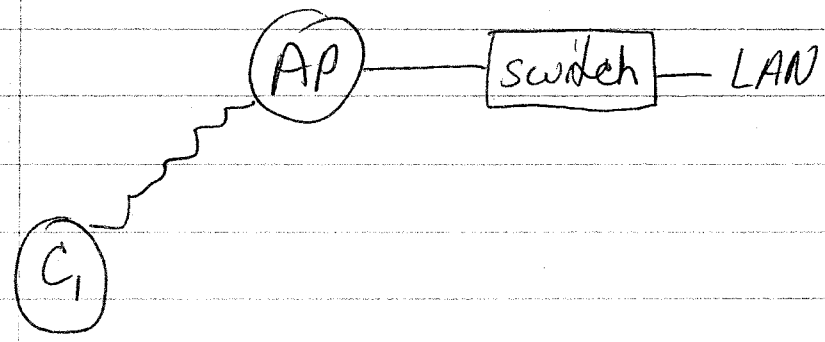
Wireless Local Area Networks
- wifi
- Wi Max
- ~~Bluetooth~~ Bluetooth

- Wi Max is not big in US, used more in other countries (line of sight)

- all use layer 2 (data link) protocol
  - must use network and physical layer

- WLAN
  - 802.1x standards (aka wifi)
  - ~~carries~~ RF or IR

Components of WLAN
- NIC
- AP



POE- power over ethernet
power the device over ethernet away from outlet

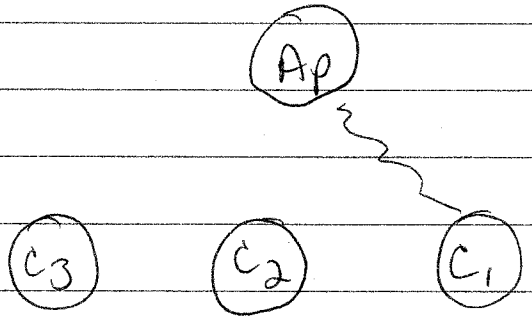
- never place a ~~device~~ server on a WLAN
- ~~WLAN~~ WLANs operate on two frequencies 2.4 GHz and 5.0 GHz

- 5.0 GHz
  - higher the freq the greater the data transmission rate
  - higher freq = greater attenuation rate
  - 5.0 GHz signal may not get in through wooden door, but 2.4 GHz would go through

- AP can only go as fast as slowest device

DIF > IFS

IFS = Interfere Slot (Time) = used to reduce data collisions, uses random times



- C_3 can't hear when C_1 broadcasts, known as the "Hidden Node" problem

- PCF = Point Coordination Function
  - AP says who can transmit and when
  - process: RTS (request to send), then CTS (clear to send) if ok-ed, then data is transmitted

- political issues, not technical, interfere with large scale provision of Wi Fi

WIMAX operates in mostly ~~un~~licensed signals
- fixed and mobile ~~types~~
- uses 802.11 standard, but has its own standard
- requires a ~~clear~~ line of sight

March 24, 2011

Bluetooth (IEEE 802.15)
- standard for WPAN
- used up to 10 meters
- used to replace short distance cabling (keyboards, headsets, etc)
- very low power; approx 1 milli watt
- uses same frequency as ~~Bluetooth~~ wifi
- limited to 8 ~~devices~~ devices
- ~~one doesn't have with two device~~
- doesn't have problem with data collisions
- piconet - device name; move in sync in the same network
- not compatible with 802.11b

Exam 2 Materieal

- Data Link Layer
- Physical
- LANs
- WLANs

- functions of data link layer
- media access control
- controlled method or ~~token~~ token ring - sending info
- half duplex, full duplex, multiplex
- Ethernet is a contergent method
- errors: DL can't detect user errors, come in in clusters
- error ~~correction~~ detection techniques: ~~Parity~~ Parity Check, Checksum, CRC
- error correction techniques: retransmit, Hamming Code
- half duplex will use stop-and-wait; ~~wait~~ waits on acknowledgement
- full duplex doesn't wait on acknowledgement
- ~~stop~~ Flow Control method, used on full duplex circuit

- Physical
  - digital and analog waves
  - analog has continuous values; digital has discrete values
  - greater security with digital format

Multiplexing
- can increase capacity
- multiplex based on frequency and time
- Frequency Division Multiplexing
- time " "
- quantizing error - diff actual signal and signal in digital
  - increase sampling rate
  - " amplitude characters

- CODEC and MODEM
- Nyquist Theorem - based on bandwidth

Exam 2 Review March 29, 2011

- share info and resources with LAN
- help a business to generate more profits, reduce costs
- dedicated server (primary) over peer to peer (2nd)
- Cat 5e most common cable (RJ-45)
- Ethernet is most common protocol
- 100 Mbps per pair
- hub - can repeat, connects all devices on network
- server vs PC - need a NOS, doesn't have to provide all network communication
- Active Directory - levels: forrest, tree, domain; controls resources and security; domain can be broken down into organizational units.
- Trusts allow a user to connect to domain resources
- logical topology for shared ethernet: bus
- carrier sense, multiple access, collision detect
- as devices connect to a port, it keeps track of what is connect to each port
- switch modes: cut-through (low latency), store and forward switching (highest latency), fragment-free

(bus) (star)
- shared vs switched ethernet
- switched is similar to point to point; shared sends to all, but only receiver will acknowledge
- switches provide greater capacity

- wifi WiMAX, Bluetooth
- 2.4GHz and 5GHz - most common frequencies for Wi-Fi

- key device: AP/Access Point
- POE is DC; don't have to deal with AC
- server behind switch on wireless network
- collision avoidance in wireless environment
- protocols: DCF, PCF; DCF is not control-based
- hidden node problem - can't hear other device transmit
- AP directs traffic in DCF (Distributed)
- Wifi - 300ft WiMAX - 30 miles
  (line of sight
- Bluetooth uses low power; different protocol; piconet up to 8 devices; master device is similar to a hub; frequency hopping over 79 channels; uses clock of master for changing channel.

Data Communications for a Global Environment

Lecture 14

1

Data Communications for a Global Environment

Chapter 6

Local Area Networks

6-2

Data Communications for a Global Environment

Why do we need a LAN?

- Information sharing
  - Having users access the same files, exchange information via email, or use common software applications such as Sharepoint, PEEPS
- Resource sharing
  - Having hardware devices shared by all users
    eg. Printers, Servers
  - Having software packages shared by all users on a LAN
    eg. E-learning, Crimson Careers, etc.

Results in better decision making and reduced cost

6-3

Data Communications for a Global Environment

Sharing COTS Software on a LAN

- Purchase software on a per seat basis
  - Install software on a server for all to use
  - No need to have a copy on every computer on the LAN
  - Reduces cost
  - Simplifies maintenance and upgrades
  - Example
    - LAN: a 30 client network
    - Purchase only a 10-seat license for a software program (instead of purchasing 20 copies of the same program)
    - *Assumes that only 10 users would simultaneously use the software*

6-4

Data Communications for a Global Environment

LAN Metering

- Used to control the number of copies of a software used on a LAN
- Typically comes with many software packages used on LANs
- Keeps track of the users
- Prohibits using more copies of the package than the licensed number
- Helps to minimize Copyright violations
  - 40% of SW used in the world is illegal, $13B Loss

6-5

Data Communications for a Global Environment

Network Types

- **Dedicated server network**
  - A server (computer) permanently assigned a specific task
  - Most popular network type
    - 90% of all LANs
- **Peer-to-peer network**
  - No dedicated servers used
  - All computers act as both clients and servers
  - Cheaper than dedicated, but less capability

6-6

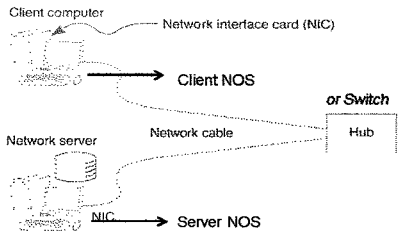
Dedicated Server Networks

- Requires one or more dedicated computers (servers)
  - Permanently assigned a specific task (Web server, e-mail server, file server or print server)
  - Enable users to share files, printers, etc.,
  - May form a powerful enterprise network replacing mainframes
  - May form a server farm (many servers part of a network)
  - Runs a server network operating system (NOS)
    - Windows NT, LINUX
  - Also requires a special communication software to enable communications with client computers

Types of Dedicated Servers

- Common Types:
  - Web servers, e-mail servers, database servers
- Others
  - File servers
    - Allows many users to share the same files on a common disk drive
    - Typically with restricted access
  - Print servers
    - Handle print requests
    - Could be a separate computer or a "black box"
  - Remote Access Servers
    - Enable users to dial in and out of the LAN by phone (via modems)

Basic LAN Components



Network Interface Cards (NICs)

- Contains physical and data link layer protocols
  - Includes a unique data link layer address (called a MAC address), placed in them by their manufacturer
  - Includes a socket allowing computers to be connected to the network
  - Organizes data into frames and then sends them out on the network

Network Cables

- Used to connect a computer physically to the network
- Types of cables
  - Unshielded twisted wire pairs (UTP) – leading LAN cable type
  - Shielded twisted pair (STP)
  - Coaxial cable – heavy, not flexible
  - Optical fiber – high capacity, just beginning in LANs
- May include multiple different types cables
  - Requires a special connector typically RJ45 (not the telephone RJ45)

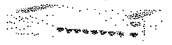
Network Cables Categories

Category	Speed	Use
1	1 Mbps	Voice Only (Telephone Wire)
2	4 Mbps	LocalTalk & Telephone (Rarely used)
3	16 Mbps	10BaseT Ethernet
4	20 Mbps	Token Ring (Rarely used)
5	100 Mbps (2 pair) 1000 Mbps (4 pair)	100BaseT Ethernet Gigabit Ethernet
5e	1,000 Mbps	Gigabit Ethernet
6	10,000 Mbps	Gigabit Ethernet

Data Communications for a Global Environment

Hubs & Switches

- Act as junction boxes, linking cables from several computers on a network
- Usually sold with 4, 8, 16 or 24 ports
- May allow connection of more than one kind of cabling, such as UTP and coax.
- Repeat (reconstruct and strengthen) incoming signals
  - Important since all signals become weaker with distance
  - Extends the maximum LAN segment distance



Data Communications for a Global Environment

Network Operating Systems

- Software that controls the LAN
- Parts of NOS
  - Server version of NOS
    - Runs on the network servers
  - Client version of NOS
    - Runs on the client computers
  - Directory Service
    - Provide information about resources on the LAN
  - Network Profiles
    - Indicate the resources available in the network and authorized users

Data Communications for a Global Environment

NOS Server Software

- Enables servers to operate
  - Handles all network functions
    - Performs data link, network, and application layer functions
  - Acts as the application software by executing and responding to the requests sent to them by clients
- Replaces the normal OS on the server
  - Optimized to provide better performance and faster response time (for its limited number of operations)
- Examples
  - MS Windows NT
  - LINUX

Data Communications for a Global Environment

NOS Client Software

- Provides data link and network layer functions
- Interacts with application software and computer's own operating system
- Included in most OS packages such as Windows VISTA and Windows 7
- Allows client to view and access available network resources

Data Communications for a Global Environment

NOS Directory Service

- Provides information about resources on the LAN
- Example is Active Directory Service (ADS) by Microsoft
  - An AD structure is a hierarchical arrangement of information about objects.
  - The objects fall into two broad categories:
    - **Resources** (e.g. printers)
    - **Security Principles** (User or computer accounts and groups)
  - Each object represents a **single entity** (user, computer, printer, or a group) and is uniquely identified by its name and its attributes (the characteristics and information that the object represents) defined by a **schema**

Data Communications for a Global Environment

NOS Directory Service

- An AD framework that holds the objects can be viewed at a number of levels:
  - Forrest
  - Tree
  - Domain
- Domains are identified by their **DNS** name structure, the **namespace**
- A **Tree** is a collection of one or more Domains in a contiguous namespace
- A **Forrest** is a collection of trees that share a common global catalog, directory schema, logical structure and directory configuration

Data Communications for a Global Environment

NOS Directory Service

- Objects held within a domain can be grouped into **Organizational Units** (OU's). The OU is the recommended level at which to apply group policies.
- Duplicate names cannot exist within a domain.
  e.g. you cannot have Fred.student.ou and Fred.staff.ou
- The AD database, *in Windows 2000 server uses the JET Blue-*based Extensible Storage Engine and is limited to 16 terabytes and 2 billion objects (but only 1 billion security principles)
- To allow users in one domain to access resources in another domain AD uses **trusts.**
  - Trusts inside a Forrest are automatically set when the domain is created
  - The Forrest sets the default boundary for a trust.
  - Implicit Transitive Trusts are automatic for all domains within a

6 - 19

Data Communications for a Global Environment

NOS Directory Service

Forrest – WidgetsCorp

Tree – Eastern
- Domain – Boston
- Domain – New York
- Domain – Philly

Tree – Southern
- Domain – Atlanta
- Domain - Dallas

Domain – Dallas
- **OU – Marketing**
  - Bob
  - Sally
  - Dave
- **OU – Sales**
  - Steve
  - Jane

6 - 20

Data Communications for a Global Environment

Topology

- Basic geometric layout of the network
  - The way computers on the network interconnected
- Logical Topology
  - How the network works conceptually
  - Like a logical data flow diagram (DFD) or
  - Like a logical entity relation diagram (ERD)
- Physical Topology
  - How the network is physically installed
  - Like physical DFD or physical ERD

6 - 21

Data Communications for a Global Environment

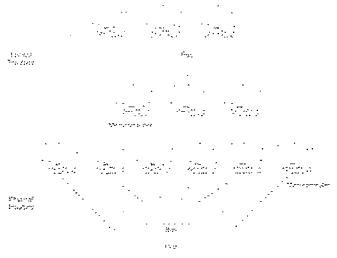
Shared Ethernet's Logical Topology

- Viewed logically as a bus topology
- All messages from any computer flow onto the central cable (bus)
- A computer receive messages from *all* other computers, whether the message is intended for it or not
- When a frame is received by a computer, the first task is to read the frame's destination address to see if the message is meant for it or not

6 - 22

Data Communications for a Global Environment

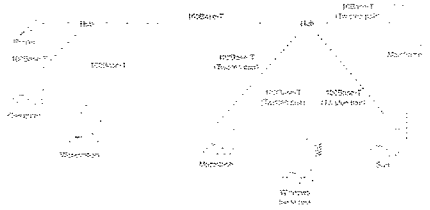
Shared Ethernet's Physical Topology



6 - 23

Data Communications for a Global Environment

Multiple Hub Ethernet Design



6 - 24

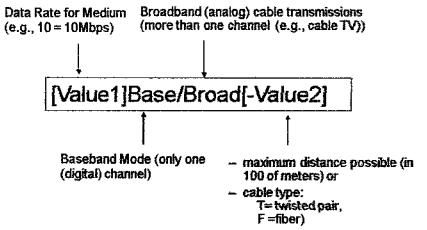
Media Access Control (MAC)

- Uses a contention-based protocol called CSMA/CD (Carrier Sense Multiple Access / Collision Detect)
- Frames can be sent by two computers on the same network at the same time
  - They will collide and become garbled
  - Can be termed as "ordered chaos"
  - Tolerates, rather than avoids, collisions

CSMA/CD

- Carrier Sense (CS):
  - Listen to the bus to see if another computer is transmitting before sending anything
  - Transmit when no one is transmitting
- Multiple Access (MA):
  - All computers have access to the network medium
- Collision Detect (CD):
  - Declared when any signal other than its own detected
  - If a collision is detected
    - To avoid a collision, wait a random amount of time and then resend message

Ethernet Physical Media Format



Twisted Pair Ethernets

- 10Base-T
  - Uses Cat 3 and Cat 5 UTP, very inexpensive
  - Runs up to 100 meters
  - Rapidly losing ground to 100Base-T
- 100Base-T
  - Uses Cat 5 UTP
  - Also called Fast Ethernet, replaced 10Base-T in sales volume
  - More common format in Ethernet today
- Combined 10/100 Ethernet
  - Some segments run 10Base-T and some run 100Base-T

Fiber Optic based Ethernets

- 1000Base-T (1 GbE)
  - Gigabit Ethernet.
  - Maximum cable length is only 100 m for UTP cat5
  - Fiber Optic based (1000Base-LX) runs up to 440 meters
- 1000Base-F
  - 1 Gbps fiber
- 10 GbE
  - 10 Gbps Ethernet. Uses fiber and is typically full duplex
- 40 GbE
  - 40 Gbps Ethernet. Uses fiber and is typically full duplex.

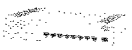
Summary - Ethernet Media Types

Name	Maximum Data Rate	Cables
10Base-T	10 Mbps	UTP cat 3, UTP cat 5
100Base-T	100 Mbps	UTP cat 5
1000Base-T	1 Gbps	UTP cat 5, UTP cat 5e, UTP cat 6
1000Base-F	1 Gbps	fiber
10 GbE	10 Gbps	UTP cat 5e, UTP cat 6, UTP cat 7, fiber
40 GbE	40 Gbps	fiber

Ethernet (IEEE 802.3)

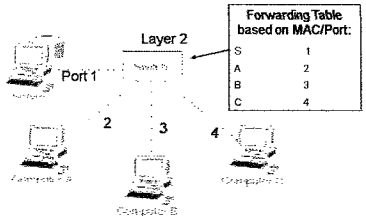
- Used by almost all LANs today
- Originally developed by a consortium of Digital Equipment Corp., Intel and Xerox
- Standardized as IEEE 802.3
- Types of Ethernet
  - Shared Ethernet
    - Uses hubs
  - Switched Ethernet
    - Uses switches

Switched Ethernet Topology



- Uses switches (instead of hubs)
  - Designed to support a small set of computers (16 to 24) in one LAN
  - Looks similar to a hub, but very different inside
  - Designed to support a group of point-to-point circuits
    - *No sharing of circuits*
- Logical and physical topology of the network becomes a star topology via switch
- Switch reads destination address of the frame and only sends it to the corresponding port
  - While a hub broadcasts frames to all ports

Basic Switch Operation



When a frame is received, the switch reads its Layer 2 data link layer destination address and sends the frame out of the corresponding port in its forwarding table.

Learning Switch Operation

- Switch starts by working like a simple hub
  - With an empty forwarding table
- It gradually fills its forwarding table by learning about the nodes
  - Reads the source MAC address of the incoming frame and records it to the corresponding port number
  - Reads the destination MAC address. If not in the Table then it broadcasts the frame to all ports
  - Waits for the destination computers to respond, and repeats the first step

Forwarding Table based on MAC/Port:	
S	1
A	2
B	3
C	4

Modes of Switch Operations

- **Cut through switching**
  - Read destination address and start transmitting
    - Without waiting for the entire message is received
  - Low latency; but may waste capacity (error messages)
  - Only on the same speed incoming and outgoing circuits
- **Store and forward switching**
  - Wait until the whole message is received, perform error control, and then transmit it
  - Less wasted capacity; slower network
  - Circuit speeds may be different
- **Fragment free switching**
  - Read the first 64 byte segment (contains the header)
  - Perform error check, if it is okay then start transmitting
  - Compromise between previous two modes

MAC in Switched Ethernet

- Each circuit shared by a computer and the switch
- Still CSMA/CD media access control used
  - Each device (computer or switch) listens before transmitting
- *Multiple messages can be sent at the same time.*
  - Computer A can send a message to computer B at the same time that computer C sends one to computer D
  - Two computers send frames to the same destination at the same time
  - Switch stores the second frame in memory until it finishes sending the first, then forwards the second

Performance Comparison

Capable of using about only 50% of capacity (10BaseT) before collisions become a problem

Runs at up to 90% capacity on 100Base-T

Factors in LAN Design

- Effective Data Rates
  - Data Link Protocol Efficiency
  - MAC Protocol Efficiency
- Costs
  - Newer technologies are expensive
  - Prices drop over time
  - 10Base-T, 100Base-T and Switched Ethernet are inexpensive
  - 1 GbE and 10GbE are still expensive

Effective Data Rates

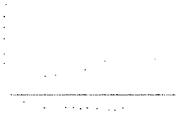
- Maximum speed in bits the hardware layers can provide
- Depends on
  - Nominal data rate (provided by Physical layer)
    - 100Base-T → 100 Mbps
  - Error rate (determines retransmissions)
  - Efficiency of data link layer protocol
    - Percentage of transmission that contains user data
      - Depends on the number of overhead bits
  - Efficiency of MAC protocol
    - How well the MAC protocol can use the nominal data rate

Data Link Protocol Efficiency

- Efficiency of Data Link layer depends on a typical packet size
  - 33-byte overhead in a 1500-byte packet
    - → 97.8% efficiency (assuming no retransmission)
  - 33-byte overhead in a 9000 byte (jumbo) packet
    - → 99.6% efficiency
  - 33-byte overhead in a 150 byte (small) packet
    - → 82% efficiency
- Average efficiency on a LAN
  - Depends on the traffic patterns
  - Typically, a small number of HTTP or SMTP request packets followed by about 20 larger packets will yield a 97% reasonable estimate for LAN traffic

MAC Protocol Efficiency

- CSMA/CD works well in low traffic LANs



- Response time vs. utilization: a good indicator
  - Works well when it is under 50% capacity
- Examples:
  - 10Base-T: 50% capacity x 97% efficiency x 10 Mbps rate
    - → 4.85 Mbps (shared by all computers on the LAN)
  - 100Base-T: 80% capacity x 97% efficiency x 100 Mbps
    - → 78 Mbps (total effective rate, but this is shared)

Effective Rate for a Computer

- Depends on number of computers using the LAN simultaneously
  - A typical LAN has 20 users; but not all of them use the LAN at the same time
- Examples of effective rate calculations:
  - 2 simultaneous users on a 10Base-T
    - 4.85 Mbps / 2 → 2.425 Mbps / per computer
  - 10 simultaneous users on a 10Base-T
    - 4.85 Mbps / 10 → 485 Kbps / per computer
  - 10 simultaneous users on a 100Base-T
    - 78 Mbps / 10 → 7.8 Mbps / per computer

Effective Rates for Switched Ethernets

- Dramatic improvements over non-switched Ethernet LANs
- 95% capacity efficiency
- Examples:
  - 10Base-T: 95% capacity x 97% efficiency x 10 Mbps rate
    - → 9.2 Mbps
  - 100Base-T: 95% capacity x 97% efficiency x 100 Mbps
    - → 92 Mbps
  - 1 GbE: implemented in full duplex (1 Gbps each direction)
    - → 1.8 Gbps
- Per computer efficiency
  - Same as above
  - Not affected by the traffic (since each has own circuit)

Effective Ethernet Rate Estimates

Technology	Effective Data Rate per User		
	Low Traffic	Moderate Traffic	High Traffic
Shared 10Base-T	[illegible]	[illegible]	[illegible]
Shared 100Base-T	[illegible]	[illegible]	[illegible]
Switched 10Base-T	9 Mbps	9 Mbps	9 Mbps
Switched 100Base-T	92 Mbps	92 Mbps	92 Mbps
Full Duplex 1 GbE	1.8 Gbps	1.8 Gbps	1.8 Gbps
Full Duplex 10 GbE	18 Gbps	18 Gbps	18 Gbps

Assumptions:
1. Ethernet packets are 1,500 bytes on average
2. No connection-oriented errors occur
3. Low traffic involves 2 active users, moderate traffic involves 5 active users, high traffic involves 10 active users

Best Practice Recommendations

- Switched 10Base-T
  - Less susceptible to response time delays
  - More robust as traffic increases
  - Provides the best cost-performance tradeoff
  - Costs almost the same as Shared 10Base-T
- Category 5 or 5e cables
  - Costs almost the same as cat3
  - Provides room for upgrades to 100Base-T or 100Base-T
- Fiber
  - LAN with very high traffic needs
  - Used with switched 100Base-T or 1 GbE
  - Currently expensive

Best Practice Recommendations

Most networks	Shared 100Base-T Ethernet over Category 5e cables
Very small networks (e.g., home networks)	Shared 10Base-T Ethernet over Category 5 or Category 5e cables
Networks with high demands (e.g., multimedia networks)	Switched 100Base-T Ethernet over Category 5e cables or full duplex 1 GbE over fiber

Improving LAN Performance

- Throughput:
  - Used often as a measure of LAN performance
  - Total amount of user data transmitted in a given period of time
- To improve throughput and LAN performance, identify and eliminate bottlenecks
  - Bottlenecks are points in the network where congestion is occurring
  - Congestion is when the network or device can't handle all of the demand it is experiencing

Identifying Network Bottlenecks

- Potential places are server vs. circuit
  - Network server
  - Network circuit (especially LAN-BN connection)
  - Client's computer (highly unlikely, unless too old)
- How to find it
  - Check the server utilization during poor performance
    - If high >60%, then the server is the bottleneck
    - If low <40%, then the network circuit is the bottleneck
    - If between 40% - 60%, both the server and circuits are the bottlenecks

