Chapter 4
The Medium Access Control Sublayer

2019 Edition

The Channel Allocation Problem

- Static Channel Allocation in LANs and MANs
- Dynamic Channel Allocation in LANs and MANs

The Medium Access Control Sublayer

- **The Channel Allocation Problem**
- **The concept of LANs**
- **Architecture and Characteristics**
- **Ethernet and IEEE 802 standards**
- **Token ring Networks**
- **FDDI**
- **Wireless LANs**

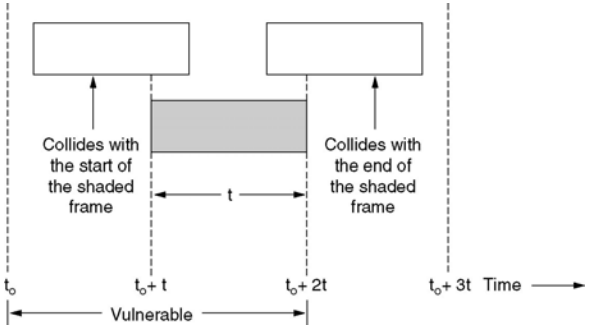
Dynamic Channel Allocation in LANs and MANs

- Station Model.
- Single Channel Assumption.
- Collision Assumption.
- (a) Continuous Time.
  (b) Slotted Time.
- (a) Carrier Sense.
  (b) No Carrier Sense.

Multiple Access Protocols

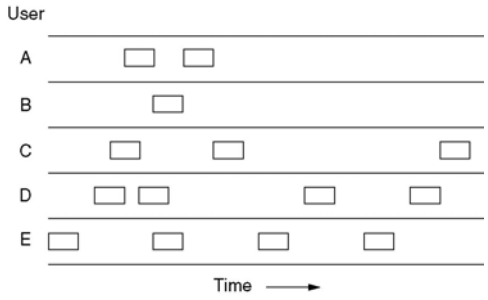
- ALOHA
- Carrier Sense Multiple Access Protocols
- Collision-Free Protocols
- Limited-Contention Protocols
- Wavelength Division Multiple Access Protocols
- Wireless LAN Protocols

Pure ALOHA (2)



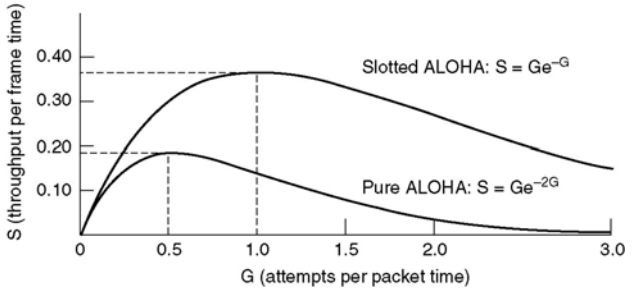
Vulnerable period for the shaded frame.

Pure ALOHA



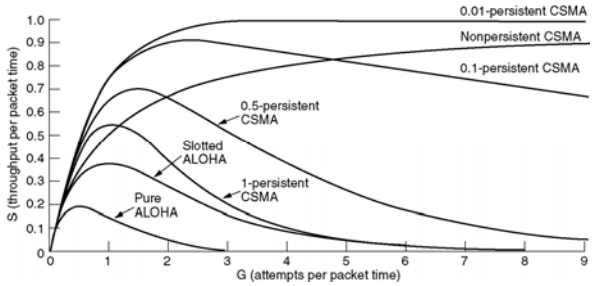
In pure ALOHA, frames are transmitted at completely arbitrary times.

Pure ALOHA (3)



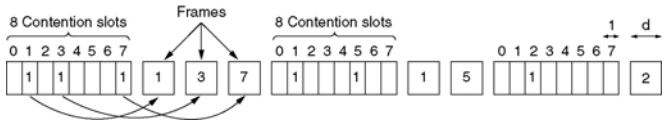
Throughput versus offered traffic for ALOHA systems.

Persistent and Nonpersistent CSMA



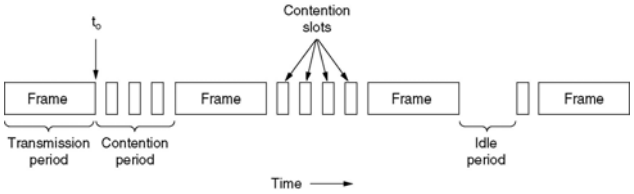
Comparison of the channel utilization versus load for various random access protocols.

Collision-Free Protocols



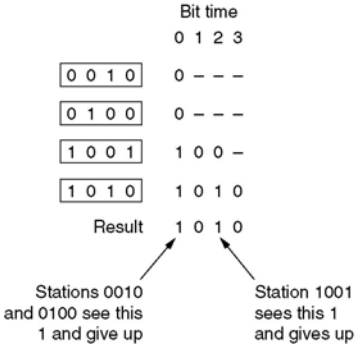
The basic bit-map protocol.

CSMA ~~with~~ Collision Detection



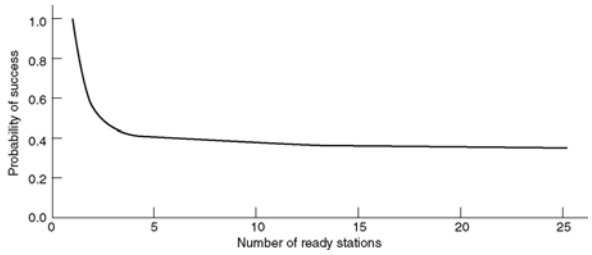
CSMA/CD can be in one of three states: contention, transmission, or idle.

Collision-Free Protocols (2)



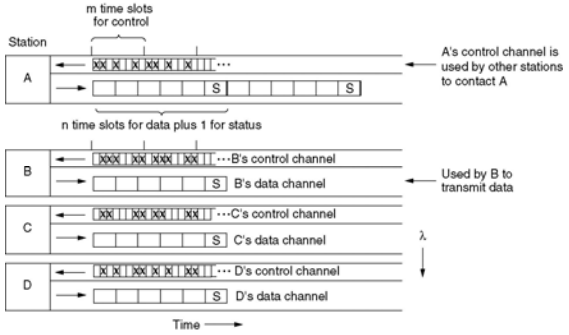
The binary countdown protocol. A dash indicates silence.

Limited-Contention Protocols



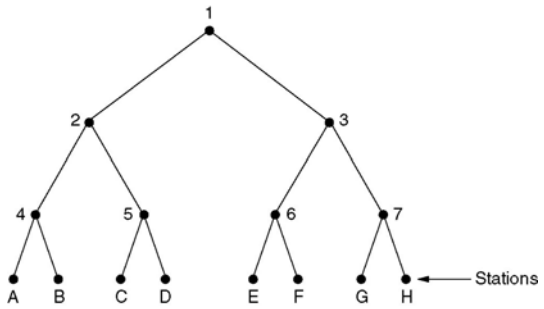
Acquisition probability for a symmetric contention channel.

Wavelength Division Multiple Access Protocols



Wavelength division multiple access.

Adaptive Tree Walk Protocol

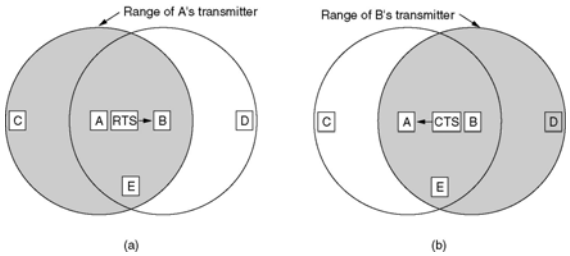


The tree for eight stations.

Wireless LAN Protocols

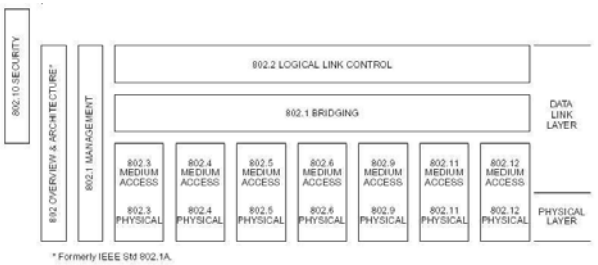
A wireless LAN. (a) A transmitting. (b) B transmitting.

Wireless LAN Protocols (2)



- The MACA protocol. (a) A sending an RTS to B.
- (b) B responding with a CTS to A.

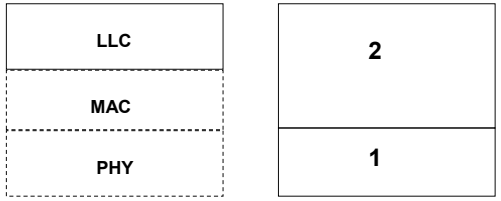
IEEE 802 Serials



Introduction to LANs

- **Introduction**
  - A local area network is a communication network that interconnects a variety of data communicating devices within a small geographic area and broadcasts data at high data transfer rates with very low error rates.
  - Since the local area network first appeared in the 1970s, its use has become widespread in commercial and academic environments

IEEE & OSI {again}

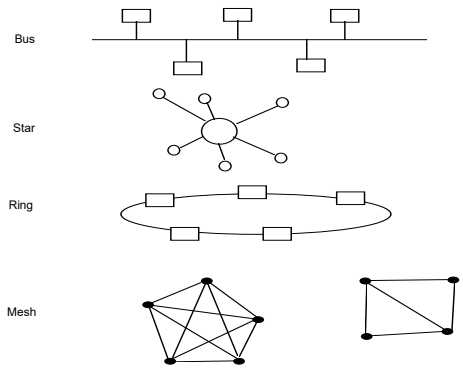


LLC = Logical Link Control
MAC = Media Access Control
PHY = Physical

Topology vs. Geography

Logical Layout	Physical Layout
"How devices talk to each other" -or- "How devices hear each other"	How the signal actually travels

Topologies

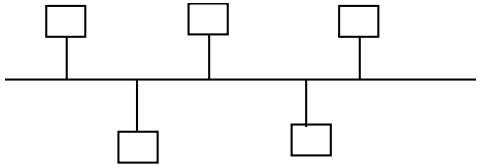


Basic Network Topology of LANs

- **Basic Network Topologies**
  - Local area networks are interconnected using one of four basic configurations:
    - 1. Bus/tree
    - 2. Star-wired bus
    - 3. Dual Ring
    - 4. Star-wired ring
    - 5. Wireless

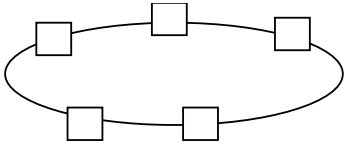
BUS

- Every node hears <u>every</u> other node's transmission directly.



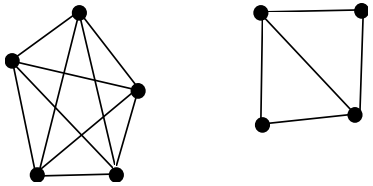
Ring

- Series of unidirectional point-to-point links without "store & forward", usually with a bypass ability.



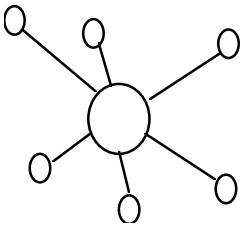
Mesh

- Each node independently routes over (bi-directional) point-to-point links.



Star

- Switching functions all in central node



IEEE 802 Standards

- IEEE 802 Standards

Standard	Responsibility	Standard	Responsibility
IEEE 802.1		IEEE 802.7	Broadband
IEEE 802.2	LLC	IEEE 802.8	Fiber Optics Cable
IEEE 802.3	CSMA/CD and 100BaseX	IEEE 802.9	Integrated Services LAN Interface
IEEE 802.4	Token Bus	IEEE 802.10	Interoperable LAN/MAN Security
IEEE 802.5	Token Ring	IEEE 802.11	Wireless LAN
IEEE 802.6	MAN (DQDB)	IEEE 802.12	100VG-AnyLAN

IEEE 802 Standards

- IEEE 802 Frame Formats
  - The IEEE 802 suite of protocols defines the frame formats for CSMA/CD (IEEE 802.3) and token ring (IEEE 802.5).
  - Each frame format describes how the data package is formed.
  - Note how the two frames are different. If a CSMA/CD network connects to a token ring network, the frames have to be converted from one to another.

IEEE 802 Standards

- Local Area Network Systems
  - IBM Token Ring
    - Deterministic LAN offered at speeds of 4, 16 and 100 Mbps.
    - Very good throughput under heavy loads.
    - More expensive components than CSMA/CD.
    - Losing ground quickly to CSMA/CD. May be extinct soon.

IEEE 802 Standards

- Local Area Network Systems
  - Ethernet or CSMA/CD
  - Most common form of LAN today.
  - Star-wired bus is most common topology but bus topology also available.
  - Ethernet comes in many forms depending upon medium used and transmission speed and technology.

IEEE 802 Standards

- FDDI (Fiber Distributed Data Interface)
  - Based on the token ring design using 100 Mbps fiber connections.
  - Allows for two concentric rings - inner ring can support data travel in opposite direction or work as backup.
  - Token is attached to the outgoing packet, rather than waiting for the outgoing packet to circle the entire ring.

IEEE 802 Standards

- 100VG-AnyLAN
  - Deterministic LAN based on demand priority access method.
  - Similar to hub topology (star design).
  - Two levels of priority - normal and high.
  - Supports a wide-variety of media types.
  - Losing ground quickly to CSMA/CD. Will be extinct soon.

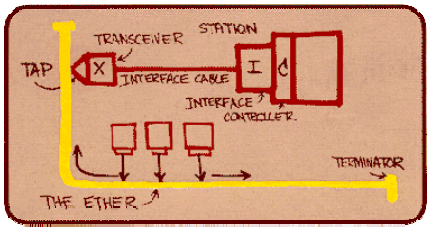
IEEE 802.3
Ethernet

Characteristics of LANs

- Throughout
- Latency
- Wiring Type and Distances
- Security
- Reliability
- Comparison

Ethernet

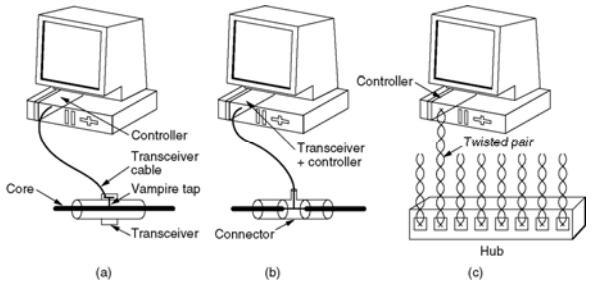
- Widely deployed because:
  - Cheap as dirt! $20 for 100Mbs!
  - First LAN technology
  - Simpler and less expensive than token LANs and ATM
  - Kept up with the speed race: 10, 100, 1000 Mbps
  - Many E-net technologies (cable, fiber etc). But they all share common characteristics



Ethernet

- Ethernet Cabling
- Manchester Encoding
- The Ethernet MAC Sublayer Protocol
- The Binary Exponential Backoff Algorithm
- Ethernet Performance
- Switched Ethernet
- Fast Ethernet
- Gigabit Ethernet
- IEEE 802.2: Logical Link Control
- Retrospective on Ethernet

Ethernet Cabling (2)



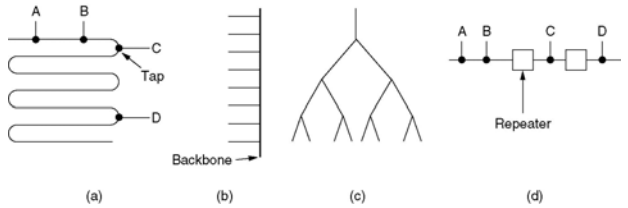
- Three kinds of Ethernet cabling.
- (a) 10Base5, (b) 10Base2, (c) 10Base-T.

Ethernet Cabling

Name	Cable	Max. seg.	Nodes/seg.	Advantages
10Base5	Thick coax	500 m	100	Original cable; now obsolete
10Base2	Thin coax	185 m	30	No hub needed
10Base-T	Twisted pair	100 m	1024	Cheapest system
10Base-F	Fiber optics	2000 m	1024	Best between buildings

The most common kinds of Ethernet cabling.

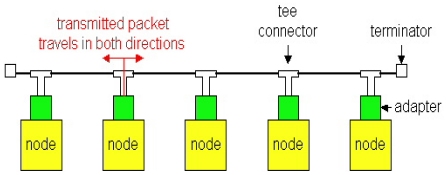
Ethernet Cabling (3)



Cable topologies. (a) Linear, (b) Spine, (c) Tree, (d) Segmented.

Ethernet Technologies: 10Base2

- 10==10Mbps; 2==under 200 meters maximum length of a cable segment; also referred to as "Cheapnet"
- Uses thin coaxial cable in a bus topology
- Repeaters are used to connect multiple segments (up to 5); a repeater repeats the bits it hears on one interface to its other interfaces, ie a physical layer device only!

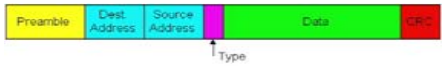


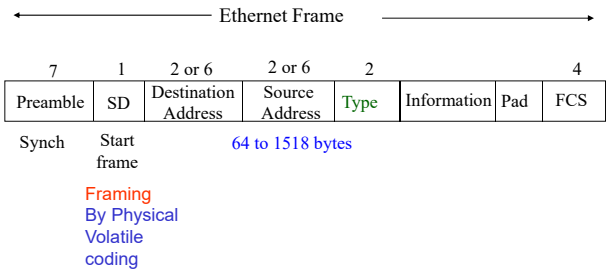
Ethernet Frame Structure (more)

- Header contains Destination and Source Addresses and a Type field
- **Addresses**: 6 bytes, frame is received by all adapters on a LAN and dropped if address does not match
- **Type**: indicates the higher layer protocol, mostly IP but others may be supported such as Novell IPX and AppleTalk)
- **CRC**: checked at receiver, if error is detected, the frame is simply dropped

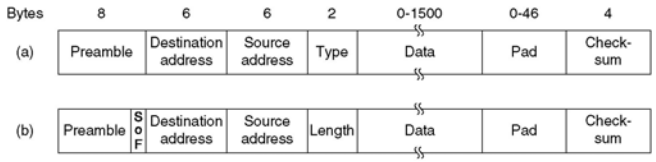
Ethernet Frame Structure

- Sending adapter encapsulates an IP datagram (or other network layer protocol packet) in **Ethernet Frame** which contains a Preamble, a Header, Data, and CRC fields
- **Preamble**: 7 bytes with the pattern 10101010 followed by one byte with the pattern 10101011; used for synchronizing receiver to sender clock (clocks are never exact, some drift is highly likely)



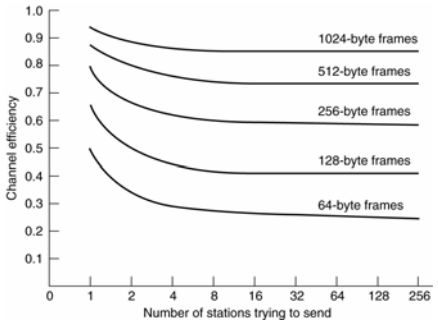


Ethernet MAC Sublayer Protocol



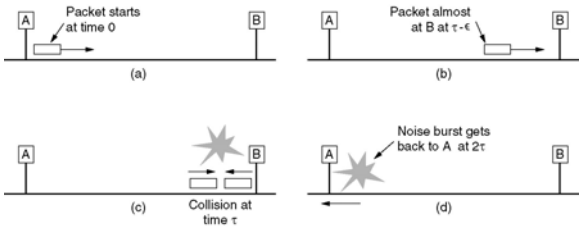
Frame formats. (a) DIX Ethernet, (b) IEEE 802.3.

Ethernet Performance



Efficiency of Ethernet at 10 Mbps with 512-bit slot times.

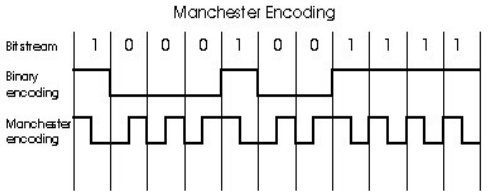
Ethernet MAC Sublayer Protocol (2)



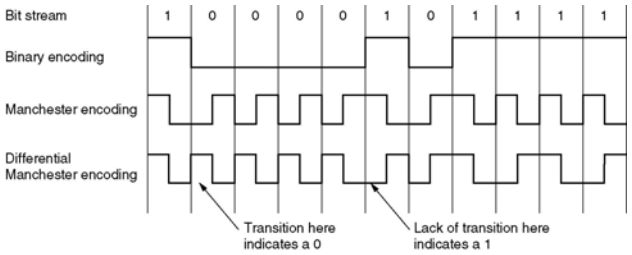
Collision detection can take as long as 2τ.

Baseband Manchester Encoding

- Baseband here means that no carrier is modulated; instead bits are encoded using Manchester encoding and transmitted directly by modified voltage of a DC signal
- Manchester encoding ensures that a voltage transition occurs in each bit time which helps with receiver and sender clock synchronization



Ethernet Cabling (4)



(a) Binary encoding, (b) Manchester encoding, (c) Differential Manchester encoding.

CSMA/CD (more)

- **Jam Signal**: to make sure all other transmitters are aware of the collision; 48 bits;
- **Exponential Backoff**:
  - Goal is to adapt the offered rate by transmitters to the estimated current load (ie backoff when load is heavy)
  - After the first collision Choose K from {0,1}; delay is K x 512 bit transmission times
  - After second collision choose K from {0,1,2,3}…
  - After ten or more collisions, choose K from {0,1,2,3,4,…,1023}

CSMA/CD

A: sense channel, **if** idle
then {
transmit and monitor the channel;
If detect another transmission
then {
abort and send jam signal;
update # collisions;
delay as required by exponential backoff algorithm;
goto A
}
else {done with the frame; set collisions to zero}
}
else {wait until ongoing transmission is over and goto A}

CSMA/CD (more)

- Note that under this scheme a new frame has a chance of sneaking in in the first attempt, even in heavy traffic
- **Ethernet Efficiency**: under heavy traffic and large number of nodes:

$$Efficiency = \frac{1}{1 + (5 * \frac{t_{prop}}{t_{trans}})}$$

Invalid packets

- FCS error
- Invalid length
  - => bit
  - => less than minimum length, CSMA/CD

10BaseT and 100BaseT

- 10/100 Mbps rate; latter called "fast ethernet"
- T stands for Twisted Pair
- Hub to which nodes are connected by twisted pair, thus "star topology"
- CSMA/CD implemented at the Hub

Fast Ethernet

Name	Cable	Max. segment	Advantages
100Base-T4	Twisted pair	100 m	Uses category 3 UTP
100Base-TX	Twisted pair	100 m	Full duplex at 100 Mbps
100Base-FX	Fiber optics	2000 m	Full duplex at 100 Mbps; long runs

The original fast Ethernet cabling.

10BaseT and 100BaseT (more)

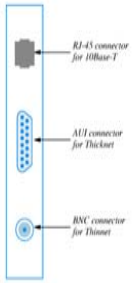
- Max distance from node to Hub is 100 meters
- Hub can disconnect a "jabbering adapter"; 10base2 would not work if an adapter does not stop transmitting on the cable
- Hub can gather monitoring information and statistics for display to LAN administrators
- 100BaseT does not use Manchester encoding; it uses 4B5B for better coding efficiency

More on LANS

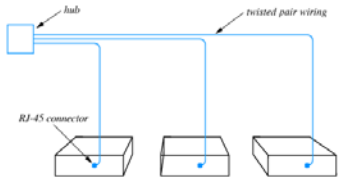
ThinNet

LAN Wiring, Interface

- Mostly covered this material already
  - Separate processor, buffers incoming/outgoing data
- –NIC = Network Interface Card
  - CPU might not be able to keep up network speeds!
  - Distributes processing to avoid overburdening CPU
  - Typically has DMA access
- –Wiring
  - ThickNet – 10Base5 ; Thick coax cable
  - ThinNet – 10Base2 ; "Thin" coax cable
    - –Use BNC connectors, "T" connectors for bus
  - 10BaseT, 100BaseT ; Twisted Pair
    - –Use central hub



10BaseT

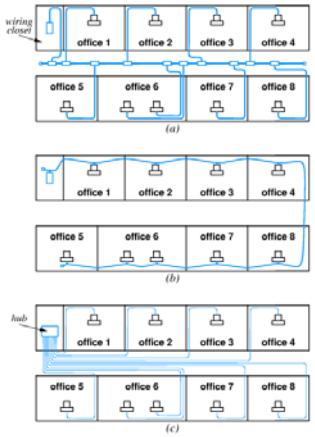


Comparison of Wiring Schemes

- 10Base2
  - Separate transceiver allows computer to be powered off or disconnected from network without disrupting other communication
  - Transceiver may be located in an inconvenient place
  - Finding malfunctioning transceiver can be hard
  - Thin coax takes minimum of cable
  - Disconnecting one computer (or one loose connection) can disrupt entire network
- 10BaseT
  - Hub wiring centralizes electronics and connections, making management easier
  - Easier to pull cable
  - Bottom line - 10Base-T most popular because of cost

Hubs and Switches

Wiring Schemes



Hub Concept

- Separate transmit and receive pair of wires
- The repeater in the hub retransmits the signal received on any input pair onto ALL output pairs, including the incoming pair.
- *Essentially the **hub** emulates a broadcast channel with collisions detected by receiving nodes.*

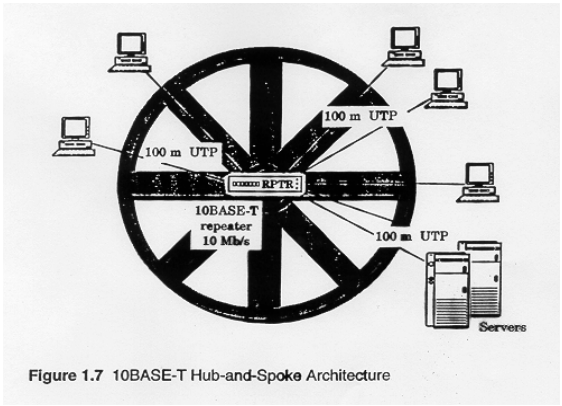
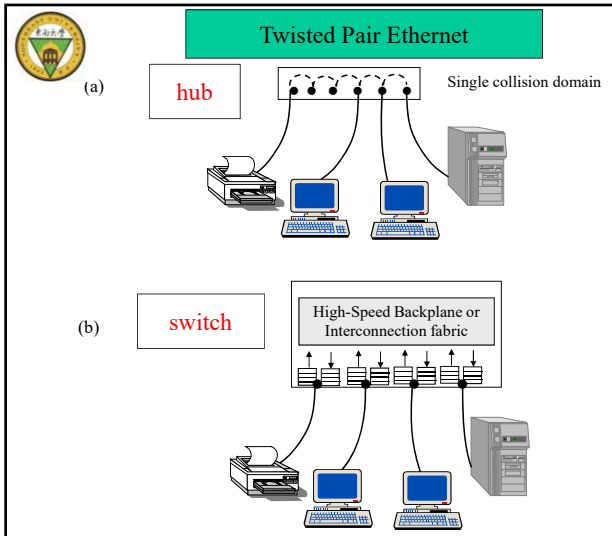


Figure 1.7 10BASE-T Hub-and-Spoke Architecture

Switched Ethernet

*Basic idea: improve on the **Hub** concept

- The switch *learns destination locations* by remembering the ports of the associated source address in a table.
- Sometimes switch may have to broadcast to all output ports except the incoming one if it do not know which port the destination belongs to.
- → a big performance advantage over a hub, if more than one frame transfer can go through the switch concurrently.



Switched Ethernet

- The advantage comes when the switched Ethernet backplane is able to repeat more than one frame in parallel *(a separate backplane bus line for each node).*
  - The frame is relayed onto the required output port via the port's own backplane bus line
- Under this scheme *collisions are still possible* when two concurrently arriving frames are destined for the same station.
- **Note – each parallel transmission can take place at 10Mbps (100Mbps for high speed Ethernet)**

Switched Ethernet Hub

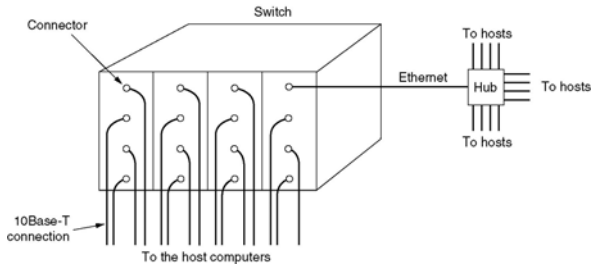
❒Since servers are often shared by multiple nodes, one can employ a ***switching hub*** with a port which operates at a higher rate than the other ports.

➔Extra buffering inside hub to handle speed mismatches.

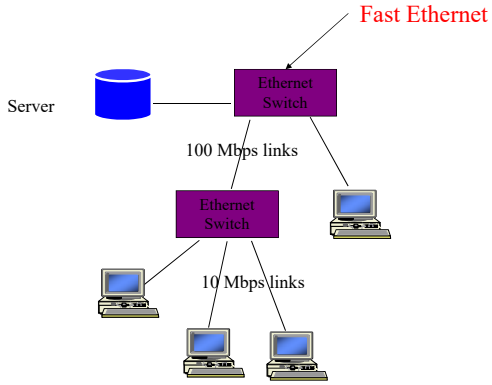
·Can be further *enhanced* by higher rated port **full-duplex**.

·By Full-duplex switched Ethernet hub, transferring and receiving can be done at the same time.

Switched Ethernet



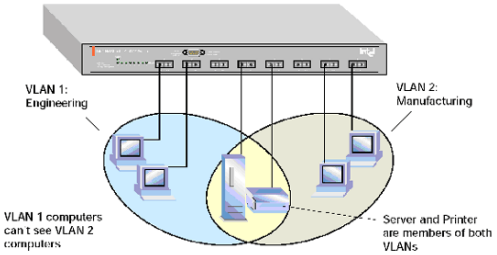
A simple example of switched Ethernet.



IEEE 802.1Q VLAN

VLAN

- VLANs are used to separate broadcast domains without creating a separate cable plant or path.



Fast Ethernet

- 100M
- 1G
- 10G

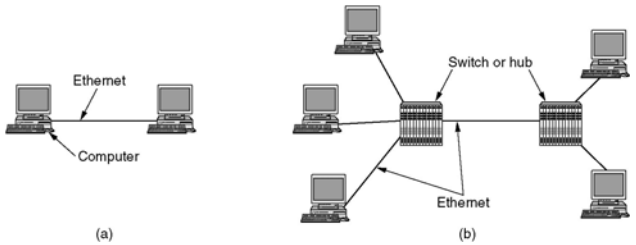
faster …. ?

Fast Ethernet

Gbit Ethernet

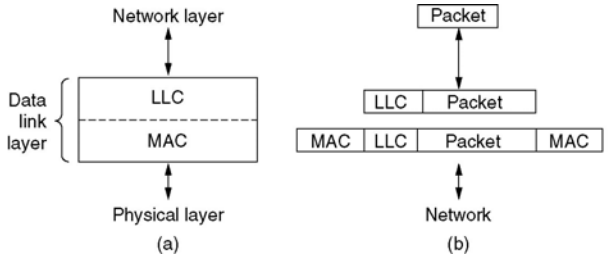
- Use standard Ethernet frame format
- Allows for Point-to-point links and shared broadcast channels
- In shared mode, CSMA/CD is used; short distances between nodes to be efficient
- Uses Hubs called here "Buffered Distributors"
- Full-Duplex at 1 Gbps for point-to-point links

Gigabit Ethernet



(a) A two-station Ethernet. (b) A multistation Ethernet.

IEEE 802.2: Logical Link Control



(a) Position of LLC. (b) Protocol formats.

Gigabit Ethernet (2)

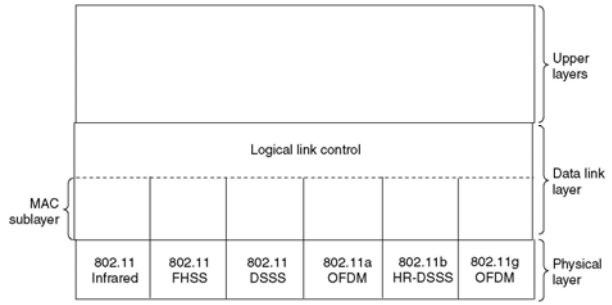
Name	Cable	Max. segment	Advantages
1000Base-SX	Fiber optics	550 m	Multimode fiber (50, 62.5 microns)
1000Base-LX	Fiber optics	5000 m	Single (10 μ) or multimode (50, 62.5 μ)
1000Base-CX	2 Pairs of STP	25 m	Shielded twisted pair
1000Base-T	4 Pairs of UTP	100 m	Standard category 5 UTP

Gigabit Ethernet cabling.

Wireless LANs

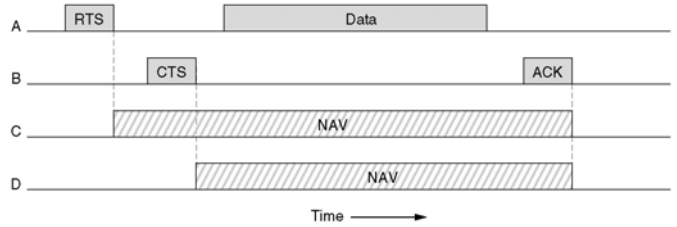
- The 802.11 Protocol Stack
- The 802.11 Physical Layer
- The 802.11 MAC Sublayer Protocol
- The 802.11 Frame Structure
- Services

The 802.11 Protocol Stack



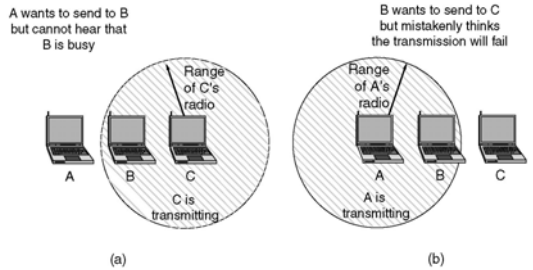
Part of the 802.11 protocol stack.

The 802.11 MAC Sublayer Protocol (2)



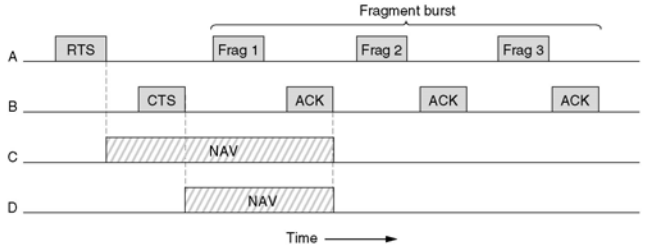
The use of virtual channel sensing using CSMA/CA.

The 802.11 MAC Sublayer Protocol



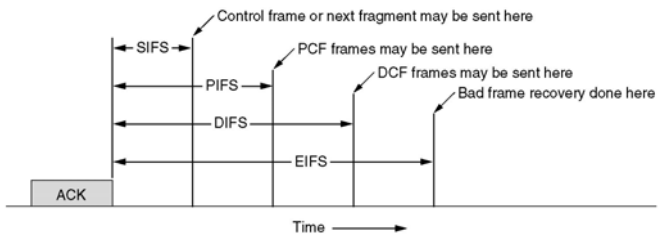
- (a) The hidden station problem.
- (b) The exposed station problem.

The 802.11 MAC Sublayer Protocol (3)



A fragment burst.

The 802.11 MAC Sublayer Protocol (4)



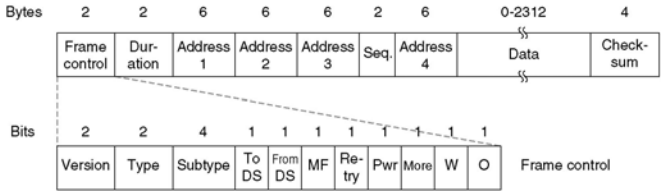
Interframe spacing in 802.11.

802.11 Services

Distribution Services

- Association
- Disassociation
- Reassociation
- Distribution
- Integration

The 802.11 Frame Structure



The 802.11 data frame.

802.11 Services

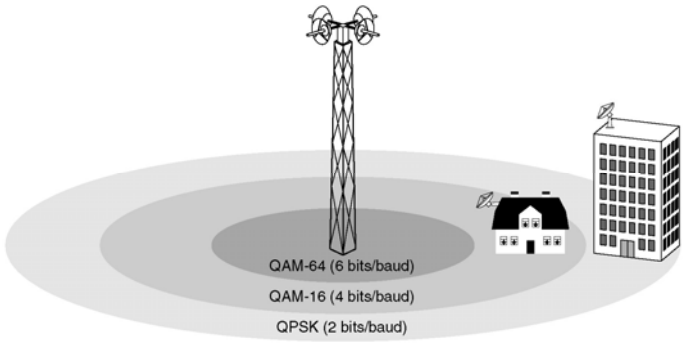
Intracell Services

- Authentication
- Deauthentication
- Privacy
- Data Delivery

Broadband Wireless

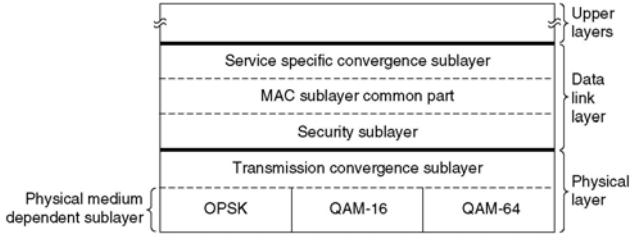
- Comparison of 802.11 and 802.16
- The 802.16 Protocol Stack
- The 802.16 Physical Layer
- The 802.16 MAC Sublayer Protocol
- The 802.16 Frame Structure

The 802.16 Physical Layer



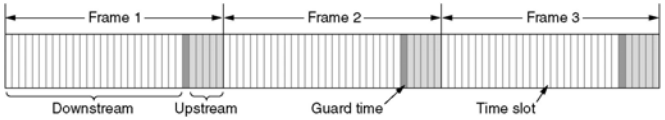
The 802.16 transmission environment.

The 802.16 Protocol Stack



The 802.16 Protocol Stack.

The 802.16 Physical Layer (2)



Frames and time slots for time division duplexing.

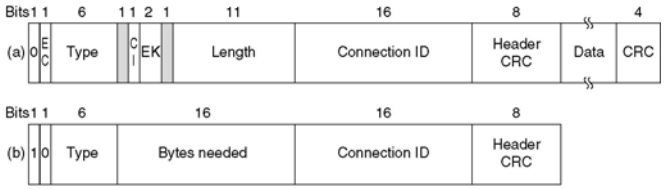
The 802.16 MAC Sublayer Protocol

- Service Classes
- Constant bit rate service
- Real-time variable bit rate service
- Non-real-time variable bit rate service
- Best efforts service

Bluetooth

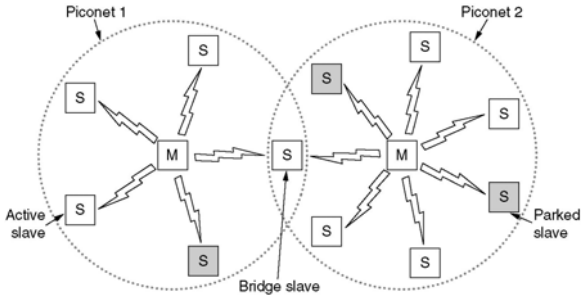
- Bluetooth Architecture
- Bluetooth Applications
- The Bluetooth Protocol Stack
- The Bluetooth Radio Layer
- The Bluetooth Baseband Layer
- The Bluetooth L2CAP Layer
- The Bluetooth Frame Structure

The 802.16 Frame Structure



(a) A generic frame. (b) A bandwidth request frame.

Bluetooth Architecture



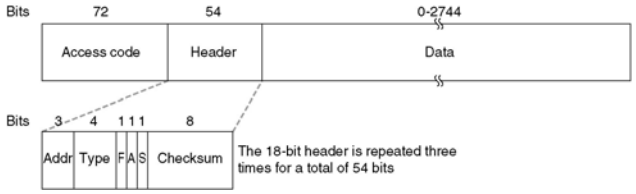
Two piconets can be connected to form a scatternet.

Bluetooth Applications

Name	Description
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
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
Cordless telephony	Connects a handset and its local base station
Intercom	Digital walkie-talkie
Headset	Intended for hands-free voice communication
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

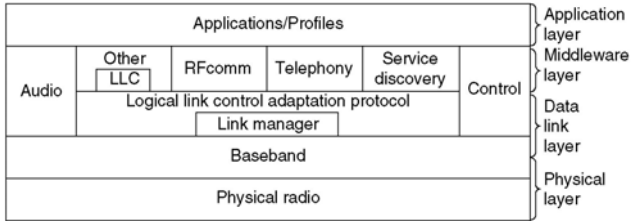
The Bluetooth profiles.

The Bluetooth Frame Structure



A typical Bluetooth data frame.

The Bluetooth Protocol Stack

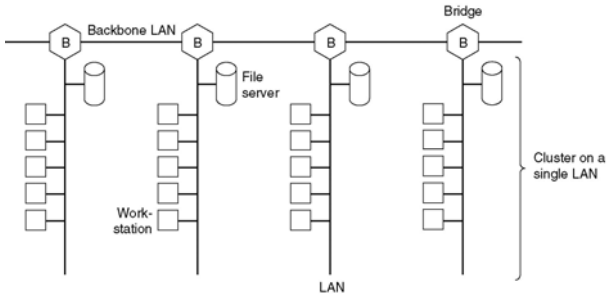


The 802.15 version of the Bluetooth protocol architecture.

Data Link Layer Switching

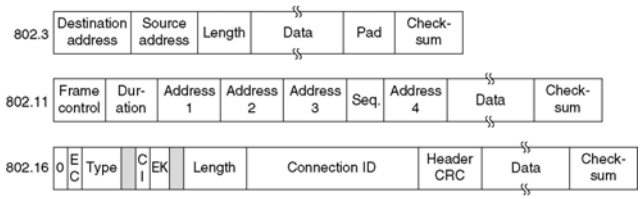
- Bridges from 802.x to 802.y
- Local Internetworking
- Spanning Tree Bridges
- Remote Bridges
- Repeaters, Hubs, Bridges, Switches, Routers, Gateways
- Virtual LANs

Data Link Layer Switching



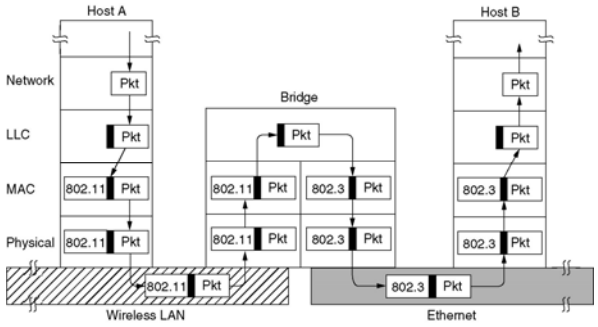
Multiple LANs connected by a backbone to handle a total load higher than the capacity of a single LAN.

Bridges from 802.x to 802.y (2)



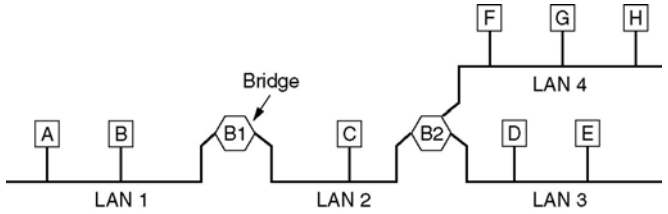
The IEEE 802 frame formats. The drawing is not to scale.

Bridges from 802.x to 802.y



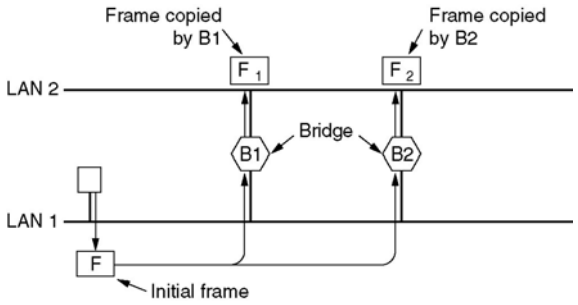
Operation of a LAN bridge from 802.11 to 802.3.

Local Internetworking



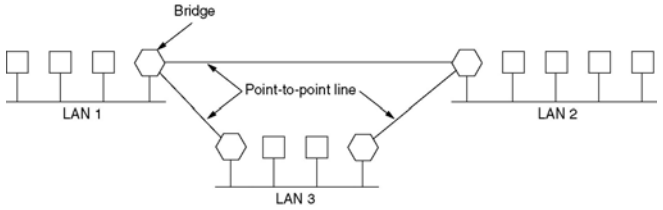
A configuration with four LANs and two bridges.

Spanning Tree Bridges



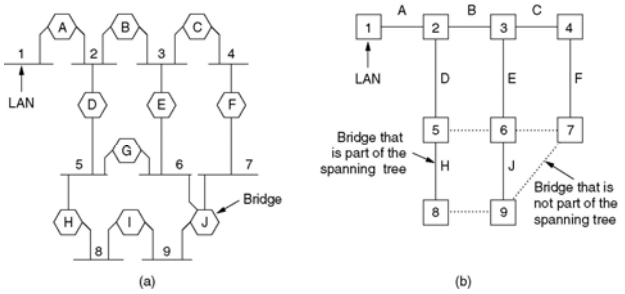
Two parallel transparent bridges.

Remote Bridges



Remote bridges can be used to interconnect distant LANs.

Spanning Tree Bridges (2)



(a) Interconnected LANs. (b) A spanning tree covering the LANs. The dotted lines are not part of the spanning tree.

How to communicate using TCP/IP protocol in Ethernet?

introduction

- In a LAN, nodes communicate by hardware address
- In TCP/IP, they communicate by IP address

So problem is:

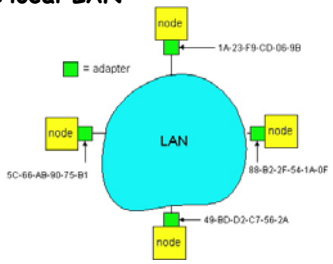
How to determine the relation of hardware address and IP address?

LAN Address (more)

- MAC address allocation administered by IEEE
- A manufacturer buys a portion of the address space (to assure uniqueness)
- Broadcast LAN address: 1111……1111

LAN Addresses and ARP

- **IP address**: drives the packet to destination **network**
- **LAN** (or MAC or Physical) **address**: drives the packet to the destination node's LAN interface card (adapter card) on the **local LAN**
- **48 bit MAC address** (for most LANs); burned in the adapter ROM



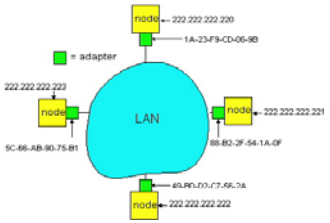
ARP: Address Resolution Protocol

- Each IP node (Host, Router) on the LAN has **ARP** module and Table
- ARP Table: IP/MAC address mappings for **some** LAN nodes

  < IP address; MAC address; TTL>

  < ……>

- TTL (Time To Live): timer, typically 20 min



ARP (more)

- Host A wants to send packet to destination IP addr XYZ on same LAN
- Source Host first checks own ARP Table for IP addr XYZ
- If XYZ **not** in the ARP Table, ARP module **broadcasts** ARP request packet:

  < XYZ, MAC (?) >
- ALL nodes on the LAN accept and inspect the ARP pkt
- Node XYZ responds with **unicast** ARP pkt carrying own MAC addr:

  < XYZ, MAC (XYZ) >
- MAC address **cached** in ARP Table

802.5 Token Ring

ARP (more)

- Host A wants to send packet to destination IP addr XYZ on differnet LAN(means different network), how to ?

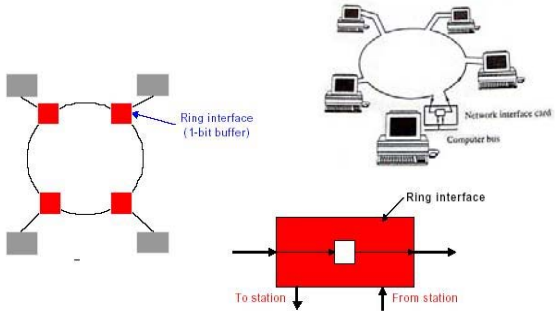
Token Ring - IEEE 802.5

What the IEEE standard covers
"Physical layer standard (gives link layer format)"

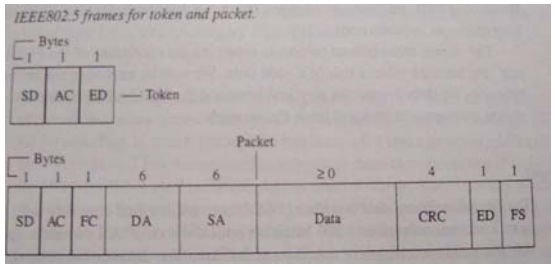
History
Essentially an IBM standard 'given' to the industry"

Differences between 802.5 and 802.3
"Guaranteed response
Priorities
Controlled delays"

Ring Connection

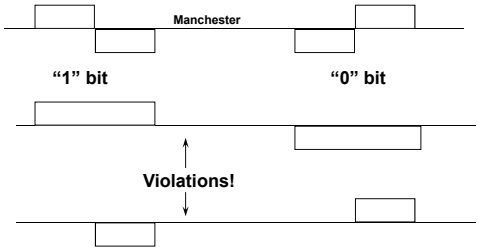


IEEE802.5 Frames For Token And Packet



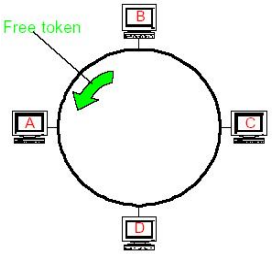
802.5 Framing

- IEEE 802.5 uses special characters, but does not use bit stuffing!



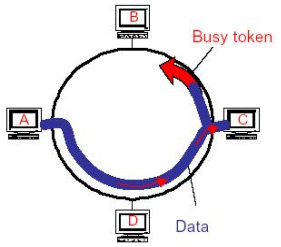
Transmission in a Token Ring

- Sender looks for free token



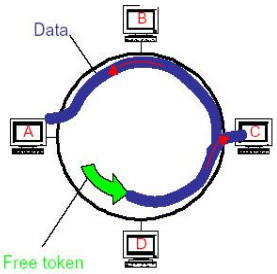
Transmission in a Token Ring

- Receiver recognizes that it is the destination of the frame. Receiver copies frame to station Note: Frame also returns to sender!



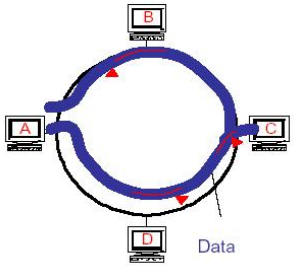
Transmission in a Token Ring

- Sender generates free token when it is done transmitting (Note: The busy token has returned)

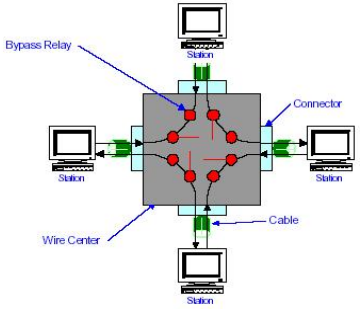


Transmission in a Token Ring

- Then…

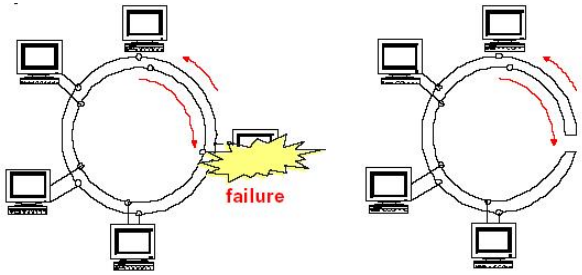


Improving Reliability: Wire Center (802.5)



Improving Reliability: Use a second ring (FDDI)

- FDDI: Fiber Distributed Data Interface

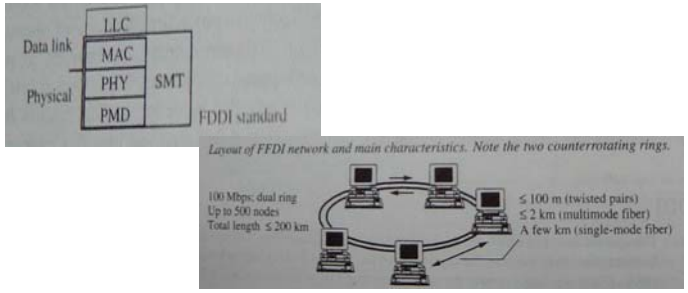


Continue…

- **FDDI (Fiber Distributed Data Interface)**
  - **Based on the token ring design using 100 Mbps fiber connections.**
  - **Allows for two concentric rings - inner ring can support data travel in opposite direction or work as backup.**
  - **Token is attached to the outgoing packet, rather than waiting for the outgoing packet to circle the entire ring.**

FDDI

- Fiber distributed data interface
- The specifications of FDDI are the subject of an ANSI(American National Standard Institute) standard that specifies the layers shown in Figure



Physical layer

- PMD: the physical medium dependent

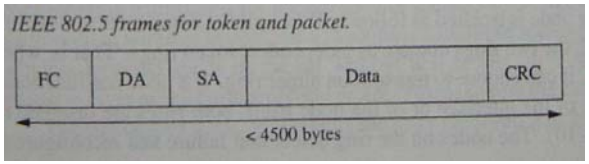
  three versions
- PHY: physical

TABLE 4.2 Main Characteristics of LANs
See Text for Comments

PMD	Max. length, m	Medium	Transmission
Original	2000	62.5-μm/125-μm graded-index fiber	1.3 μm
SMF	> 2000	8-μm/125-μm single-mode fiber	1.3 μm
TP	100	Type 1 shielded TP or cat 5 UTP	4B5B

FDDI

MAC



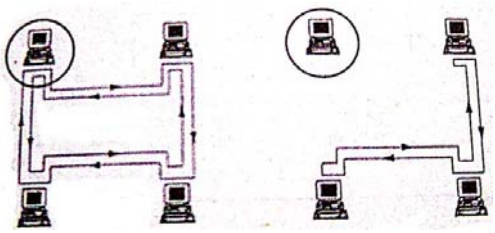
Difference between FDDI and IEEE802.5

- Why?
- To meet the requirement of high transfer speed
- High efficiency

1.Once identify token, stop token to transfer(not forward), catch the token,after finish receiving the token,transfer data at once;

2.Station which send data release the token at once(although it may not receive the frame from itself.)

FDDI:Station Management



Token Ring Technology Summary

- Access method by which network attachments gain access to the cable plant by acquiring a special frame called the token. {Token is a special 24-bit pattern that continuously circulates the ring.}
- Token Ring is a broadcast medium. {To receive data, a destination station performs an address match.}
- The destination station merely copies the frame as it repeats it back to the ring.
- When the frame arrives back to the source station, it strips the frame from the ring and then releases the token.

Extending and interconnection of LANs

LAN Distance

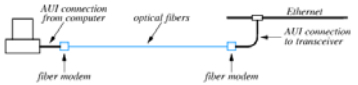
- Length of medium affects strength of electrical signals and noise immunity
- LANs use shared medium - Ethernet, token ring
  - Length of medium affects consistency and fair, shared access to medium
    - Token passing - circulation time for token increases with long cable
    - CSMA/CD –with minimum frame size, if propagation delay too long we won't detect collision while transmitting
- Standards set a maximum distance for LANs
  - 100 meters for UTP
  - 200 to 500 meters for coax
- Can extend distances with fiber optic connections
  - Install a fiber modem from computer to transceiver, perhaps in a different building

Extending LANs

- LANs were designed with constraints of speed, distance, cost, and usage
  - Typical distance = 100 to 500 meters
  - CSMA/CD optimal with bursty traffic
  - Works best to connect computers in a single floor or building
- Possible to improve on LAN performance
  - Scale up to larger amounts of traffic
  - Extend to connect computers across longer distances

Fiber Modems

- Fiber modems
  - Convert Ethernet signals to digital signal for fiber
  - Transmit digital signals via fiber optic cable to other modem
  - Most often used to connect two LANs - typically through a bridge - different buildings
  - Fiber is a good choice due to low latency and high bandwidth
  - Extending distance from interface to physical layer



Repeaters (中继器)

- May want to extend LAN medium
  - Ethernet - timing constraints allow longer medium
  - Signal strength constraints limit length
- *Repeater* – simplest form is a bidirectional, analog amplifier that retransmits analog signals. layer?
  - Simply copy signals between segments; includes noise/collision
  - Do not understand frame formats or addresses
    - Not the case with digital repeaters
  - Hub acts as a repeater
- One repeater can effectively double the length of an LAN segment, e.g. 100m to 200m

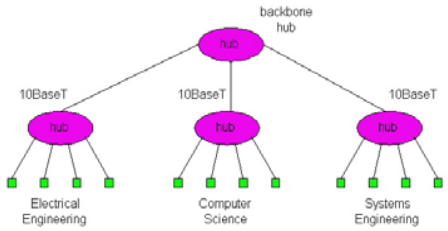
Hubs (more)

- Each connected LAN is referred to as a LAN **segment**
- Hubs **do not isolate** collision domains: a node may collide with any node residing at any segment in the LAN

- Hub Advantages:
  - Simple, inexpensive device
  - Multi-tier provides graceful degradation: portions of the LAN continue to operate if one of the hubs malfunction
  - Extends maximum distance between node pairs (100m per Hub)

Hubs(集线器)

- Physical Layer devices: essentially repeaters operating at bit levels: repeat received bits on one interface to all other interfaces
- Hubs can be arranged in a hierarchy (or **multi-tier design**), with a **backbone** hub at its top



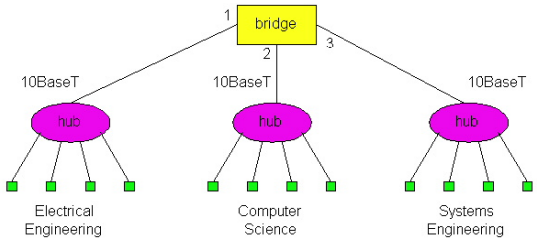
Hubs (more)

- Hub Limitations:
  - Single collision domain results in no increase in max throughput; the multi-tier throughput same as the the single segment throughput
  - Individual LAN restrictions pose limits on the number of nodes in the same collision domain (thus, per Hub); and on the total allowed geographical coverage
  - Cannot connect different Ethernet types (e.g., 10BaseT and 100baseT)

Bridges(网桥)

- **Link Layer devices**: they operate on Ethernet frames, examining the frame header and selectively forwarding a frame base on its destination
- Bridge **isolates collision** domains since it buffers frames
- When a frame is to be forwarded on a segment, the bridge uses CSMA/CD to access the segment and transmit, etc looks like a standard device

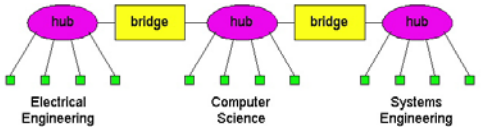
Backbone Bridge



Bridges (more)

- Bridge advantages:
  - Isolates collision domains resulting in higher total max throughput, and does not limit the number of nodes nor geographical coverage
  - Can connect different type Ethernet since it is a store and forward device
  - Transparent: no need for any change to hosts LAN adapters

Interconnection Without Backbone



- **Not recommended** for two reasons:
  - Single point of failure at Computer Science hub
  - All traffic between EE and SE must path over CS segment

Bridge Filtering

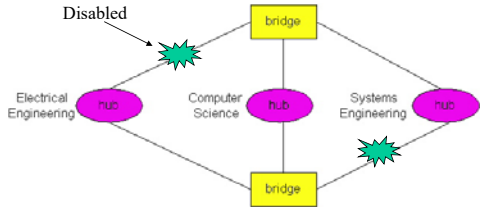
- Bridges learn which hosts can be reached through which interfaces and maintain filtering tables
- A filtering table entry:

  (Node LAN Address, Bridge Interface, Time Stamp)
- Filtering procedure:

```
if destination is on LAN on which frame was received
    then drop the frame
    else { lookup filtering table
        if entry found for destination
            then forward the frame on interface indicated;
            else flood;    /* forward on all but the interface on
                              which the frame arrived*/
    }
```

Bridges Spanning Tree(…支撑树)

- For increased reliability, it is desirable to have redundant, alternate paths from a source to a destination
- With multiple simultaneous paths however, cycles result on which bridges may multiply and forward a frame forever
- Solution is organizing the set of bridges in a spanning tree by disabling a subset of the interfaces in the bridges:

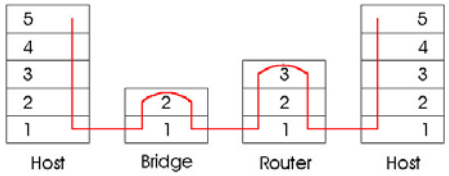


Bridge Learning

- When a frame is received, the bridge "learns" from the source address and updates its filtering table (Node LAN Address, Bridge Interface, Time Stamp)
- Stale entries in the Filtering Table are dropped (TTL can be 60 minutes)

Bridges vs. Routers

- Both are store-and-forward devices, but Routers are Network Layer devices (examine network layer headers) and Bridges are Link Layer devices
- Routers maintain routing tables and implement routing algorithms, bridges maintain filtering tables and implement filtering, learning and spanning tree algorithms



Routers vs. Bridges

❒Bridges + and -

+ Bridge operation is simpler requiring less processing bandwidth

- Topologies are restricted with bridges: a spanning tree must be built to avoid cycles

- Bridges do not offer protection from broadcast storms (endless broadcasting by a host will be forwarded by a bridge)

Ethernet Switches

❒A switch is a device that incorporates bridge functions as well as point-to-point 'dedicated connections'

❒A host attached to a switch via a dedicated point-to-point connection; will always sense the medium as idle; no collisions ever!

❒Ethernet Switches provide a combinations of shared/dedicated, 10/100/1000 Mbps connections

Routers vs. Bridges

❒Routers + and -

+ Arbitrary topologies can be supported, cycling is limited by TTL counters (and good routing prots)

+ Provide firewall protection against broadcast storms

- Require IP address configuration (not plug and play)

- Require higher processing bandwidth

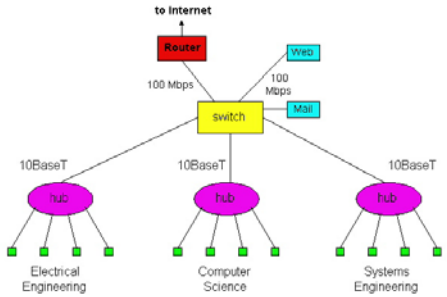
❒Bridges do well in small (few hundred hosts) while routers are required in large networks (thousands of hosts)

Ethernet

❒Some E-net switches support cut-through switching: frame forwarded immediately to destination without awaiting for assembly of the entire frame in the switch buffer; slight reduction in latency

❒Ethernet switches vary in size, with the largest ones incorporating a high bandwidth interconnection network

Ethernet Switches (more)

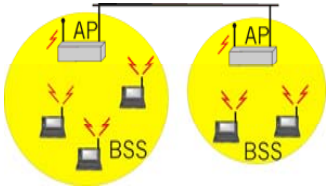


Ad Hoc Networks

- IEEE 802.11 stations can dynamically form a group without AP
- Ad Hoc Network: no pre-existing infrastructure
- Applications: "laptop" meeting in conference room, car, airport; interconnection of "personal" devices (see bluetooth.com); battelfield; pervasive computing (smart spaces)
- IETF MANET (Mobile Ad hoc Networks) working group

IEEE 802.11 Wireless LAN

- Wireless LANs are becoming popular for mobile Internet access
- Applications: nomadic Internet access, portable computing, ad hoc networking (multihopping)
- IEEE 802.11 standards defines MAC protocol; unlicensed frequency spectrum bands: 900Mhz, 2.4Ghz
- **Basic Service Sets + Access Points => Distribution System**

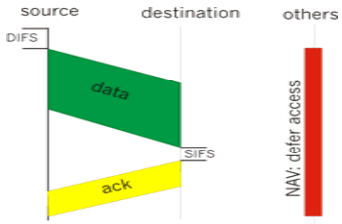


IEEE 802.11 MAC Protocol

CSMA Protocol:

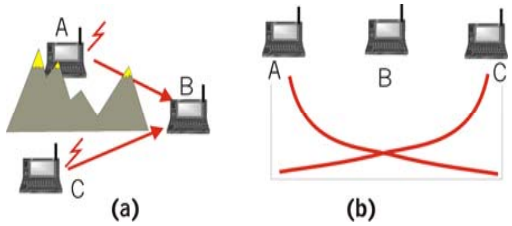
- sense channel idle for **DISF** sec (Distributed Inter Frame Space)
- transmit frame (no Collision Detection)
- receiver returns ACK after **SIFS** (Short Inter Frame Space)
- if channel sensed busy then binary backoff

NAV: Network Allocation Vector
(min time of deferral)



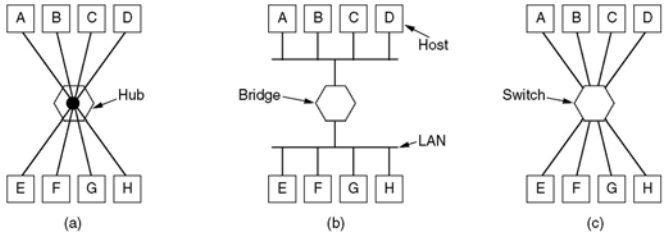
Hidden Terminal effect

- CSMA inefficient in presence of hidden terminals
- Hidden terminals: A and C cannot hear eachother because of obstacles or signal attenuation; so, their packets collide at B
- Solution? **CSMA/CA**
- **CA** = Collision Avoidance

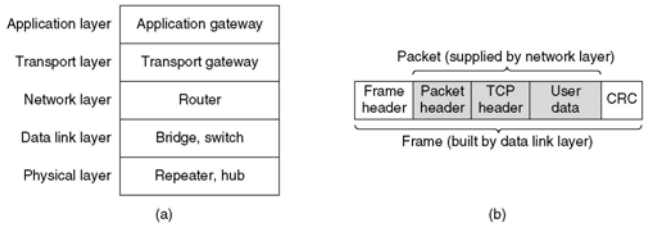


Repeaters, Hubs, Bridges, Switches, Routers and Gateways (2)

(a) A hub. (b) A bridge. (c) a switch.



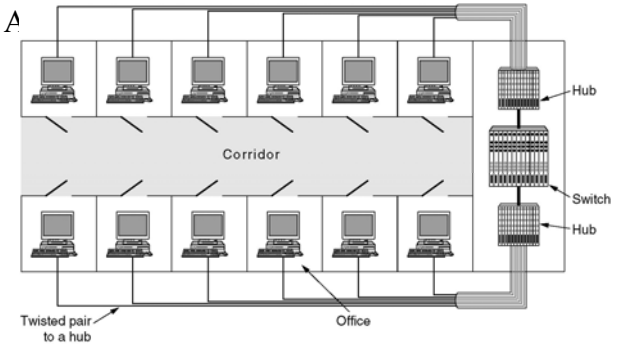
Repeaters, Hubs, Bridges, Switches, Routers and Gateways



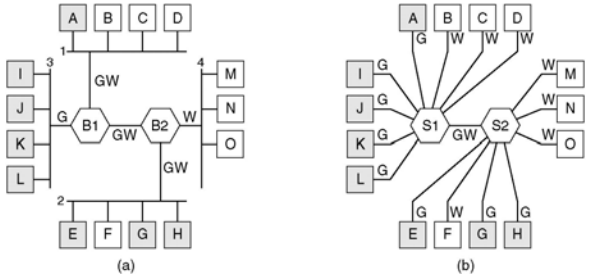
(a) Which device is in which layer.

(b) Frames, packets, and headers.

Virtual LANs

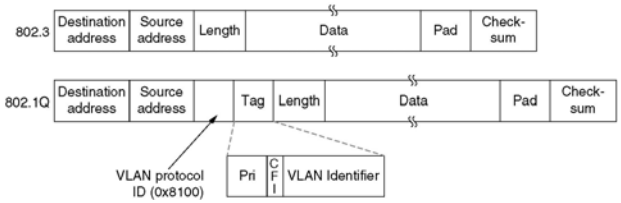


Virtual LANs (2)

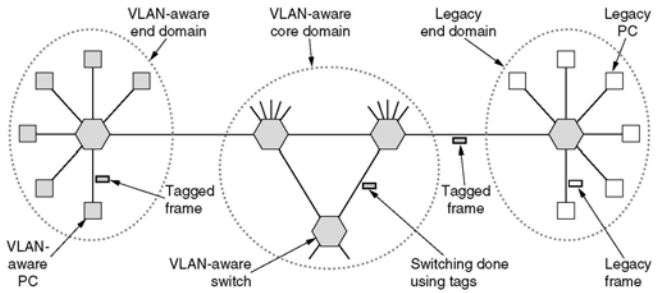


(a) Four physical LANs organized into two VLANs, gray and white, by two bridges. (b) The same 15 machines organized into two VLANs by switches.

The IEEE 802.1Q Standard (2)



The IEEE 802.1Q Standard

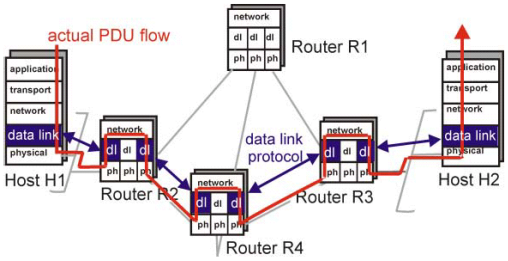


Summary

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

Channel allocation methods and systems for a common channel.

Link Layer Protocols



Assignment P338 2 6 15 21

LLC Service type

- LLC1:With unacknowledged message, connectionless

  no flow control,error control,simple,suit for broadcast and multicast
- LLC2: acknowledged message ,Connect-oriented

  similar to virtual circuit,include setup,transfer,relearse three stage
- LLC3:With acknowledged message, connectless

  improve realiablity
- LLC4:Transfer with high speed specialized MAN