CS4220
Computer Networks

Lecture 4 Medium Access Control

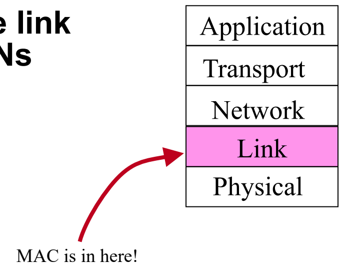
Dr. Xiaobo Charles Zhou
Department of Computer Science

Medium Access Control Sublayer
Chapter 4

- Channel Allocation Problem
- Multiple Access Protocols
- Ethernet
- Wireless LANs
- Broadband Wireless
- Bluetooth
- RFID
- Data Link Layer Switching

The MAC Sublayer

- Responsible for deciding who sends next on a multi-access link
  - An important part of the link layer, especially for LANs

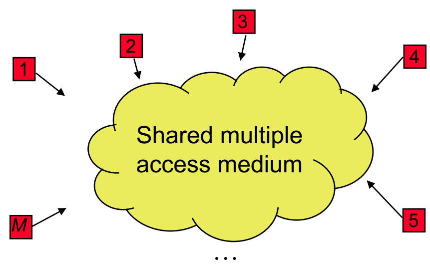


Chapter Overview

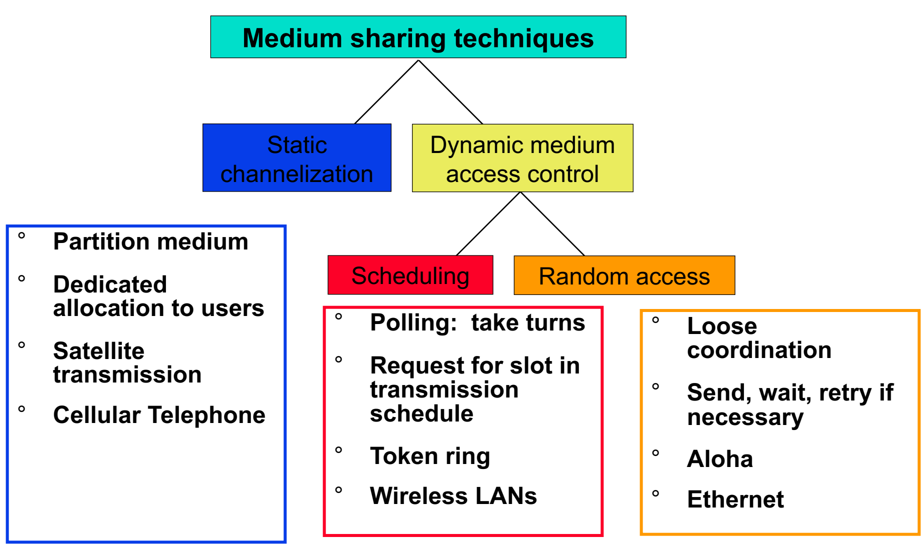
- Broadcast Networks
  - **All information sent to all users**
  - **No routing**
  - **Shared media**
  - **Radio**
    - **Cellular telephony**
    - **Wireless LANs**
  - **Copper & Optical**
    - **Ethernet LANs**
    - **Cable Modem Access**
- *Medium Access Control*
  - **To coordinate access to shared medium**
  - **Data link layer since direct transfer of frames**
- *Local Area Networks*
  - **High-speed, low-cost communications between co-located computers**
  - **Typically based on broadcast networks**
  - **Simple & cheap**
  - **Limited number of users**

Multiple Access Communications

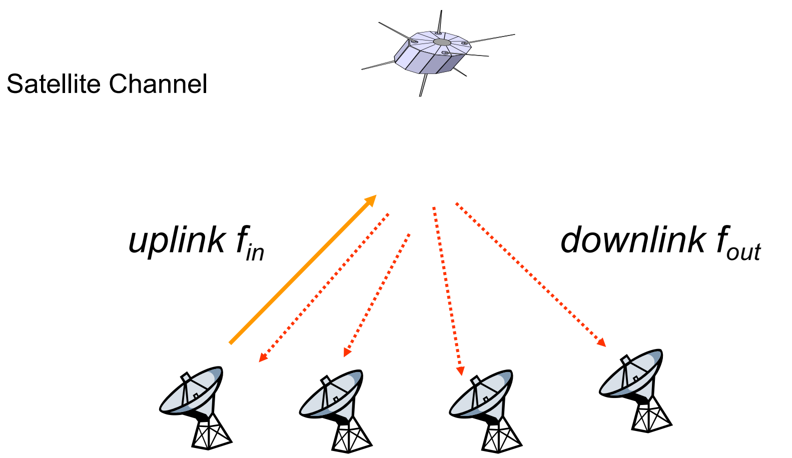
- Shared media basis for broadcast networks
  - Inexpensive: radio over air; copper or coaxial cable
  - M users communicate by broadcasting into medium
- Key issue: How to share the medium (multi-access) when there is a competition for it?
  - The control protocols are in MAC sublayer



Approaches to Media Sharing



Channelization: Satellite



What we can learn from the foundations of queueing theory?

Static Channel Allocation in LANs and MANs

- **Frequency Division Multiplexing (FDM): for *N* users, divide the bandwidth of the channel into *N* equal-sized portions**
- **Given a multi-access channel with capacity *C* bps, the average arrival rate of *N* users λ frames/sec (Poisson), average frame size $1/\mu$ bits/frame (exponential).**

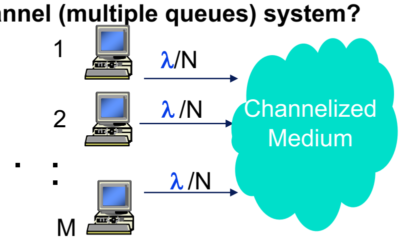
What is the service rate?

What is the average response time (= 1 / (service rate – arrival rate) of frames in a single channel (queue) system?

What is the average response time (= 1 / (service rate – arrival rate) of frames in a multi-channel (multiple queues) system?

When they are the same?

What is the problem of FDM?



Dynamic Channel Allocation in LANs and MANs

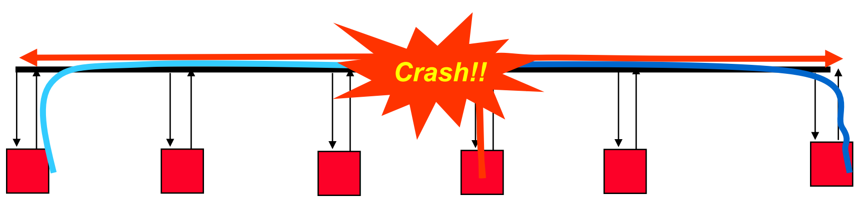
Assumptions

- **Station Model: *N* independent stations generating frames at a constant rate, one-by-one transmission**
- **Single Channel: only one for all stations equivalently**
- **Collision: if two frames are transmitted simultaneously, the resulting signal is garbled**
- **(a) Continuous Time: transmission begins at any instant.**
  (b) Slotted Time: transmission begins at the start of a slot.
- **(a) Carrier Sense: stations can sense the channel busy or idle.**
  (b) No Carrier Sense: just go ahead transmission

LANs generally have carrier sense, how about wireless networks?

Random Access

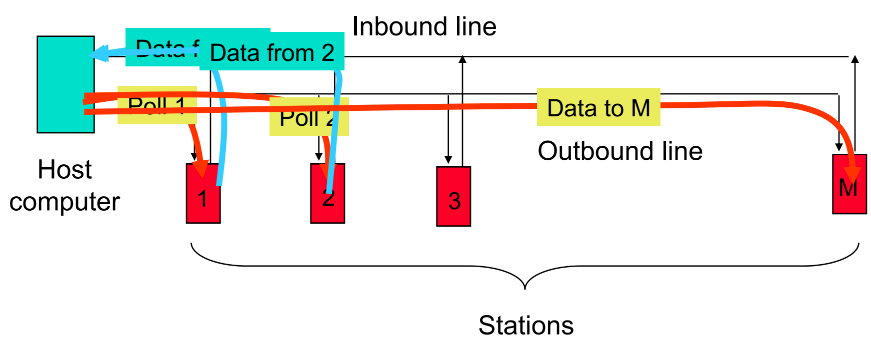
Multi-tapped (mulit-access) Bus



Transmit when ready

Transmissions can occur; need retransmission strategy

Scheduling: Polling

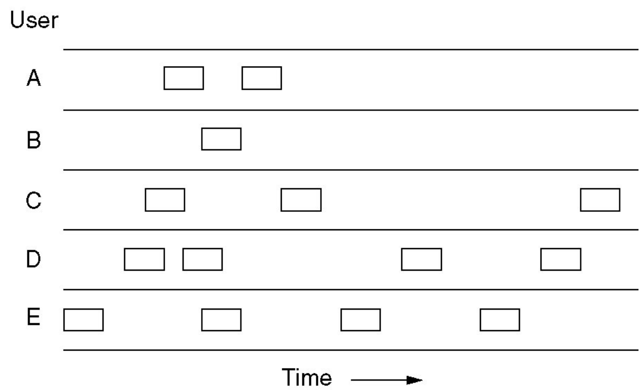


Multiple Access Protocols

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

Pure ALOHA

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



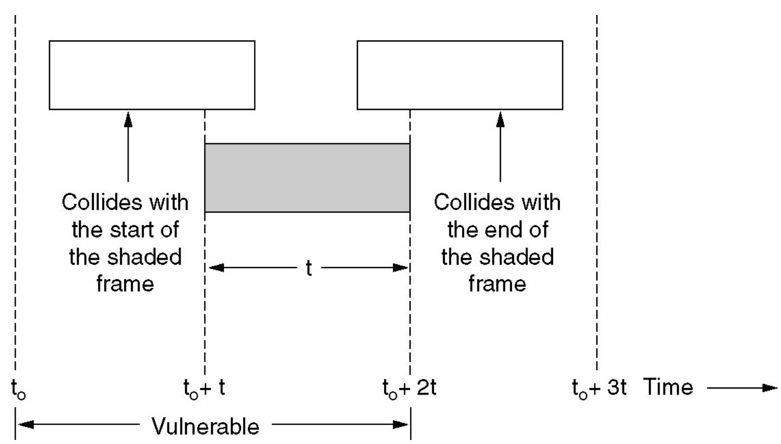
How a station knows its frame was destroyed due to collision?

Feedback property of broadcasting.

What is the efficiency of an ALOHA channel?

Pure ALOHA (2)

- ***G*** **per frame time be the mean number of transmission attempts per frame time, and *P_0* is the probability of a transmission does not suffer a collision, throughput *$S = GP_0$***



Vulnerable period for the shaded frame.

Slotted ALOHA

- **A station is required to wait for the beginning of the next slot, one time slot corresponding to one frame time**

What is the vulnerable period for a frame?

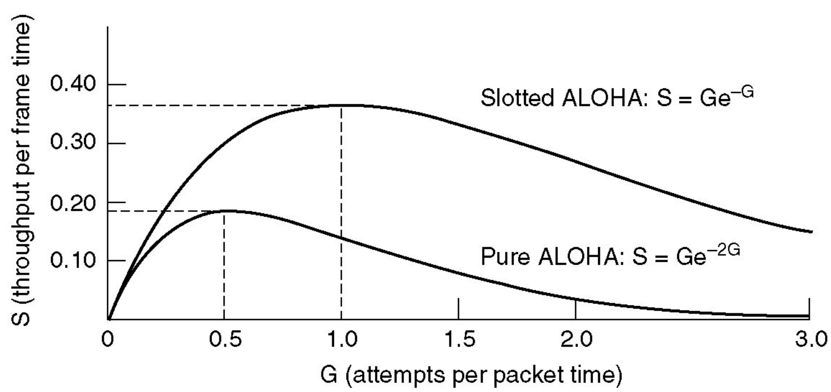
What is required to turn a pure ALOHA to a slotted ALOHA?

What benefit received by slotted ALOHA?

What is the price for the benefit? And how much?

Throughput of ALOHA Systems

Throughput versus offered traffic for ALOHA systems.

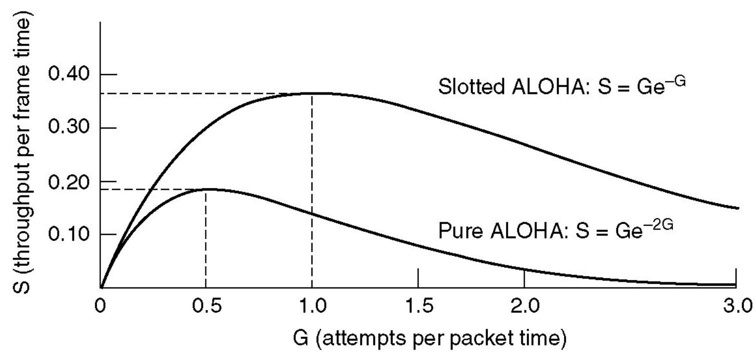


Are ALOHA protocols carrier sense?

Example

- Five thousand banking stations are competing for the use of a single slotted ALOHA channel. The average station makes 72 requests/hour. A slot is 125 µsec. What is the average total channel load? And what is the throughput S?

G = 5000 x 0.02 x 0.00125 = 1/80



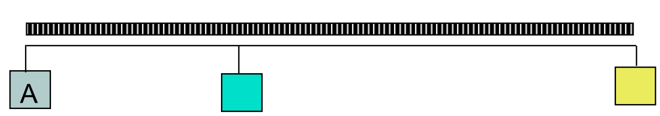
Comparison of the channel utilization versus load.

Carrier Sensing Multiple Access (CSMA)

- A station senses the channel before it starts transmission
  - If busy, either wait or schedule backoff (different options)
  - If idle, start transmission
  - Vulnerable period is reduced to t_{prop} (*channel capture* effect)
  - When collisions occur they involve entire frame transmission times
  - Always better than ALOHA?

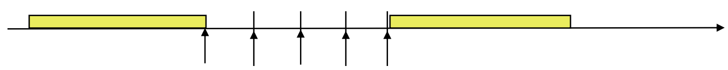
Station A begins transmission at $t = 0$

Station A captures channel at $t = t_{prop}$

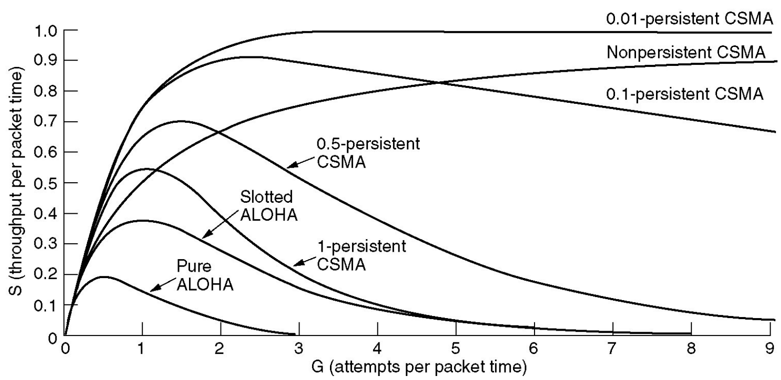


CSMA Options

- Transmitter behavior when busy channel is sensed
  - 1-persistent CSMA (most greedy)
    - Start transmission as soon as the channel becomes idle
    - Possible simultaneously transmission in a propagation delay
    - Low delay and low efficiency
  - Non-persistent CSMA (least greedy)
    - If busy, wait a backoff period, then sense carrier again
    - High delay and high efficiency
  - p-persistent CSMA (adjustable greedy)
    - Wait till channel becomes idle, transmit with prob. p; or wait one mini-slot time & re-sense with probability 1-*p*
    - Delay and efficiency can be balanced



CSMA Performance



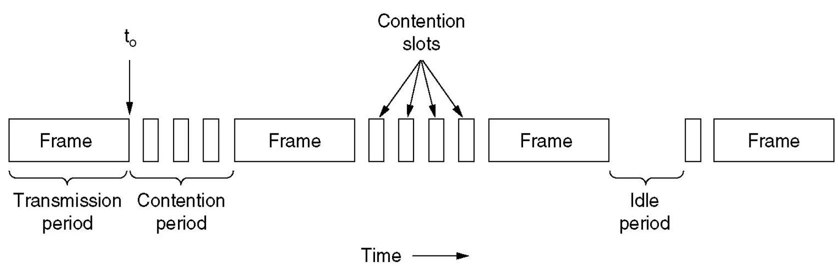
Comparison of the channel utilization versus load.

What is the price of non-persistent and p-persistent protocols?

Longer delay

CSMA with Collision Detection

- CSMA/CD: a station aborts is transmission ASAP a detection of collision – quickly terminating a damaged frame saves T& BW
  - Widely used on LANs in the MAC sublayer



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

Can collision occurs with CSMA/CD? If so, when occurs and not occurs?

When a station can seize the channel for transmission (how long is the contention)?

Why CSMA/CD More Efficient?

- Monitor for collisions & abort transmission
  - Stations with frames to send, first do carrier sensing
  - After beginning transmissions, stations continue listening to the medium to detect collisions
  - If collisions detected, all stations involved stop transmission, reschedule random backoff times, and try again at scheduled times
- In CSMA collisions result in wastage of X seconds spent transmitting an entire frame
- CSMA-CD reduces wastage to time to detect collision and abort transmission

Delay-Bandwidth Product

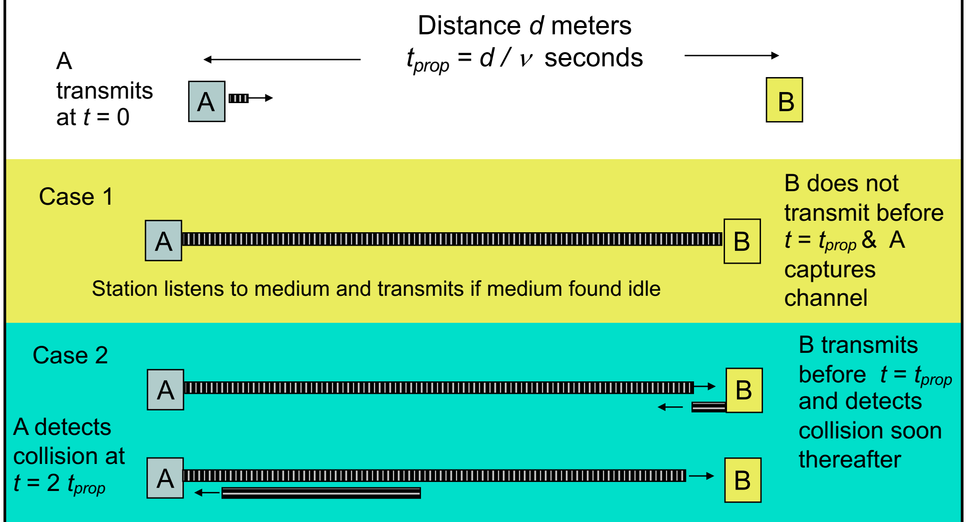
- ***Delay-bandwidth*** **product key parameter**
  - **Coordination in sharing medium involves using bandwidth (explicitly or implicitly)**
  - **Difficulty of coordination commensurate with delay-bandwidth product**

- **Simple two-station example**
  - **Station with frame to send listens to medium and transmits if medium found idle**
  - **Station monitors medium to detect collision**
  - **If collision occurs, station that begin transmitting earlier retransmits (propagation time is known)**

When a station can know it has seized the channel for transmission successfully?

Two-Station MAC Example

Two stations are trying to share a common medium



Efficiency of Two-Station Example

- Each frame transmission requires $2t_{prop}$ of quiet time
  - Station B needs to be quiet t_{prop} before *and* after time when Station A transmits
  - *R* transmission bit rate
  - *L* bits/frame

$$Efficiency = \rho_{\max} = \frac{L}{L + 2t_{prop}R} = \frac{1}{1 + 2t_{prop}R/L} = \frac{1}{1+2a}$$

$$MaxThroughput = R_{eff} = \frac{L}{L/R + 2t_{prop}} = \frac{1}{1+2a}R \text{ bits/second}$$

Normalized Delay-Bandwidth Product

$$a = \frac{t_{prop}}{L/R}$$

t_{prop}: Propagation delay

L/R: Time to transmit a frame

Typical MAC Efficiencies

Two-Station Example:

$$Efficiency = \frac{1}{1+2a}$$

CSMA-CD (Ethernet) protocol:

$$Efficiency = \frac{1}{1+5.44a}$$

Token-ring network

$$Efficiency = \frac{1}{1+a'}$$

a' = latency of the ring (bits)/average frame length

- If $a \ll 1$, then efficiency close to 100%
- As a approaches 1, the efficiency becomes low

Typical Delay-Bandwidth Products

Distance	10 Mbps	100 Mbps	1 Gbps	Network Type
1 m	3.33×10^{-02}	3.33×10^{-01}	3.33×10^{0}	Desk area network
100 m	3.33×10^{01}	3.33×10^{02}	3.33×10^{03}	Local area network
10 km	3.33×10^{02}	3.33×10^{03}	3.33×10^{04}	Metropolitan area network
1000 km	3.33×10^{04}	3.33×10^{05}	3.33×10^{06}	Wide area network
100000 km	3.33×10^{06}	3.33×10^{07}	3.33×10^{08}	Global area network

° **Max size Ethernet frame (payload): 1500 bytes = 12000 bits**

° **Long and/or fat pipes give large a**

Carrier Sensing and Priority Transmission

° **Certain applications require faster response than others, e.g. ACK messages**

° **Impose different inter-frame times**
- **High priority traffic sense channel for time τ_1**
- **Low priority traffic sense channel for time $\tau_2 > \tau_1$**
- **High priority traffic, if present, seizes channel first**

° **This priority mechanism is used in IEEE 802.11 wireless LAN**

Next: Scheduling for Medium Access Control

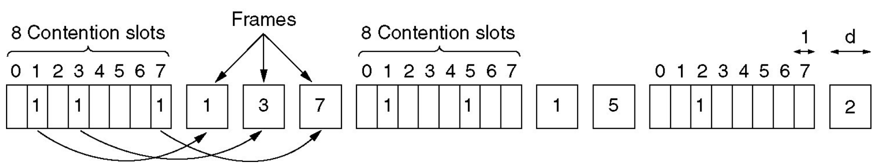
- Schedule frame transmissions to avoid collision in shared medium
  - ✓ More efficient channel utilization
  - ✓ Less variability in delays
  - ✓ Can provide fairness to stations
  - × Increased computational or procedural complexity
- Two main approaches
  - Reservation
  - Polling

Reservation System Options

- Centralized or distributed system
  - *Centralized systems*: A central controller listens to reservation information, decides order of transmission, issues grants
  - *Distributed systems*: Each station determines its slot for transmission from the reservation information
- Single or Multiple Frames
  - *Single frame reservation*: Only one frame transmission can be reserved within a reservation cycle
  - *Multiple frame reservation*: More than one frame transmission can be reserved within a frame
- Channelized or Random Access Reservations
  - *Channelized (typically TDMA) reservation*: Reservation messages from different stations are multiplexed without any risk of collision
  - *Random access reservation*: Each station transmits its reservation message randomly until the message goes through

Collision-Free (1): A Bit-Map Reservation Protocol

- **Assumptions: N stations have unique addresses 0 to N -1**
  - **Which station gets the channel after a successful transmission?**
- **A bit-map protocol:**
  - **a contention period has exactly N slots and a station j announces it has a frame to send by inserting a bit of 1 into slot j**



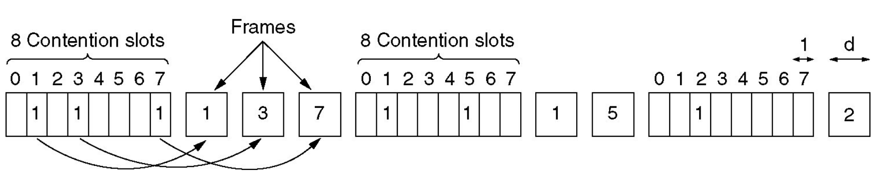
The basic bit-map protocol.

How long should be one contention slot?

Is it fair to stations with different addresses?

Analysis of a Bit-Map Protocol

- **How long does a station have to wait in the worst case before it can start transmitting its from over a LAN that uses the basic bit-map protocol**?



The basic bit-map protocol.

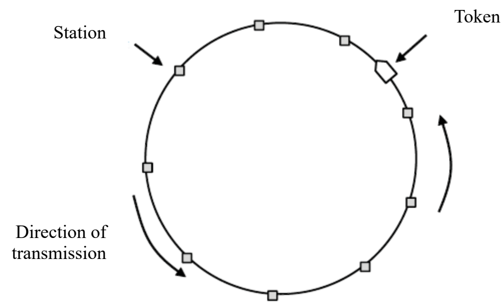
What is the overhead per frame and the efficiency at high and low load?
(if propagation delay is negligible) how about delay?

Low load: d/(N+d)

High load: 1/(d+1)

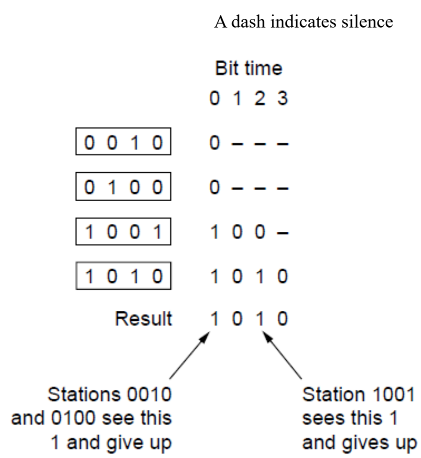
Collision-Free (2) – Token Ring

- Token sent round ring defines the sending order
  - Station with token may send a frame before passing
  - Idea can be used without ring too, e.g., token bus



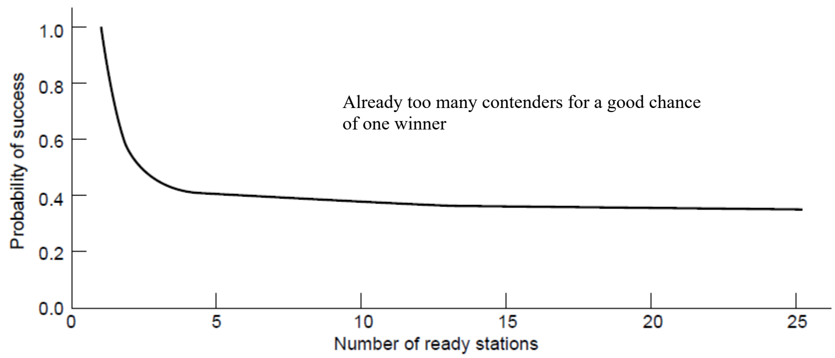
Collision-Free (3) – Countdown

- Binary countdown improves on the bitmap protocol
  - Stations send their address in contention slot (log N bits instead of N bits)
  - Medium ORs bits; stations give up when they send a "0" but see a "1"
  - Station that sees its full address is next to send



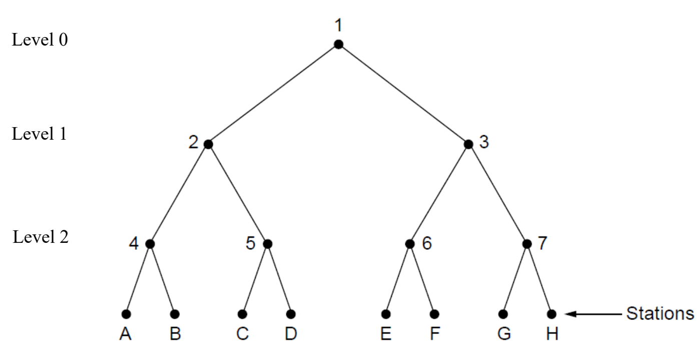
Limited-Contention Protocols (1)

- Idea is to divide stations into groups within which only a very small number are likely to want to send
  - Avoids wastage due to idle periods and collisions



Limited Contention (2) –Adaptive Tree Walk

- Tree divides stations into groups (nodes) to poll
  - Depth first search under nodes with poll collisions
  - Start search at lower levels if >1 station expected

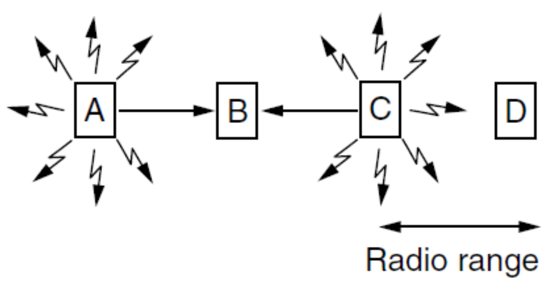


Wireless LAN Protocols (1)

- Wireless has complications compared to wired.
- Nodes may have different but fixed coverage regions
  - If a receiver is within the range of two active transmitter, the resulting signal will be garbled and useless
  - Leads to hidden and exposed terminals
- Nodes can't detect collisions, i.e., sense while sending
  - Makes collisions expensive and to be avoided

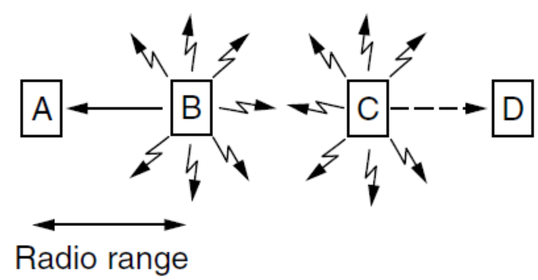
Wireless LANs (2) – Hidden terminals

- Hidden terminals are senders that cannot sense each other but nonetheless collide at intended receiver
  - Want to prevent; loss of efficiency
  - A and C are hidden terminals when sending to B

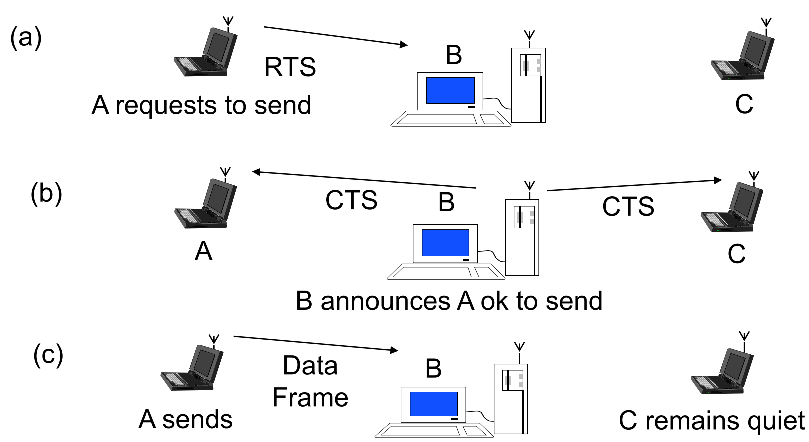


Wireless LANs (3) – Exposed terminals

- **Exposed terminals are senders who can sense each other but still transmit safely (to different receivers)**
  - **Desirably concurrency; improves performance**
  - **B → A and C → D are exposed terminals**



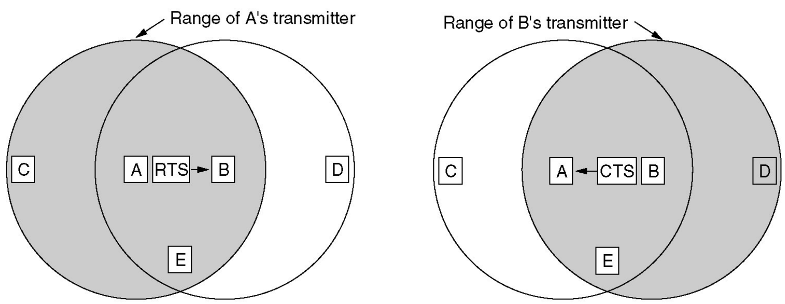
CSMA with Collision Avoidance (MACA)



How C knows how long to set NAV (network allocation vector)?

Wireless LAN Protocols - MACA

- Multiple access with collision avoidance: the sender stimulates the receiver into outputting a short frame so stations nearly can detect the transmission and avoid transmitting for the duration of the upcoming data frame.



A sending an RTS to B. **B responding with a CTS to A.**

Can C transmit the data somewhere simultaneously? Can D? Can E?

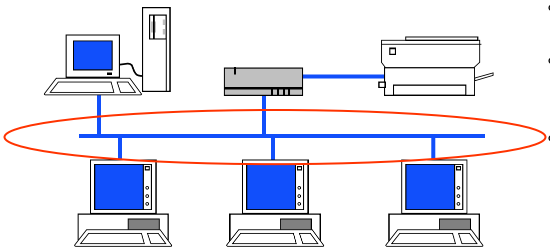
Can a collision still occur?

What is a LAN?

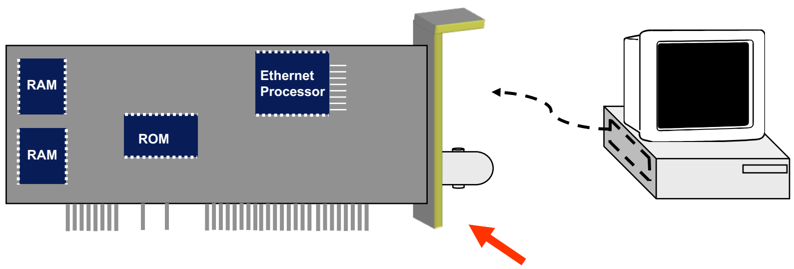
Local area means:

- **Private ownership**
  - **freedom from regulatory constraints of WANs**
- **Short distance (~1km) between computers**
  - **low cost**
  - **very high-speed, relatively error-free communication**
  - **complex error control unnecessary**
- **Machines are constantly moved**
  - **Keeping track of location of computers a chore**
  - **Simply give each machine a unique address**
  - *Broadcast* ***all messages to all machines in the LAN***
- **Need a *medium access control protocol***

Typical LAN Structure



- Transmission Medium
- Network Interface Card (NIC)
- *Unique MAC “physical” address*



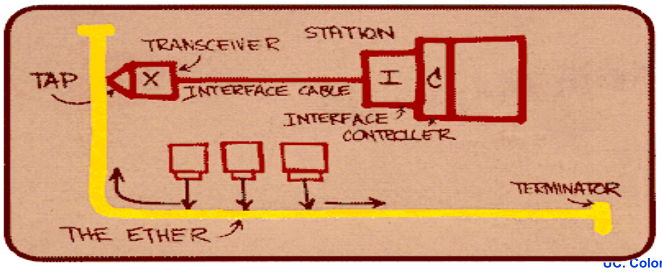
Ethernet

- 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

A bit of history…

- 1970 ALOHAnet radio network deployed in Hawaiian islands
- 1973 Metcalf and Boggs invent Ethernet, random access in wired net
- 1979 DIX Ethernet II Standard
- 1985 IEEE 802.3 LAN Standard (10 Mbps)
- 1995 Fast Ethernet (100 Mbps)
- 1998 Gigabit Ethernet
- 2002 10 Gigabit Ethernet
- Ethernet is the dominant LAN standard

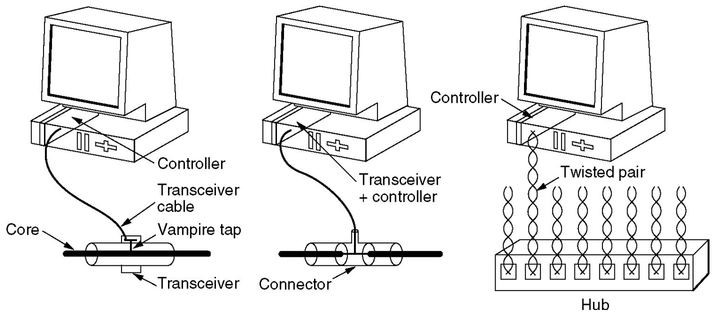
Metcalf's Sketch



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.



10Base5, 10Base2, 10Base-T.

IEEE 802.3 MAC: Ethernet

MAC Protocol:

° **CSMA/CD**

° ***Slot Time* is the critical system parameter**
- **upper bound on time to detect collision**
- **upper bound on time to acquire channel**
- **upper bound on length of frame generated by collision**
- **quantum for retransmission scheduling**
- **At least round-trip propagation**

° **Truncated binary exponential backoff**
- **for nth retransmission: $0 < r < 2^k$, where k=min(n,10)**
- **Give up after 16 retransmissions**

Ethernet MAC Sublayer Protocol

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

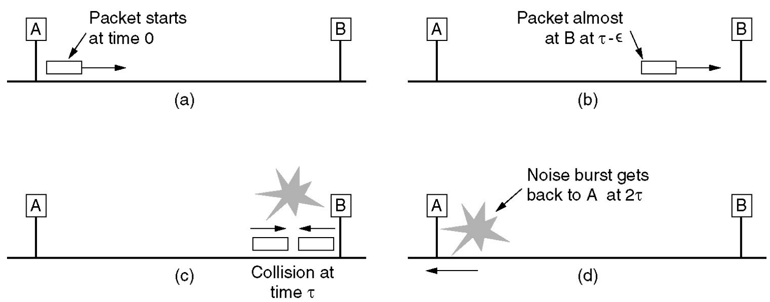
Bytes	8		6	6	2	0-1500	0-46	4
(a)	Preamble		Destination address	Source address	Type	Data	Pad	Check-sum
(b)	Preamble	S o F	Destination address	Source address	Length	Data	Pad	Check-sum

Multicast, broadcast, and group management

What is a the maximum and minimum size of an Ethernet frame?
Why Pad is 0-46? Can we say the maximum is 1518?

Ethernet MAC Sublayer Protocol (2)

- Why there is a minimum length (64B) for a frame?
  - All frames must take more than 2τ to send so that the transmission is still taking place when the noise burst gets back to the sender.



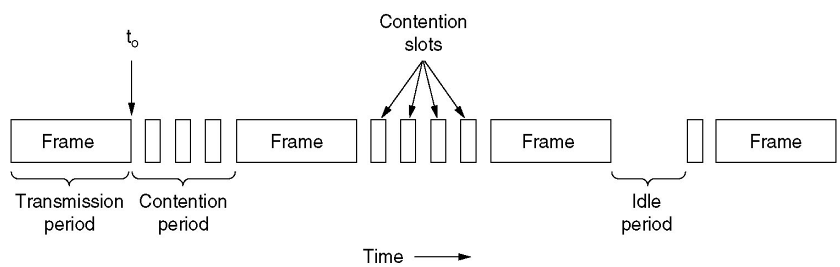
Collision detection can take as long as 2τ (50 μsec in 10 Mbps 2500m).

CS422 MAC.49

UC. Colorado Springs

The Binary Exponential Backoff Algorithm

- CSMA/CD: a station aborts its transmission ASAP a detection collision – quickly terminating a damaged frame saves T& BW
  - If there is a collision, a station waits a random amount of time to try again, how randomization is done?
  - Binary exponential backoff: after *i* collisions, a random number between 0 to 2^*i* – 1 is chosen, that number of slots is skipped



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

What is a time slot used in Ethernet?

CS422 MAC.50

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Ethernet Performance

- How long does it take to resolve contention?
- Contention is resolved ("success') if exactly 1 station transmits in a slot:

$$P_{success} = kp(1-p)^{k-1}$$

- By taking derivative of $P_{success}$ we find max occurs at p=1/k

$$P_{success}^{max} = k\frac{1}{k}(1-\frac{1}{k})^{k-1} = (1-\frac{1}{k})^{k-1} \rightarrow \frac{1}{e}$$

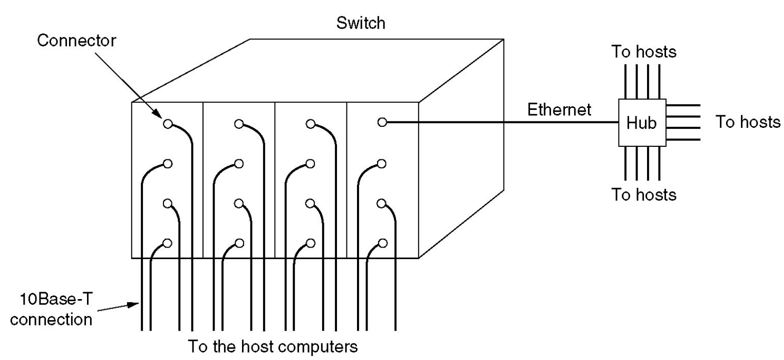
- On average, $1/P^{max}$ = e = 2.718 time slots to resolve contention

$$\text{Average Contention Period} = 2t_{prop}e \text{ seconds}$$

$$\text{Efficiency} = \frac{1}{1+5.44a}$$

Switched Ethernet

A simple example of switched Ethernet.



How about collision domain (and buffering)?

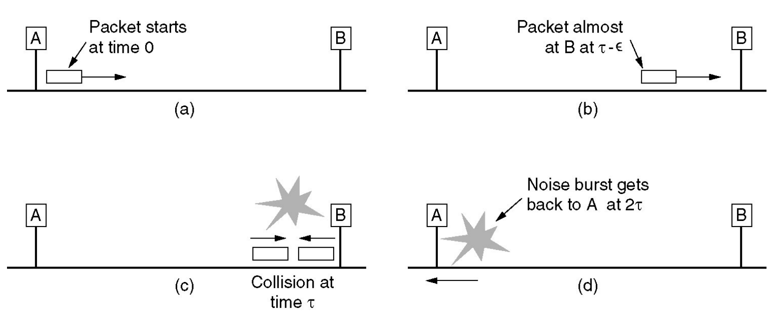
Fast Ethernet

The original fast Ethernet cabling.

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

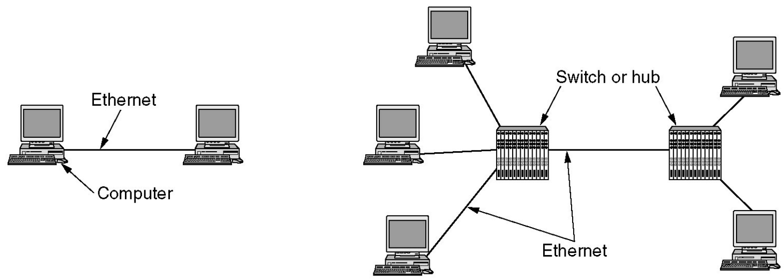
Fast Ethernet (2)

- Ethernet frames must be at least 64 bytes long to ensure that the transmitter is still going in the event of a collision at the far end of the cable. Fast Ethernet has the same 64-byte minimum frame size but can get the bits out ten times faster. How is it possible to maintain the same minimum frame size?



Collision detection can take as long as 2τ (50 → 5 μsec).

Gigabit Ethernet



(a) A two-station Ethernet. **(b) A multi-station p2p G-Ethernet.**

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

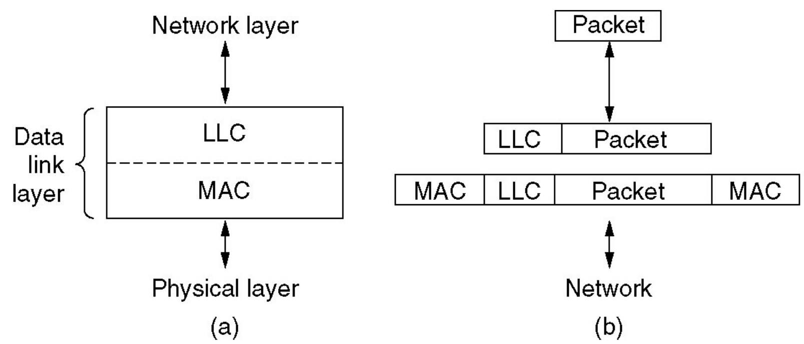
Medium Access Control Sublayer

° **In IEEE 802.2, Data Link Layer divided into:**

1. **Medium Access Control Sub-layer**
   - **Coordinate access to medium**
   - **Connectionless frame transfer service**
   - **Machines identified by MAC/physical address**
   - **Broadcast frames with MAC addresses**
2. **Logical Link Control Sub-layer**
   - **Between Network layer & MAC sublayer**
   - **Hides the difference between the various 802 networks**
   - **Can provide reliable communication – enhance services provided by MAC sub-layer**
   - **Closely based on the HDLC protocol**

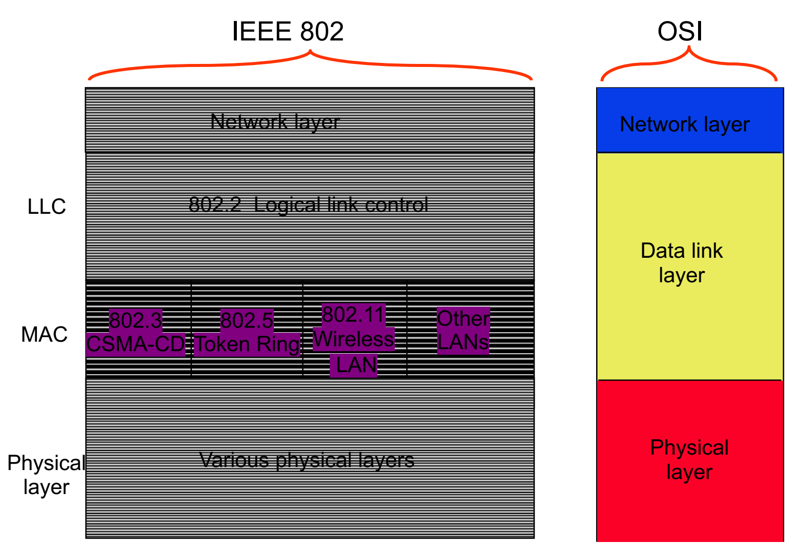
IEEE 802.2: Logical Link Control

- LLC: an error-controlled flow-controlled data link protocol
  - also hides the differences between various kinds of 802 networks by providing a single format and interface to the network layer.



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

MAC Sub-layer



Logical Link Control Services

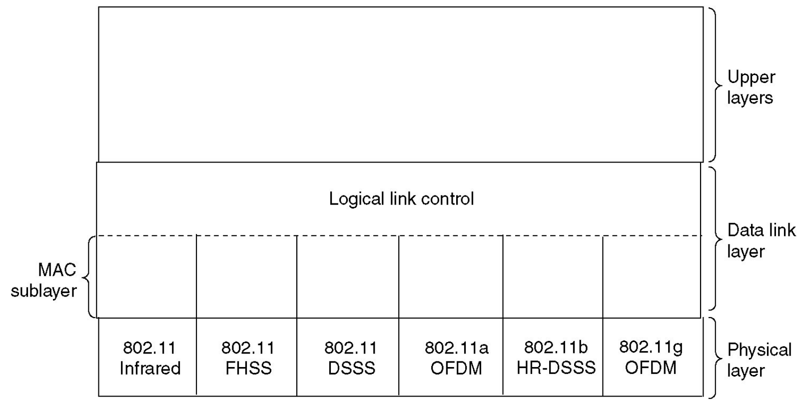
- Type 1: Unacknowledged connectionless service
  - Unnumbered frame mode of HDLC
- Type 2: Reliable connection-oriented service
  - Asynchronous balanced mode of HDLC
- Type 3: Acknowledged connectionless service
- Additional addressing
  - A workstation (NIC) has a single MAC physical address
  - Can handle several logical connections, distinguished by their SAP (service access points).

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.



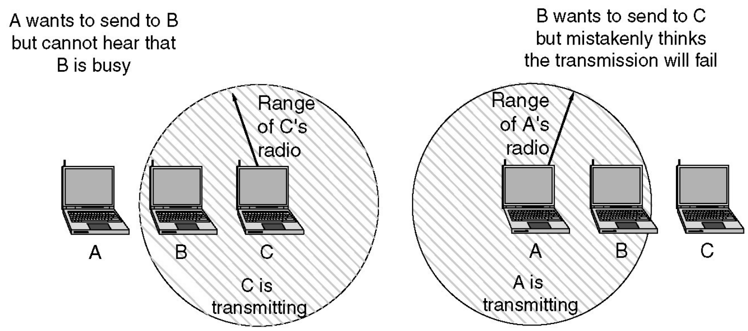
802.11 physical layer

- **NICs are compatible with multiple physical layers**
  - **E.g., 802.11 a/b/g**

Name	**Technique**	**Max. Bit Rate**
802.11b	Spread spectrum, 2.4 GHz	11 Mbps
802.11g	OFDM, 2.4 GHz	54 Mbps
802.11a	OFDM, 5 GHz	54 Mbps
802.11n	OFDM with MIMO, 2.4/5 GHz	600 Mbps

The 802.11 MAC Sublayer Protocol

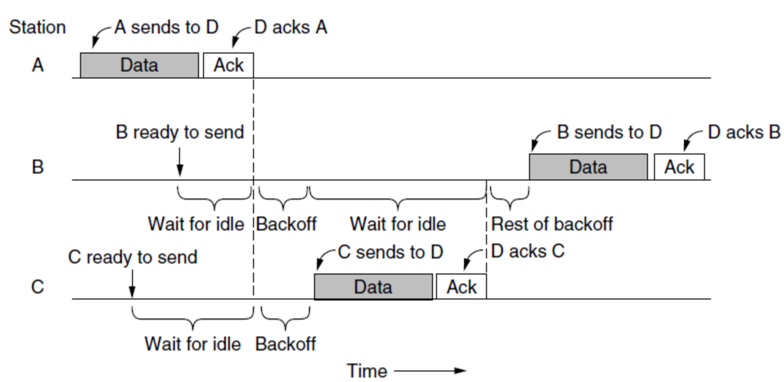
- **DCF: distributed coordination function**
- **PCF: point coordination function**



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

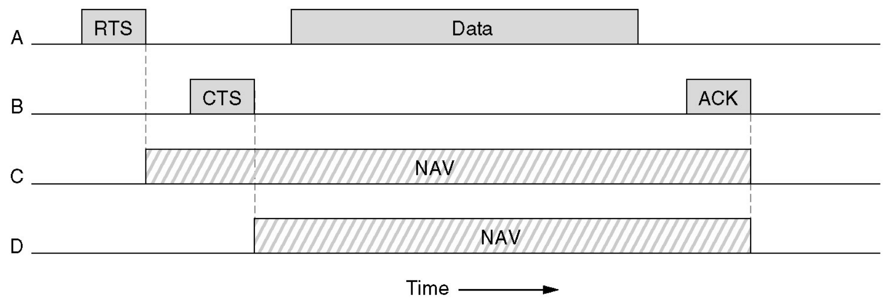
The 802.11 MAC Sublayer Protocol (1)

- **CSMA/CA inserts backoff slots to avoid collisions**
- **MAC uses ACKs/retransmissions for wireless errors**



The 802.11 MAC Sublayer Protocol (2):

° **Virtual channel sensing with the NAV and optional RTS/CTS (often not used) avoids hidden terminals**



The use of virtual channel sensing using CSMA/CA (MACA).

How C and D knows how long to set NAV (network allocation vector)?

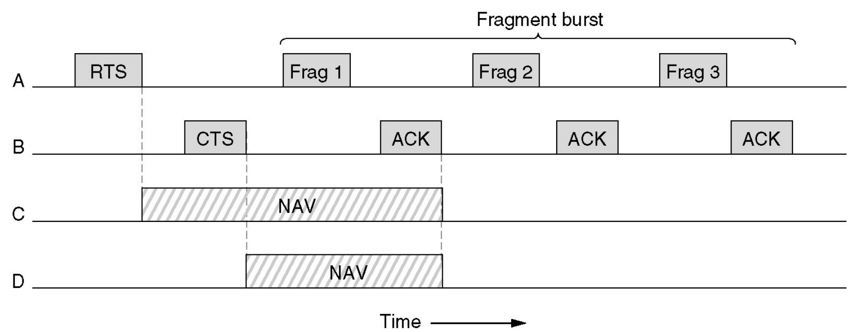
The 802.11 MAC Sublayer Protocol (3)

- **What is the problem with the reliability of sending a long frame in wireless networks?**
- **Example: probability of any bit being in error is *p*, what is the probability of an n-bit frame being received entirely correct?**
  - **(1 – p)^n ~ 30% for p = 10^ -4 for a full-size Ethernet frame**
  - **(1 – p) ^n ~ 11% for p = 10^ -5 for a full-size Ethernet frame**

Main benefit?

The 802.11 MAC Sublayer Protocol (4)

- If a frame is too long, very little of chance getting through undamaged and will probably have to be retransmitted
  - 802.11 allows frames to be fragmented to smaller pieces, each individually sequenced and acked with Stop&Wait
  - A fragment burst after a RTS/CTS

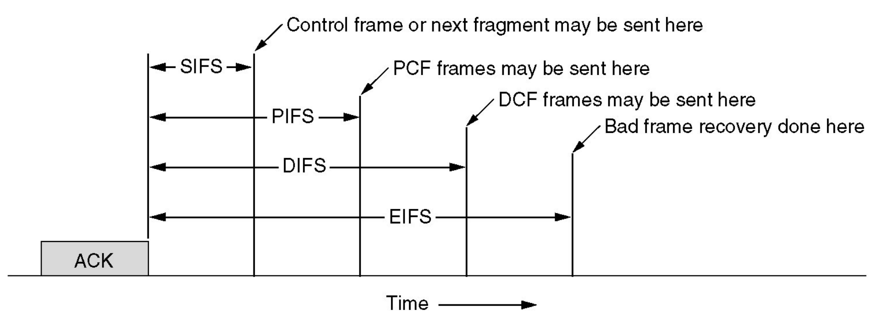


A fragment burst.

Main benefit?

The 802.11 MAC Sublayer Protocol (5)

- Different backoff slot times add quality of service
  - SIFS: receiver sends CTS, receiver sends ACK, sender sends a fragment without sending an RTS again
  - PIFS: base station send a beacon frame or poll frame
  - DIFS: any station can attempt to acquire a channel
  - EIFS: receiver to recover a bad frame

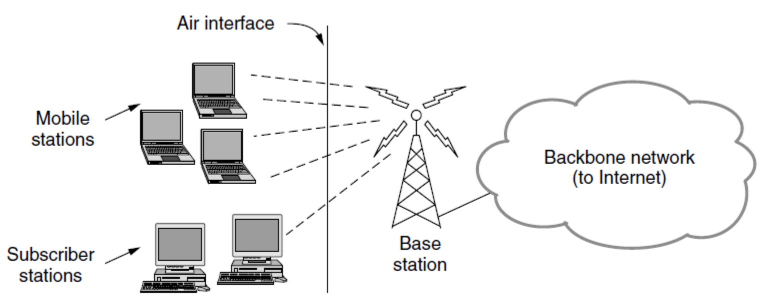


Broadband Wireless

- 802.16 Architecture / Protocol Stack »
- 802.16 Physical Layer »
- 802.16 MAC »
- 802.16 Frames »

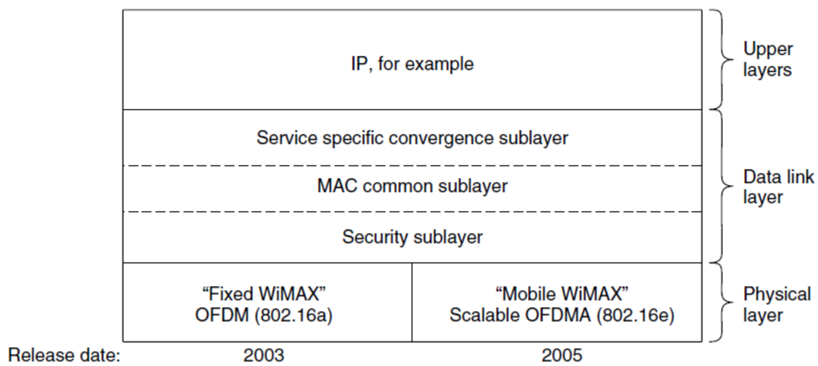
802.16 Architecture/Protocol Stack (1)

- Wireless clients connect to a wired base-station (like 4G)



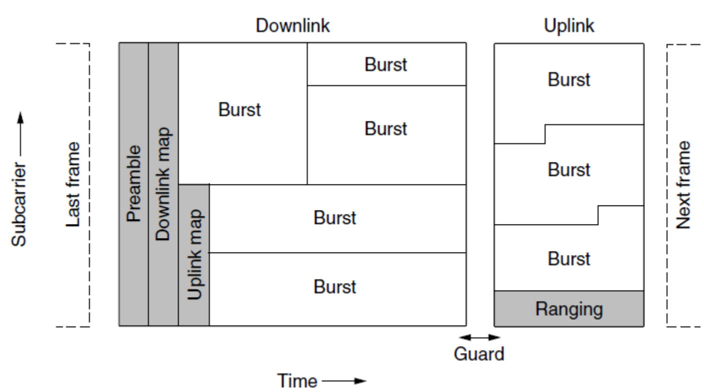
802.16 Architecture/Protocol Stack (2)

- MAC is connection-oriented; IP is connectionless
  - Convergence sublayer maps between the two



802.16 Physical Layer

- Based on OFDM; base station gives mobiles bursts (subcarrier/time frame slots) for uplink and downlink

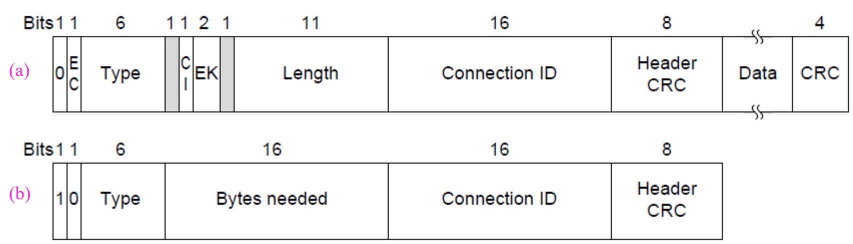


802.16 MAC

- Connection-oriented with base station in control
  - Clients request the bandwidth they need
- Different kinds of service can be requested:
  - Constant bit rate, e.g., uncompressed voice
  - Real-time variable bit rate, e.g., video, Web
  - Non-real-time variable bit rate, e.g., file download
  - Best-effort for everything else

802.16 Frames

- Frames vary depending on their type
- Connection ID instead of source/destination addresses



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

Bluetooth

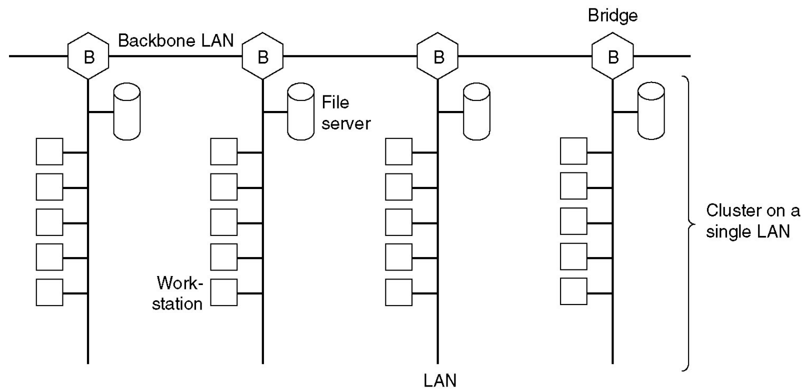
- Bluetooth Architecture
- Bluetooth Applications
- The Bluetooth Protocol Stack
- The Bluetooth Radio Layer
- The Bluetooth Baseband Layer
- The Bluetooth L2CAP Layer
- The Bluetooth Frame Structure

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.



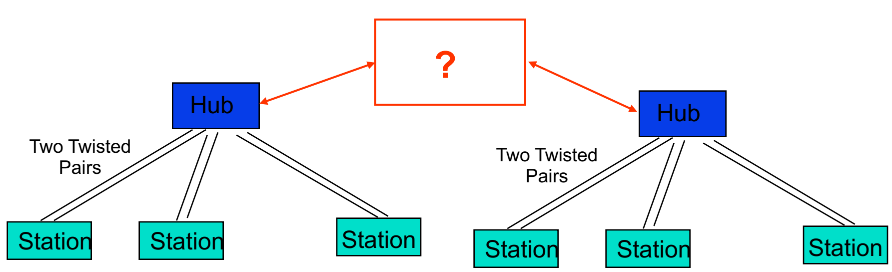
Autonomy, cost, load sharing, collision domain, distance, reliability, security

Local Internetworking: Hubs, Bridges & Routers

- **Interconnecting LANs**
  - **Repeater/hub: Signal regeneration**
    - **All traffic appears in both LANs**
  - **Bridge: MAC address filtering**
    - **Local traffic stays in own LAN**
  - **Routers: Internet routing**
    - **All traffic stays in own LAN**

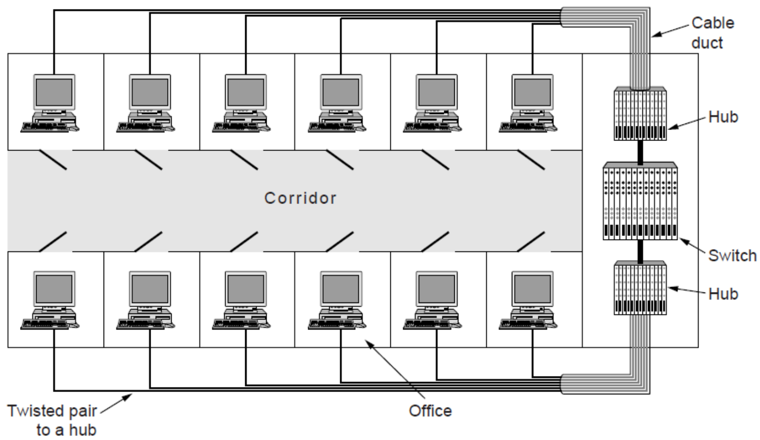
Higher Scalability

Efficiency?



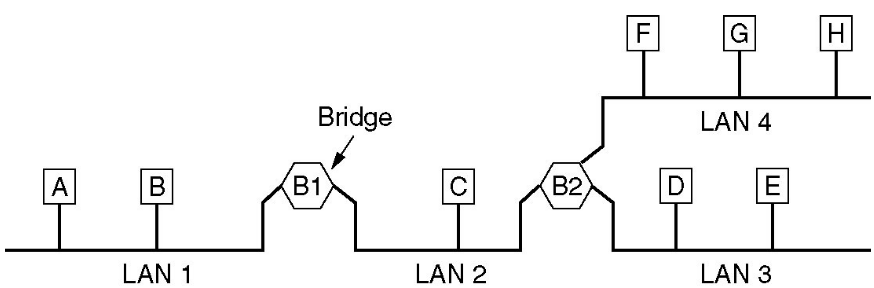
Uses of Bridges

° **Common setup is a building with centralized wiring**
  - **Bridges (switches) are placed in or near wiring closets**

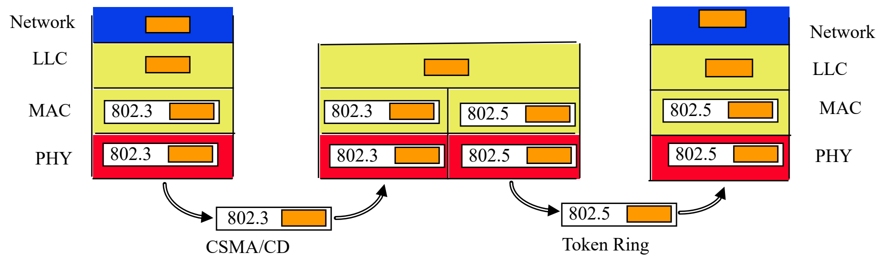


Local Internetworking

A configuration with four LANs and two bridges.

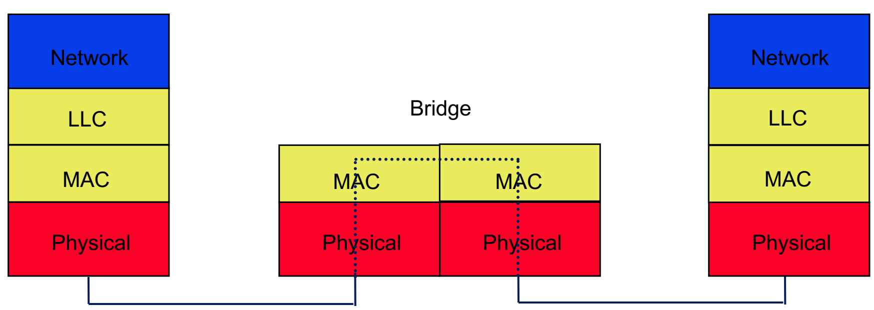


General Bridge Issues



- Operation at data link level implies capability to work with multiple MAC sub-layers
- However, must deal with
  - Difference in MAC formats
  - Difference in data rates; buffering; timers; security
  - Difference in maximum frame length

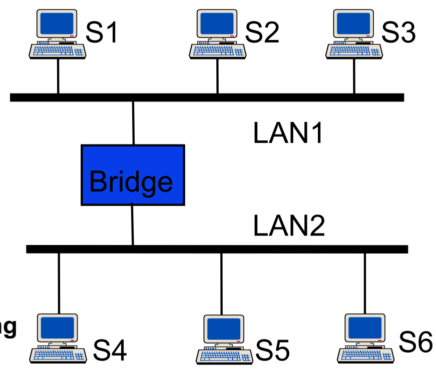
Bridges of Same Type



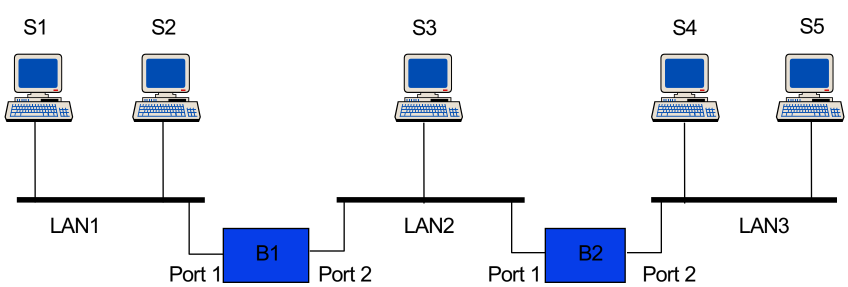
- Common case involves LANs of same type
- Bridging is done at MAC level

Transparent Bridges

- Interconnection of IEEE LANs with complete transparency
- Use table lookup, and
  - discard frame, if source & destination in same LAN
  - forward frame, if source & destination in different LAN
  - use *flooding*, if destination unknown
- Use *backward learning* to build table
  - observe source address of arriving LANs
  - handle topology changes by removing old entries



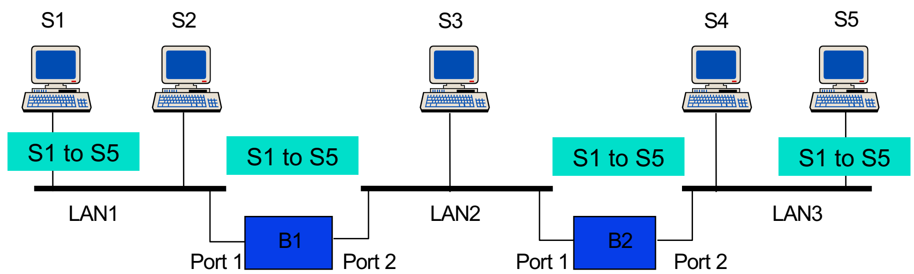
Backward Learning



Address	Port

Address	Port

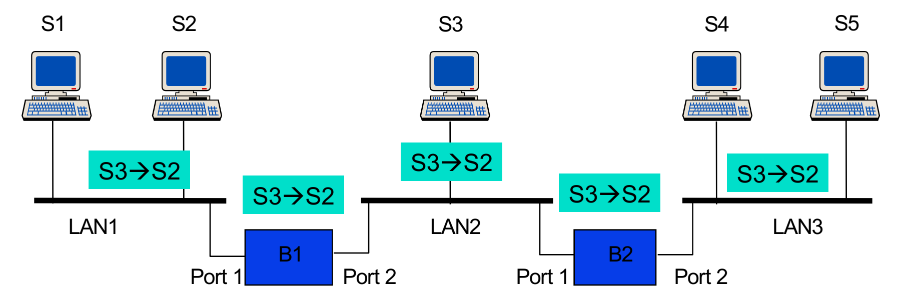
S1→S5



Address	Port
S1	1

Address	Port
S1	1

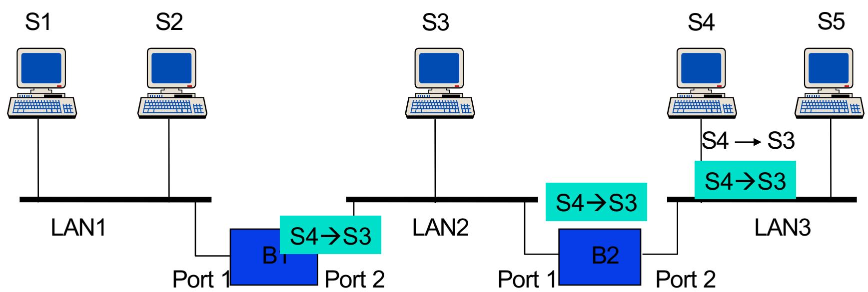
S3→S2



Address	Port
S1	1
S3	2

Address	Port
S1	1
S3	1

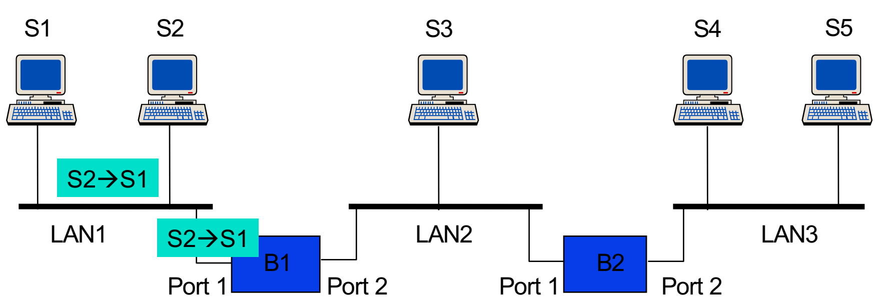
S4→S3



Address	Port
S1	1
S3	2
S4	2

Address	Port
S1	1
S3	1
S4	2

S2→S1



Address	Port
S1	1
S3	2
S4	2
S2	1

Address	Port
S1	1
S3	1
S4	2

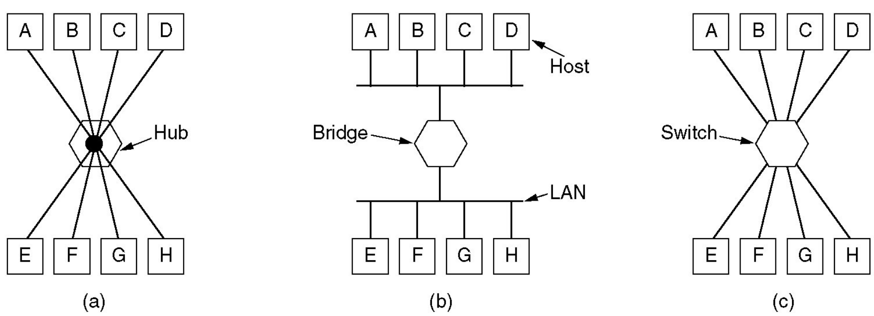
Adaptive Learning

- In a static network, tables eventually store all addresses & learning stops
- In practice, stations are added & moved all the time
  - Introduce timer (minutes) to age each entry & force it to be relearned periodically
  - If frame arrives on port that differs from frame address & port in table, update immediately

Why not bridging the Internet?

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

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

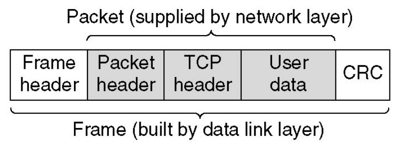


Cut-through switches vs. store-and-forward switches
Different collision domains

Repeaters, Hubs, Bridges, Switches, Routers and Gateways

Application layer	Application gateway
Transport layer	Transport gateway
Network layer	Router
Data link layer	Bridge, switch
Physical layer	Repeater, hub

(a)



(b)

(a) Which device is in which layer.

(b) Frames, packets, and headers.

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.

Reading

- Chapter 4 of the textbook
- Homework: see website