EEC-484/584
Computer Networks

Lecture 10

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(Lecture nodes are based on materials supplied by
Dr. Louise Moser at UCSB and Prentice-Hall)

Outline

- The Medium Access Control Sublayer
  - Bluetooth
  - Data link layer switching
- Review for midterm #1
- Reminder: Midterm #1, Oct 5 Wednesday
  - Chapters 1-4
  - Closed book, closed notes

Bluetooth

- Bluetooth Architecture
- Bluetooth Applications
- The Bluetooth Protocol Stack
- The Bluetooth Frame Structure

Bluetooth

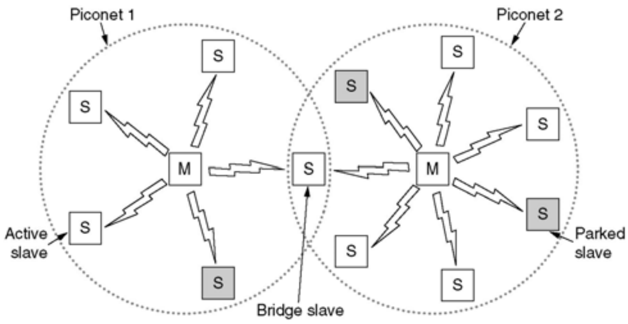
- **Bluetooth**: a wireless standard for interconnecting computing and communication devices and accessories using short-range, low-power, inexpensive wireless radios
  - Bluetooth SIG: formed by Ericsson, IBM, Intel, Nokia and Toshiba
  - Named after Harald Blaatand (Bluetooth) II (940-981)
    - A Viking king who unified Denmark and Norway, also without cables
- Bluetooth SIG issued a 1500-page spec v1.0, in 1999
- IEEE 802.15 standardizes only the physical and data link layers
  - As a personal area network (PAN) standard

Bluetooth Architecture

- **Piconet** – basic unit of a Bluetooth system
  - Consists of a **master node** and up to 7 **active slave nodes** within a distance of 10 meters, and up to 255 **parked nodes**
  - **Master node** controls the clock and determines which device gets to communicate in which time slot, using TDM
  - **Slave nodes** are fairly dumb, just doing whatever the master tells them to do
  - **Parked nodes** – devices that the master has switched to a low-power state, they respond only to an activation or beacon signal from the master
  - All communication is between the master and a slave; direct slave-slave communication is not possible

Bluetooth Architecture

- **Scatternet** – an interconnected collection of piconets
  - Connected via a bridge node



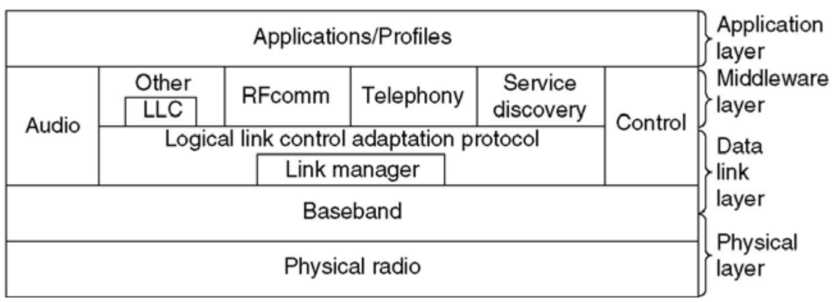
Bluetooth Applications

- The Bluetooth profiles

	Name	Description
Generic services	Generic access	Procedures for link management
	Service discovery	Protocol for discovering offered services
	Serial port	Replacement for a serial port cable
	Generic object exchange	Defines client-server relationship for object movement
networking	LAN access	Protocol between a mobile computer and a fixed LAN
	Dial-up networking	Allows a notebook computer to call via a mobile phone
	Fax	Allows a mobile fax machine to talk to a mobile phone
telephony	Cordless telephony	Connects a handset and its local base station
	Intercom	Digital walkie-talkie
	Headset	Intended for hands-free voice communication
Exchanging objects	Object push	Provides a way to exchange simple objects
	File transfer	Provides a more general file transfer facility
	Synchronization	Permits a PDA to synchronize with another computer

The Bluetooth Protocol Stack

- The 802.15 version of the Bluetooth protocol architecture



The Bluetooth Protocol Stack

- **Physical radio layer** – deals with radio transmission and modulation
  - Low-power system with a range of 10 meters operating in the 2.4 GHz band
  - The band is divided into 79 channels of 1MHz each
  - Modulation is frequency shift keying, with 1 bit per Hz => gross data rate of 1 Mbps
  - Frequency hopping spread spectrum, with 1600 hops/sec and dwell time of 625 μsec
  - All nodes in a piconet hop simultaneously, with master dictating the hop sequence

The Bluetooth Protocol Stack

- **Baseband layer** – deals with how the master controls time slots and how these slots are grouped into frames
  - Master node in each piconet defines a series of 625 μsec time slots. Master node uses the even slots, slave nodes use the odd slots
  - Frames can be 1, 3, or 5 slots long
  - A settling time of 250-260 μsec per hop to allow radio circuits to become stable
    - For single-slot frame, 366 left => 126 access code & header, only 240 bits for data
    - For five-slot frame, 2781 bits for data
  - Each frame is transmitted over a logical channel, called a link
    - ACL (Asynchronous Connection-Less) link – used for packet-switched data, go through L2CAP layer, best effort
    - SCO (Synchronous Connection Oriented) link, for real-time data, using forward error correction, each SCO link can transmit one 64,000 bps PCM audio channel

The Bluetooth Protocol Stack

- **L2CAP (Logical link control adaptation protocol) –** shields upper layers from details of transmission, analogous to 802 LLC sublayer
  - Accepts packets of up to 64 KB from upper layers, breaks (reassembles) them into (from) frames
  - Handles multiplexing and de-multiplexing of multiple packet sources, determine which upper-layer protocol to hand it to
  - Handles quality of service requirements, both when links are established and during normal operation
    - Negotiates max payload size allowed

The Bluetooth Protocol Stack

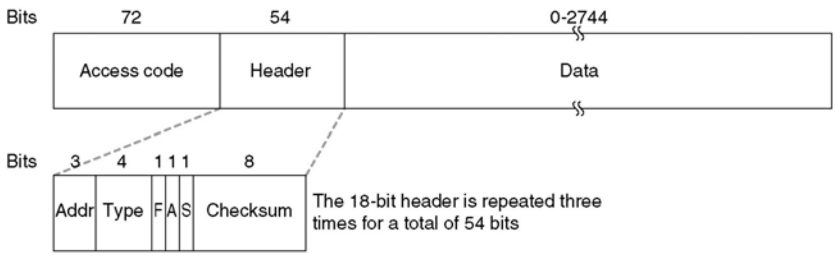
- **Link manager –** handles establishment of logical channels between devices
  - Including power management, authentication, and quality of service
- **Audio and control protocols –** deals with audio and control, apps can use them directly

The Bluetooth Protocol Stack

- **Middleware layer –** a mix of different protocols
  - LLC inserted by IEEE for compatibility with other 802 networks
  - RFcomm – emulates standard serial port found on PCs for connecting keyboard, mouse and modem
  - Telephony – a real-time protocol used for the three speech-oriented profiles, also manages call setup and termination
  - Service discovery – used to locate services within network
- **Application layer –** each app has its own dedicated subset of the protocols

The Bluetooth Frame Structure

- A typical Bluetooth data frame.
  - Access code – identifies master node
  - 54-bit header containing typical MAC sublayer fields
  - Data field, up to 2744 bits (five-slot frame)



Data Link Layer Switching

- Bridges from 802.x to 802.y
- Local Internetworking
- Spanning Tree Bridges
- Remote Bridges
- Repeaters, Hubs, Bridges, Switches, Routers, Gateways
- Virtual LANs

Data Link Layer Switching

- Bridge – device that connects LANs together
- Common situations in which bridges are used
  - Connects LANs that belong to different departments
  - Connects LANs that geographically apart
  - Connects LANs that were split to accommodate the load
    - Load might be local to a LAN
  - Connects LANs that were split for better reliability
    - To cope with a faulty NIC that broadcasts frames like crazy
  - Connects LANs that were split for better security
    - Most NICs are capable of running promiscuous mode
    - Isolate parts of the network so that its traffic cannot escape and fall into the wrong hands

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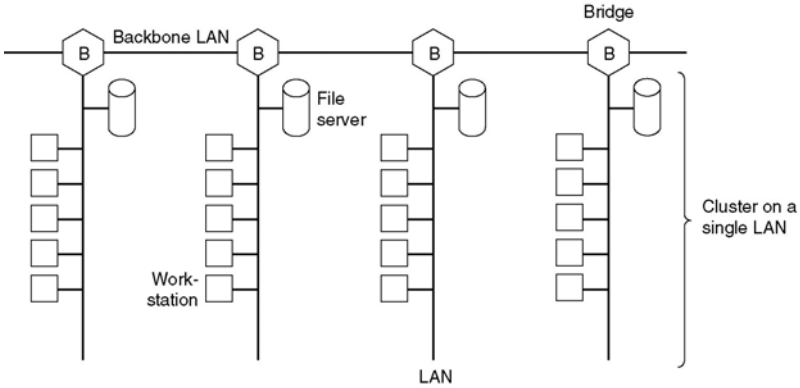
Data Link Layer Switching

- Multiple LANs connected by a backbone to handle a total load higher than the capacity of a single LAN



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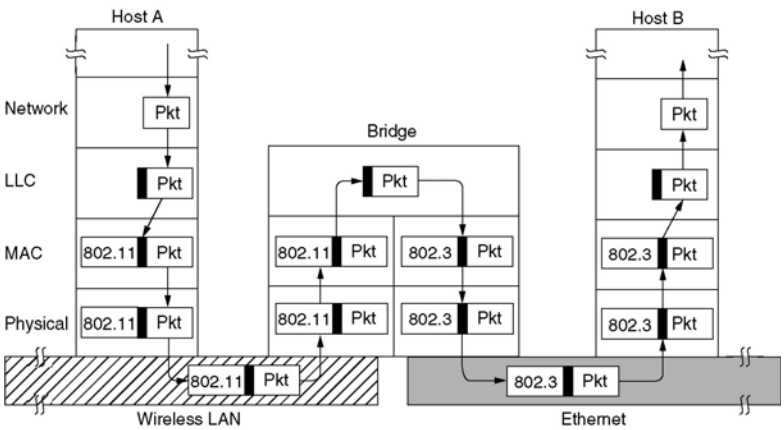
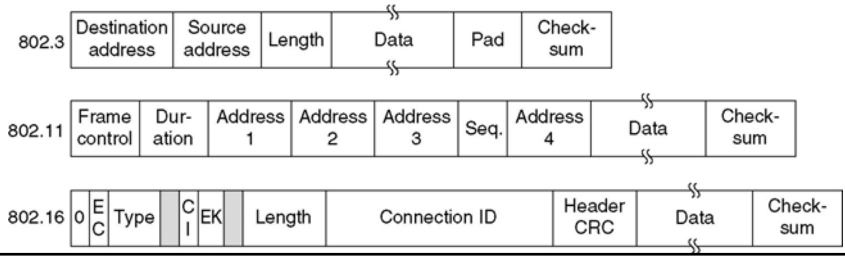
Bridges from 802.x to 802.y

- Operation of a LAN bridge from 802.11 to 802.3



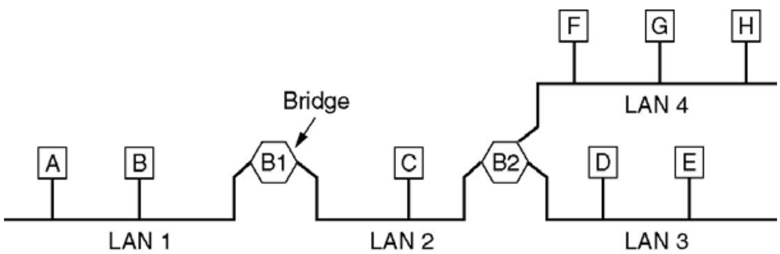
Bridges from 802.x to 802.y

- Frame translation is not trivial
  - Reformatting necessary => takes CPU time, new CRC, may introduce undetected errors due to bad bits in bridge's memory
  - LANs may have different data rates
  - LANs have different max frame size
  - Security – some LAN uses encryption, some not
  - Quality of service – some does, some does not



Local Internetworking

- A configuration with four LANs and two bridges
- A bridge typically runs the promiscuous mode



Routing Procedure

- Up on receiving a frame
  - If destination and source LANs are the same, discard the frame
  - If the destination and source LANs are different, forward the frame
  - If the destination LAN is unknown, use flooding

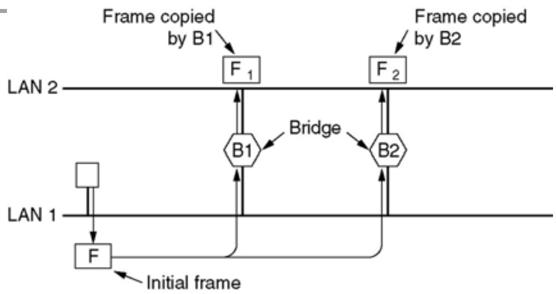
Routing Procedure

- Flooding algorithm
  - Every incoming frame for an unknown destination is output on all the LANs to which the bridge is connected except the one it arrived on
  - As time goes on, the bridges learn where destinations are

Routing Procedure

- Backward Learning Algorithm
  - A bridge learns which machine is accessible on which LAN by looking at the source address of a frame
  - It makes an entry in its hash table

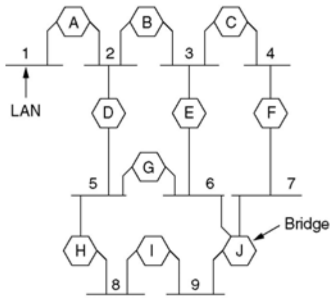
Spanning Tree Bridges



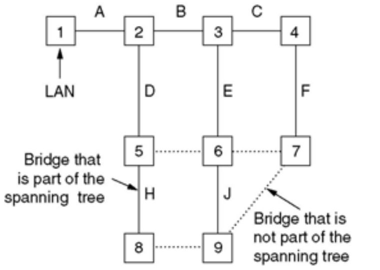
- Two parallel transparent bridges
  - Used to increase reliability
  - But introduce problem – creates loops in the topology
  - Solution – bridges communicate with each other and overlay the actual topology with a **spanning tree** that reaches every LAN. Some potential connections between LANs are ignored

Spanning Tree Bridges

- How to build a spanning tree
  - Choose one bridge as root
  - A tree of shortest paths from the root to every bridge and LAN is constructed => spanning tree
  - If a bridge of LAN fails, a new one is computed



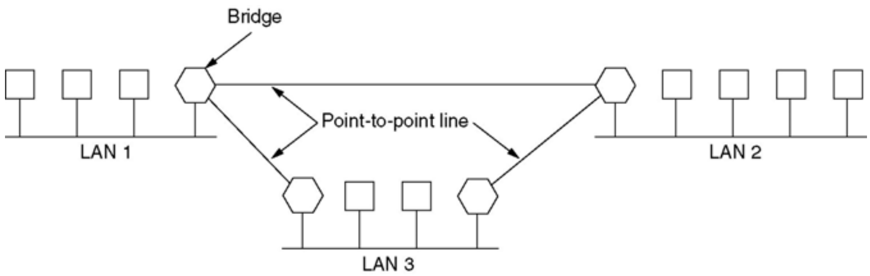
Interconnected LANs



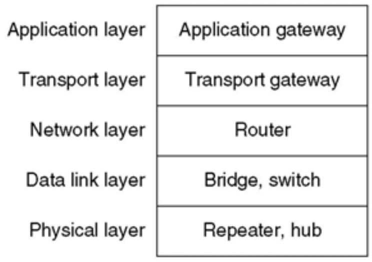
A spanning tree covering the LANs. The dotted lines are not part of the spanning tree

Remote Bridges

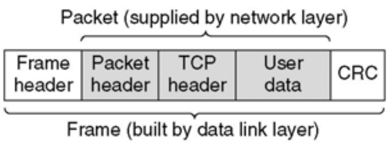
- Remote bridges can be used to interconnect distant LANs. Various protocols can be used on the point-to-point lines
  - PPP, putting complete MAC frames in the payload field
  - Strip off the MAC header and trailer, ship the rest as payload, then add a new MAC header & trailer at destination bridge



Repeaters, Hubs, Bridges, Switches, Routers and Gateways

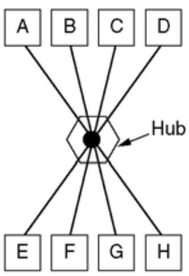


(a)
Which device is in which layer

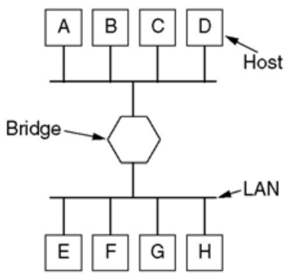


(b)
Frames, packets, and headers

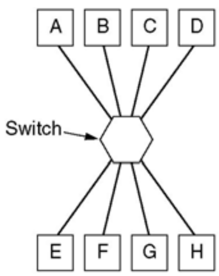
Repeaters, Hubs, Bridges, Switches, Routers and Gateways



(a)
A hub



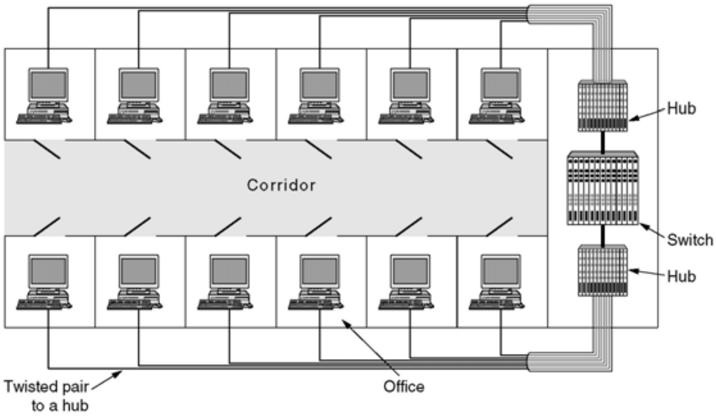
(b)
A bridge



(c)
A switch

Virtual LANs

- A building with centralized wiring using hubs and a switch



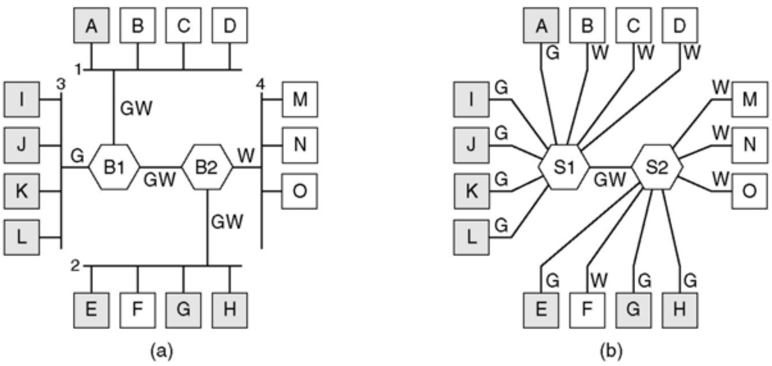
Virtual LANs

- VLAN (Virtual LAN) - Rewire entirely in software for more flexibility
  - Based on specially-designed VLAN-aware switches
  - Network administrator decides
    - how many VLANs there will be,
    - which computers will be on which VLAN,
    - and what the VLANs will be called
  - Often VLANs are named by colors

Virtual LANs

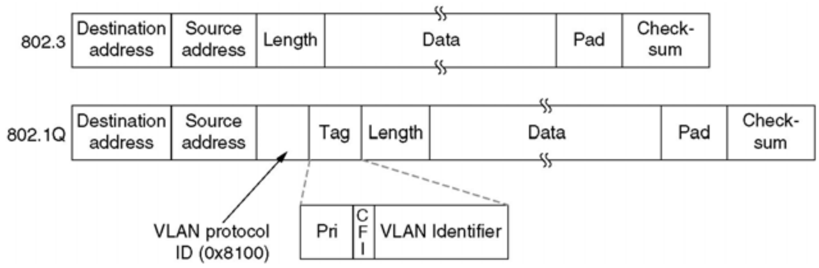
- How a switch/bridge knows what color an incoming frame is?
  - Every port is assigned a VLAN color
  - Every MAC address is assigned a VLAN color
  - Every layer 3 protocol or IP address is assigned a VLAN color

Virtual LANs



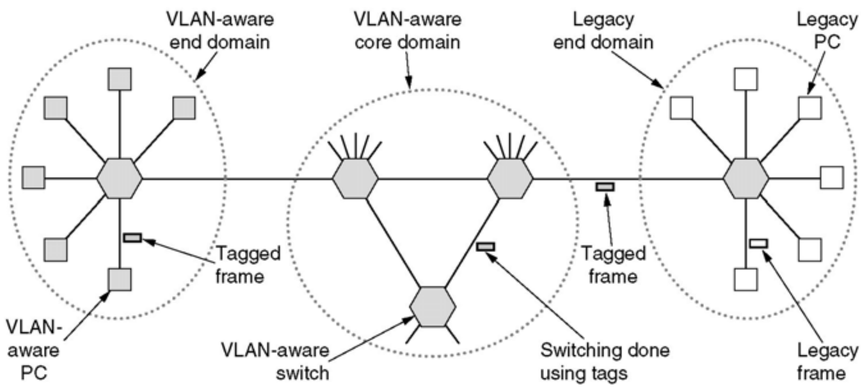
The IEEE 802.1Q Standard

- Let the MAC frame itself carry the VLAN info
- The 802.3 (legacy) and 802.1Q Ethernet frame formats.



The IEEE 802.1Q Standard

- Transition from legacy Ethernet to VLAN-aware Ethernet
  - New frame format is used at the first VLAN-aware switch, the VLAN field is stripped off before deliver to a legacy NIC



Channel Allocation Methods and Systems for A Common Channel

Method	Description
FDM	Dedicate a frequency band to each station
WDM	A dynamic FDM scheme for fiber
TDM	Dedicate a time slot to each station
Pure ALOHA	Unsynchronized transmission at any instant
Slotted ALOHA	Random transmission in well-defined time slots
1-persistent CSMA	Standard carrier sense multiple access
Nonpersistent CSMA	Random delay when channel is sensed busy
P-persistent CSMA	CSMA, but with a probability of p of persisting
CSMA/CD	CSMA, but abort on detecting a collision
Bit map	Round robin scheduling using a bit map
Binary countdown	Highest numbered ready station goes next
Tree walk	Reduced contention by selective enabling
MACA, MACAW	Wireless LAN protocols
Ethernet	CSMA/CD with binary exponential backoff
FHSS	Frequency hopping spread spectrum
DSSS	Direct sequence spread spectrum
CSMA/CA	Carrier sense multiple access with collision avoidance

Chapter 1 - Introduction

- Uses of computer networks
- Network Hardware
- Network software
- Reference models
- Example networks
- Network standardization

Network Hardware

- No generally accepted taxonomy. Two dimensions
- Transmission technology
  - Broadcast links
  - Point-to-point links (unicasting)
- Scale

Interprocessor distance	Processors located in same	Example
1 m	Square meter	Personal area network
10 m	Room	Local area network
100 m	Building	Local area network
1 km	Campus	Local area network
10 km	City	Metropolitan area network
100 km	Country	Wide area network
1000 km	Continent	Wide area network
10,000 km	Planet	The Internet

Wide Area Networks

- Spans a large geographical area, often a country or continent
- Network structure in WAN
  - **Host** or end system
  - **Communication Subnet** – connects hosts
    - Two components: transmission lines and routers
    - Two types of designs: point-to-point and broadcast channels

Network Software

- Protocol hierarchies / Network architectures
- Design issues for the layers
- Connection-oriented and connectionless services
- The relationship of services to protocols

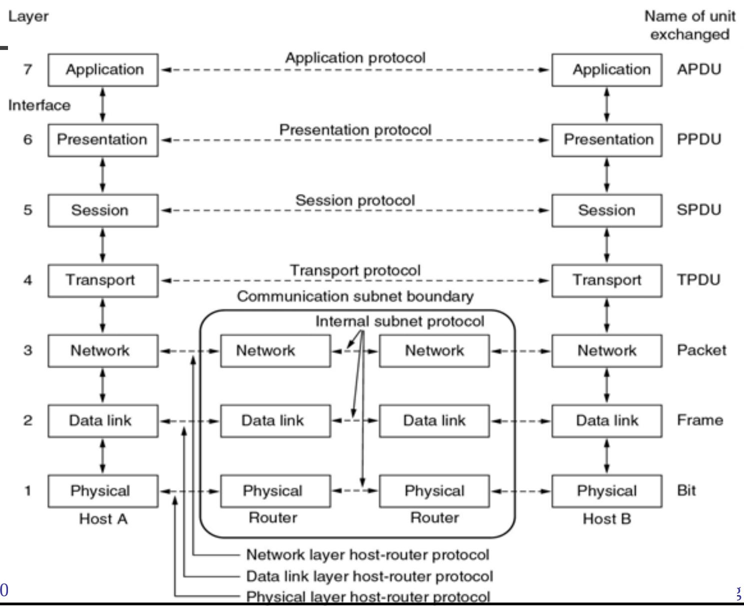
Protocol Hierarchies

- **Protocol hierarchies** are organized into layers or levels with different protocols at each layer
- Each layer offers certain services to higher layers, hiding the details of implementation of those services
- Layer n on one machine communicates with layer n on another machine
- Interface between adjacent layers defines operations and services offered by lower layer to upper layer
- **Protocol Stack** - A list of protocols used by a certain system, one protocol per layer

Connection-Oriented and Connectionless Services

- Connection-oriented service
  - Modeled after telephone system – establish connection before communication
  - Some service allow a **negotiation** among sender, receiver and subnet regarding the parameters to be used, such as max message size, etc.
- Connectionless service
  - Modeled after postal system – a message carries full destination address, and each one is routed through the system independent of all the others
- Quality of Service
  - **Reliable service** – it does not lose data
    - Implemented by having the receiver acknowledge the receipt of each message
    - The acknowledgement process introduces overhead and delays

The OSI Reference Model

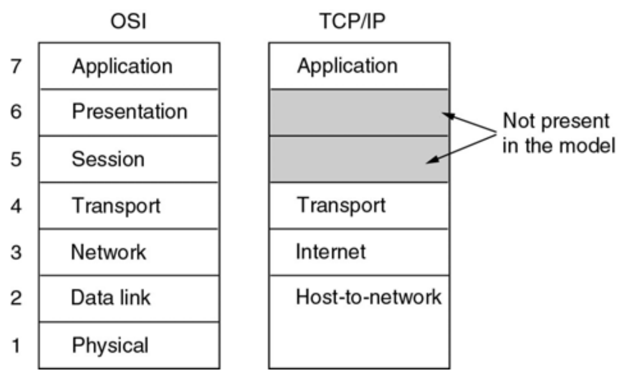


Concepts Central to the OSI Model

- Services – what layer does
- Protocols – how layer does it
- Interfaces – tells upper layer how to access services of lower layer

TCP/IP Reference Model

- TCP – Transmission Control Protocol
- IP – Internet Protocol
- Used in Internet and its predecessor ARPANET



TCP/IP Reference Model

- Internet Layer
  - Packet switched, Connectionless
  - Injects packets into the network; delivers them to the destination
  - May be delivered out-of-order
  - Packet routing and congestion control are key issues
- Transport layer, two protocols
  - TCP (Transmission Control Protocol) – Point-to-point, Connection-oriented, Reliable, Source ordered, Flow control, Bye stream
  - UDP (User Datagram Protocol) – Point-to-point, Connectionless, Unreliable, Not source ordered, No flow control, Preserve message boundary

Network Standardization

- Why standard?
  - Each vendor/supplier has its own ideas of how things should be done, the only way out is to agree on some network standards
  - Standards also increase the market for products adhering to them
  - Two kinds of standards
    - De facto – from the fact (standards that just happened)
    - De jure – by law (formal, legal standards adopted by authorized organization)

Chapter 2 – Physical Layer

- Theoretical basis for data communication
- Guided transmission media
- Wireless transmission
- Communication satellites
- Public switched telephone network
- Mobile telephone system
- Cable television

Fourier Analysis

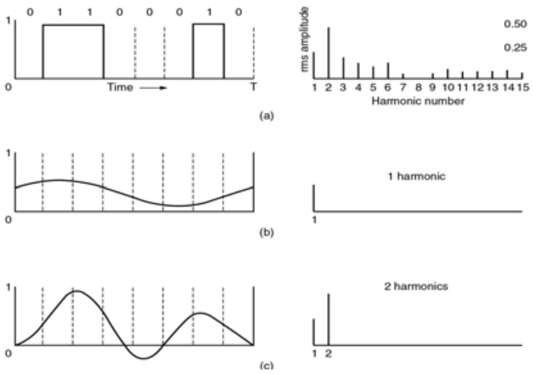
- Info is transmitted by varying voltage or current
- Let f(t) be value of voltage or current at time t, any well-behaved periodic function g(t) with period T can be represented as Fourier series

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$

  where f=1/T, the fundamental frequency, a_n and b_n are sine and cosine amplitudes of nth harmonics (terms)
- The amplitudes and constant are given by

$$a_n = \frac{2}{T}\int_0^T g(t)\sin(2\pi nft)\,dt \qquad b_n = \frac{2}{T}\int_0^T g(t)\cos(2\pi nft)\,dt \qquad c = \frac{2}{T}\int_0^T g(t)\,dt$$

Bandwidth-Limited Signals



A binary signal and its root-mean-square Fourier amplitudes.

(b) – (c) Successive approximations to the original signal.

Maximum Data Rates of a Channel

- **Theorem (Nyquist 1924) for noiseless channels**
  - If an arbitrary signal is run through a low-pass filter of bandwidth H, then the filtered signal can be completely reconstructed by making on 2H samples per second
  - **Max data rate = 2H $\log_2$V bits/sec**, where signal consists of V discrete lines
  - Ex: H = 3000 Hz, V = 2 (binary)
max data rate = 2*3000*$\log_2$2 = 6000 bits/sec
  - Ex: H = 3000 Hz, V = 64
max data rate = 2*3000*$\log_2$64 = 36,000 bits/sec

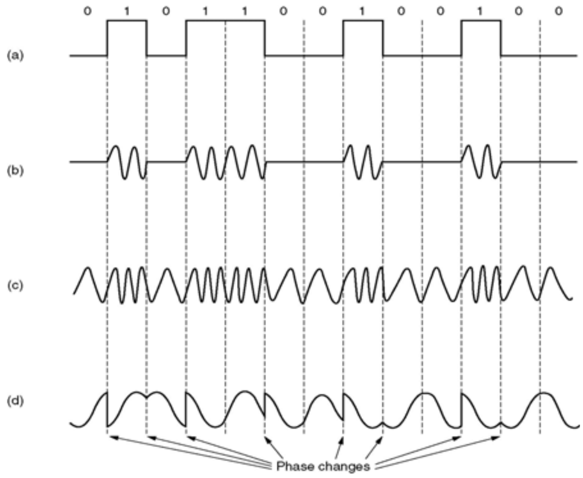
Maximum Data Rates of a Channel

- **Theorem (Shannon 1948) noisy channels**
  - Amount of thermal noise = signal to noise ratio = signal power / noise power = S/N
  - Decibel (dB): 10 $\log_{10}$S/N
  - **Max data rate = H $\log_2$(1+S/N) bits/sec**
  - Ex: H = 3000 Hz, S/N = 30dB = 1000
    max data rate = 3000*$\log_2$(1+1000) = 30,000
    upper bound is hard to reach, 9600 bits/sec is good

Modems

- **Modem** – device used between digital computer and analog telephone system. It converts digital bit stream into modulated analog signal and vice versa
- **Codec** – inverse of a modem. It is a device that converts a continuous analog signal into a digital bit stream
- **Baud** – number of samples per second. During each baud, one symbol is sent. One symbol can carry multiple bits

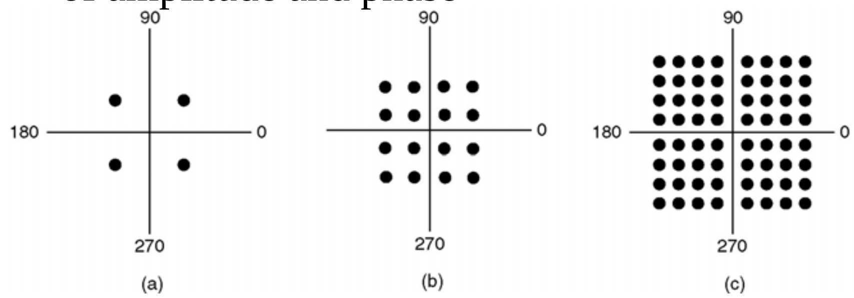
Modems



(a) A binary signal
(b) Amplitude modulation
(c) Frequency modulation
(d) Phase modulation

Modems

Constellation Diagrams – legal combinations of amplitude and phase



(a) QPSK: Quadrature Phase Shift Keying
(b) QAM-16: Quadrature Amplitude Modulation
(c) QAM-64.

Trunks and Multiplexing

- Idea: multiplex many conversations over single physical channel with high bandwidth
- FDM – **Frequency Division Multiplexing**
  - Frequency spectrum divided into logical channel
  - Each user has exclusive use of own frequency band
- TDM – **Time Division Multiplexing**
  - Time divided into slots each user has time slot
  - Users take turns in round robin fashion

Analog to Digital Modulation

- Encoding systems for digitizing analog signals – use statistical techniques to reduce number of bits/channel (signal changes slowly compared to sampling frequency)
  - **Differential pulse code modulation** – output difference between current value and previous value rather than digitized amplitude
  - **Predictive encoding** – Extrapolate previous few values to predict next value. Encode difference between actual signal and predicted one
  - **Delta modulation** – Requires each sampled value to differ from its predecessor by +/-1

Switching

- Two types of switching
  - **Circuit switching –** physical path set up from source to destination before any data transmitted, e.g., phone system
    - Adv: no congestion problem, only delay is propagation time
    - Disadv: unused bandwidth on allocated circuit is wasted
  - **Packet switching –** store-and-forward, one hop at a time, uses pipelining, each packet has limited size
    - Adv: low overhead – no setup required, high utilization
    - Disadv: packets may be received out of order, packets may be lost due to buffer overflow

CDMA – Code Division Multiple Access

A: 0 0 0 1 1 0 1 1
B: 0 0 1 0 1 1 1 0
C: 0 1 0 1 1 1 0 0
D: 0 1 0 0 0 0 1 0

(a)

A: (−1 −1 −1 +1 +1 −1 +1 +1)
B: (−1 −1 +1 −1 +1 +1 +1 −1)
C: (−1 +1 −1 +1 +1 +1 −1 −1)
D: (−1 +1 −1 −1 −1 −1 +1 −1)

(b)

Six examples:

− − 1 −	**C**	$S_1 = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$
− 1 1 −	**B + C**	$S_2 = (-2\ 0\ 0\ 0\ +2\ +2\ 0\ -2)$
1 0 − −	**A +** $\overline{\mathbf{B}}$	$S_3 = (0\ 0\ -2\ +2\ 0\ -2\ 0\ +2)$
1 0 1 −	**A +** $\overline{\mathbf{B}}$ **+ C**	$S_4 = (-1\ +1\ -3\ +3\ +1\ -1\ -1\ +1)$
1 1 1 1	**A + B + C + D**	$S_5 = (-4\ 0\ -2\ 0\ +2\ 0\ +2\ -2)$
1 1 0 1	**A + B +** $\overline{\mathbf{C}}$ **+ D**	$S_6 = (-2\ -2\ 0\ -2\ 0\ -2\ +4\ 0)$

(c)

$S_1 \bullet C = (1\ +1\ +1\ +1\ +1\ +1\ +1\ +1)/8 = 1$
$S_2 \bullet C = (2\ +0\ +0\ +0\ +2\ +2\ +0\ +2)/8 = 1$
$S_3 \bullet C = (0\ +0\ +2\ +2\ +0\ -2\ +0\ -2)/8 = 0$
$S_4 \bullet C = (1\ +1\ +3\ +3\ +1\ -1\ +1\ -1)/8 = 1$
$S_5 \bullet C = (4\ +0\ +2\ +0\ +2\ +0\ -2\ +2)/8 = 1$
$S_6 \bullet C = (2\ -2\ +0\ -2\ +0\ -2\ -4\ +0)/8 = -1$

(d)

(a) Binary chip sequences for 4 stations
(b) Bipolar chip sequences
(+1 for 1, and -1 for 0)
(c) Six examples of transmissions
(d) Recovery of station C's signal

- Let **S** be m-chip vector for station S
- All chip sequences are orthogonal
  - Normalized inner product of any two distinct chip seq, **S** and **T**, is 0, i.e., **S*T**=0
- **S*S** = 1

Chapter 3 – Data Link Layer

- Data Link Layer Design Issues
- Error Detection and Correction
- Elementary Data Link Protocols
- Sliding Window Protocols
- Protocol verification
- Example data link layer protocols
  - HDLC (High-level Data Link Control)
  - PPP (Point-to-Point Protocol)

Data Link Layer Design Issues

- Services Provided to the Network Layer
  - Point-to-point, source-to-destination, "wirelike"
- Framing: Physical bit stream divided up into frames
- Error Control
  - Acks and nacks
- Flow Control
  - Sender may transmit frames faster than receiver can receive them
  - Throttle sender so sends no faster than receiver can receive them

Framing

- How does DL layer form frames?
  - Insert time gaps between frames
  - Character count
  - Flag bytes with byte stuffing
  - Starting and ending flags, with bit stuffing
  - Physical layer coding violations

Error-Correcting Codes

- N-bit **codeword –** an n-bit unit containing data and check bits (m bits of data, r bits redundant/check bits)
- Given any two codewords, it is possible to determine how many corresponding bits differ, using exclusive OR and counting number of 1 bits in the result
- **Hamming distance –** number of bit positions in which two codewords differ

Error-Correcting Codes

- In general, all 2^m possible data messages are legal, but not all 2^n possible codewords are used
- Given the algorithm for computing the check bits, it is possible to
  - Construct a complete list of legal codewords
  - Find two codewords whose Hamming distance is minimum
  - This distance is the Hamming distance of the **complete code**
- To detect d errors, need a distance d+1 code
- To correct d errors, need a distance 2d+1 code

Hamming Code

- The bits of codeword are numbered consecutively, starting with bit 1 at the left end, bit 2 to its immediate right and so on
- The bits that are powers of 2 (1,2,4,8,16,etc) are check bits
  - The rest are filled up with the m data bits
- Each parity bit calculates the parity for some of the bits in the code word. The position of the parity bit determines the sequence of bits that it alternately checks and skips
- Set a parity bit to 1 if the total number of ones in the positions it checks is odd. Set a parity bit to 0 if the total number of ones in the positions it checks is even (assuming even parity is used)

Cyclic Redundant Code

- Sender and receiver agree on generate polynomial G(*x*), with high and low order bits = 1
- To compute checksum for some frame with *m* bits corresponding to M(*x*)
  - $m > \deg G(x) = r$
- Append checksum to end of frame so polynomial T(*x*) corresponding to checksummed frame is divisible by G(*x*)
- When receiver gets checksummed frame, divides T(*x*) by G(*x*)
- If remainder R(*x*) != 0, then transmission error

Data Link Protocols

- An Unrestricted Simplex Protocol
- A Simplex Stop-and-Wait Protocol
- A Simplex Protocol for a Noisy Channel
- A One-Bit Sliding Window Protocol
- A Protocol Using Go Back N
- A Protocol Using Selective Repeat

Sliding Window Protocols

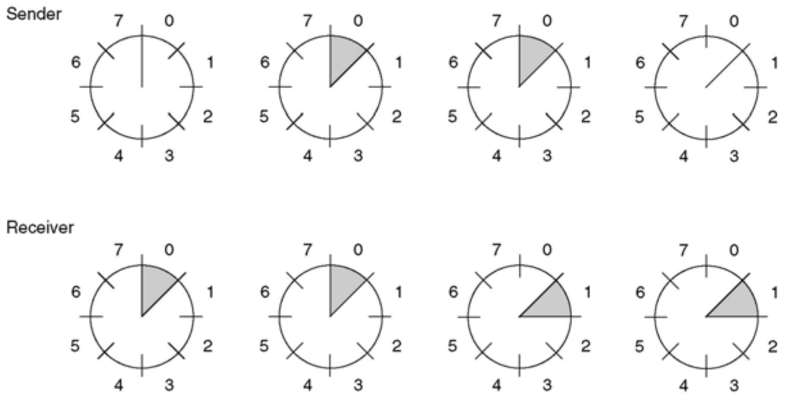
- **Sending window –** list of consecutive sequence numbers of frames that sender is permitted to send
  - When new packet arrives from NL, it is given next highest sequence number, and upper edge of window is incremented
  - When ack arrives from receiver, lower edge of window is incremented
  - Within sending window, frame sent but not acked
    - Sender must keep those frames for possible retransmission
    - If max window size = *w*, need *w* buffers

Sliding Window Protocols

- **Receiving window –** list of consecutive sequence numbers of frames that receiver is permitted to accept
  - When frame with (seq num = lower edge of window) arrives
    - Frame is passed to NL
    - Ack is generated
    - Window slid down by 1 (remains same size as was initially)

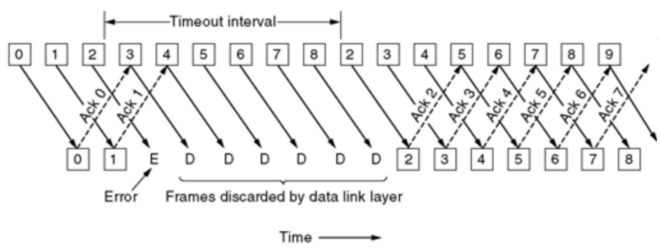
Sliding Window Protocols

A sliding window of size 1, with a 3-bit sequence number

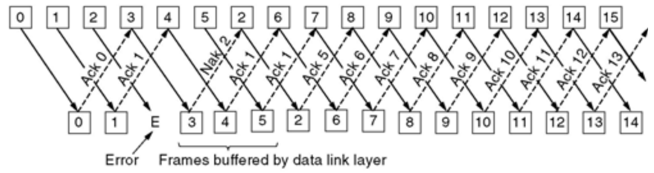


(a) Initially (b) After first frame sent (c) After first frame received (d) After first ack received

Pipelining and Error Recovery

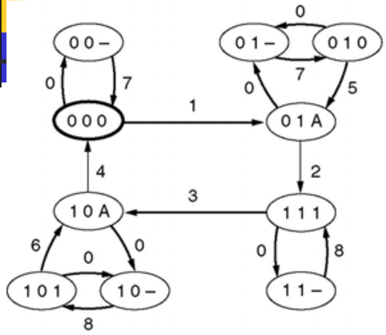


Go back *n*: Effect of an error when receiver's window size is 1



Selective repeat: Effect of an error when receiver's win. size is large

Finite State Machine Models



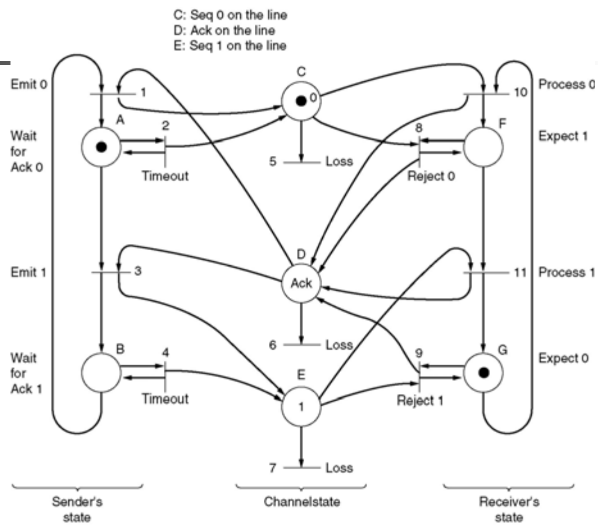
(a)

Transition	Who runs?	Frame accepted	Frame emitted	To network layer
0	–	(frame lost)		–
1	R	0	A	Yes
2	S	A	1	–
3	R	1	A	Yes
4	S	A	0	–
5	R	0	A	No
6	R	1	A	No
7	S	(timeout)	0	–
8	S	(timeout)	1	–

(b)

- Each state is labeled by SRC
  - S – frame the sender is trying to send: 0, 1
  - R – frame the receiver expects: 0, 1
  - C – state of the channel: 0, 1, A, - (empty)

Petri Net Models - Example



Chapter 4 – Medium Access Control

- The Channel allocation problem
- Multiple access protocols
- IEEE 802 standards
- Data link layer switching

Multiple Access Protocols

- ALOHA
  - Pure Aloha and slotted Aloha
- Carrier Sense Multiple Access Protocols
  - (1,p,0)-persistant CSMA; CSMA/CD
- Collision-Free Protocols
  - Bitmap protocol, binary countdown
- Limited-Contention Protocols
  - Adaptive tree walk protocol
- Wavelength Division Multiple Access Protocols
- Wireless LAN Protocols (MACA, MACAW)

IEEE 802 Standards

- IEEE 802 standards for LAN and MAN
  - 802.3 – Ethernet
  - 802.11 – Wireless LAN
  - 802.15 – Bluetooth
  - 802.16 – Wireless MAN
  - 802.2 – Logical link control sublayer
    - 802.3 and 802.11 converge on 802.2