Study Material By Manikrao Dhore
Sub: Computer Networks
Section I: Unit-III Medium Access Control

Course Outcome:
CO3: Propose mechanisms for server channel allocation in wired and wireless computer networks

Unit-III Medium Access Control:
[CO3 → PO1, PO2, PO3, PO4, PO6, PO7, PSO04 – CO Strength 2,3,2,1,1,3,2]
Medium Access Control: **Channel Allocation:** Static and Dynamic, **Multiple Access Protocols:** Pure and Slotted ALOHA, CSMA, WDMA. **Legacy Standard** : 10 Mbps IEEE 802.3 Standard(Ethernet), Wiring Schemes and Frame Formats, CSMA/CD, Binary Exponential Back-off Algorithm. **High Speed Ethernet Standards:** Fast, Gigabit and 10Gigabit. **Wireless Standards:** Radio Spectrum, Frequency Hopping (FHSS) and Direct Sequence (DSSS), IEEE 802.11a/b/g/n/ac, IEEE 802.15, IEEE 802.15.4 and IEEE 802.16 Standards, CSMA/CA **[4 Hrs]**

Course Outcome: Design mechanisms to demonstrate server channel allocation in wired and wireless computer networks.

LANs are broadcast (WANs are P To P):
- Key issue is who will go next, who will get channel
- Broadcast channels are called multi-access or random access channels
- Problem is: How to allocate Channel
- Needs a protocol to decide who will go next

Static Channel Allocation:
- Traditional way is FDM
- For N user divides the BW/N portions
- Each user gets separate frequency band
- Simple and efficient mechanism

Problems are:
For N band if users are <n, it will waste BW
If users are >N permission will be denied
Poor performance for peak traffic

Dynamic Channel Allocation (Multiple Access Protocols)
Multiple Access Protocols
_ Pure and Slotted ALOHA
_ Carrier Sense Multiple Access Protocols
_ Collision-Free Protocols
_ Limited-Contention Protocols
_ Wavelength Division Multiple Access
_ Wireless LAN Protocols

Five key assumptions
1. Station model

- N independent stations (also called terminals)
- Probability of a frame being generated in an interval Dt is lDt (constant arrival rate l)
- Once a frame has been generated, the station is blocked until the frame is transmitted successfully

2. Single channel shared by all stations

3. Collision – When two frames are transmitted simultaneously, the resulting signal is garbled and collision is detected by all machines

4. Frame transmission time

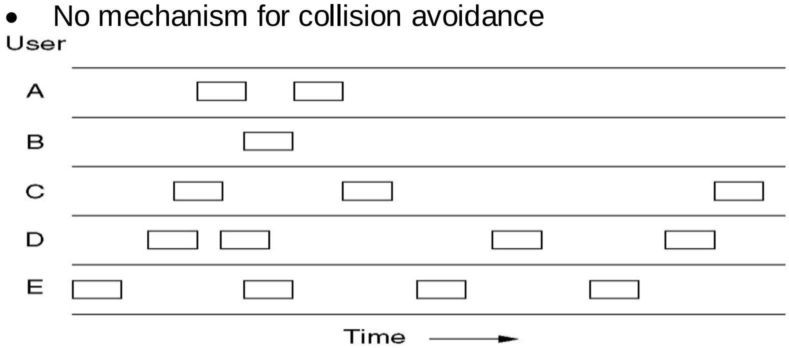
- Continuous time – Begins at any instant
- Slotted time – Begins at the start of a slot

5. Carrier sense or not

- Carrier sense – Stations can tell if the channel is busy. Do not send if channel is busy
- No carrier sense – Just go ahead and send

Pure ALOHA (Radio Broadcasting)

- In 1970 by University of Hawai by Norman Abramson to connect main campus
- Let users transmit whenever they have data to send
- User does not listen before transmitting
- If collision occurs, colliding frames will be destroyed
- sender waits a random amount of time, sends again
- Sender always gets the feedback from channel
- Requires many retransmissions
- No mechanism for collision avoidance

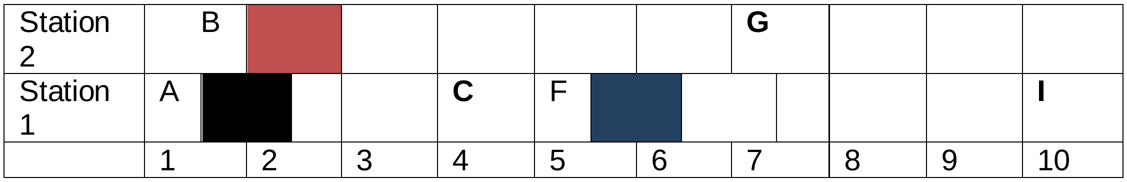


Performance of Pure ALOHA

We assume that

- All the data frames have the same size and each frame takes time T to transmit
- Each station generates frames independent of other stations
- Transmit time T is frame size divided by bit rate.
- Time to transmit a frame T is unit of time
- Only one frame at a time on a channel
- Therefore the channel capacity is one frame per unit time
- If collision occur the throughput S is less than 1

Station 4					E			**H**		
Station 3				D						

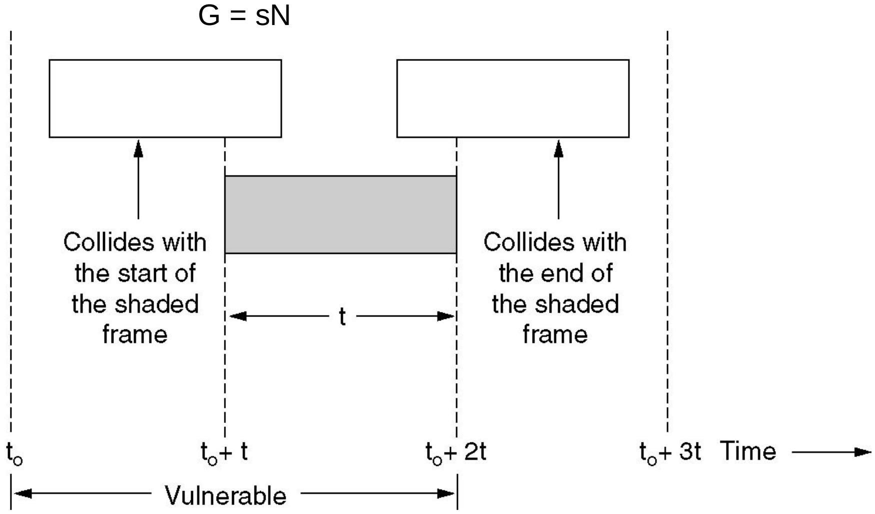


In above figure

Throughput S = 04/10 = 0.4 and Load G = 9/10 =0.9

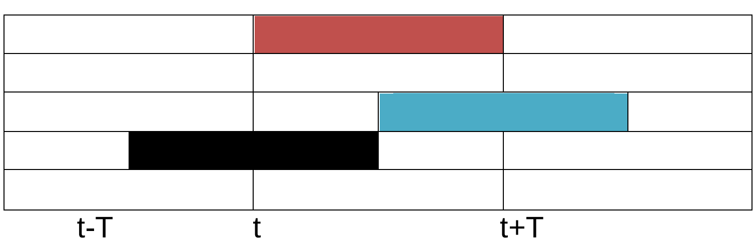
If G>1 there are many collisions
If G <1 there are few collisions
If S=G there are no collisions
Let
Probability of generating the frame by station in time T is s
Therefore the average number of frames generated by the N stations in time T is given by

$$G = sN$$



Vulnerable period for the shaded frame

Collisions of Frames



Let us assume that station generates a frame at time t.
For successful transmission there should not be any frame generated during t-T and t+T
Probability of no transmission by a station in t-T to t =(1-s)
Probability of no transmission by N-1 stations in t-T to t $=(1-s)^{N-1}$
Probability of no transmission by N-1 stations in t+T to t $=(1-s)^{N-1}$
Probability of no transmission by a station in t-T to t +T$=(1-s)^{2(N-1)}$
Probability of a successful transmission by a station $=s(1-s)^{2(N-1)}$

Since there are N stations , the throughput is given by

$$S = sN(1-s)^{2(N-1)}$$

$$S = Ge^{-2G}$$

If we plot the graph it shows maximum throughput for G=0.5

Therefore S = 1/2e and e = 2.717 we get 0.184

Slotted ALOHA

- In 1972 by Robert
- Idea: Divide time into intervals
- Each interval corresponds to one frame
- Only one frame at a time on a channel
- Therefore the channel capacity is one frame per unit time
- Slot boundaries
- Special node emits a pip at the start of each interval
- Waits for beginning of slot
- **Station is not permitted to send whenever a frame is ready, but must wait for beginning of next slot**
- **Vulnerable period is halved**

Probability of no collision in time slot = e^{-G}

Probability of a collision = $1 – e^{-G}$

Probability of a transmission requiring exactly k attempts,

i.e., k-1 collisions followed by 1 success

$$P_k = e^{-G} (1- e^{-G})^{k-1}$$

Expected number of transmissions (new + retransmissions)

$$E = \sum_{k=1}^{\infty} kP_k = \sum_{k=1}^{\infty} ke^{-G}(1-e^{-G})^{k-1} = e^{G}$$

Throughput $S = G\,e^{-G}$

Maximum occurs when G = 1, S ~ 2*0.184 = 0.368

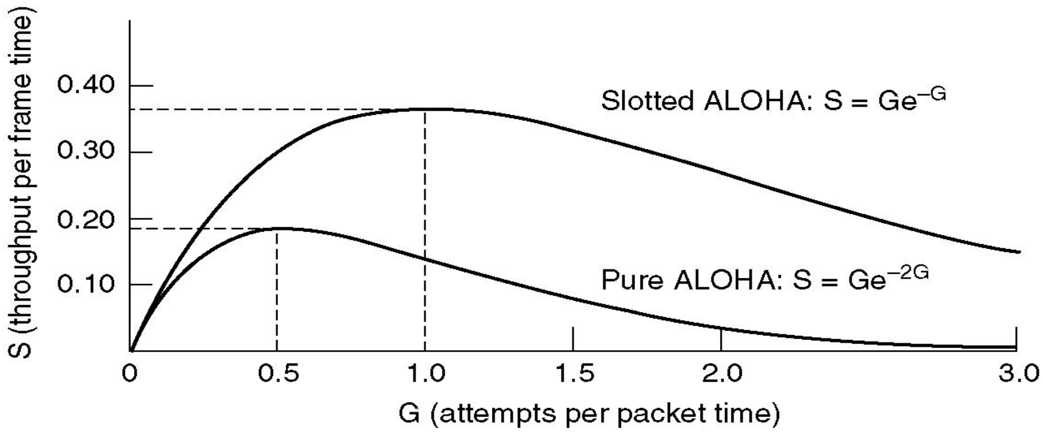
Slotted ALOHA doubles the throughput of Pure ALOHA!

Operating at higher values of G reduces number of empty slots, increases number of collisions

Small increase in channel load G can drastically reduce performance

Pure and Slotted ALOHA

Throughput vs offered load



- For ALOHA protocols for low load there is low delay. For high load performance is worst.
- For collision free protocol for low load there is high delay. For high load performance is good

Carrier Sense Multiple Access (CSMA)

Before transmission, stations listen for the carrier and acts accordingly

Method-I : 1-Persistent CSMA :

- Continuous check of channel , transmit with probability 1
- When station has data to send, listens to channel to see if anyone else is transmitting
- If channel is idle, station transmits a frame, else station waits for it to become idle i.e. **it continuously sense the channel**
- If collision occurs, station waits random amount of time, tries over again
- called 1-persistent CSMA
- With probability 1, station transmits if channel is idle

Method-II: Non-Persistent CSMA:

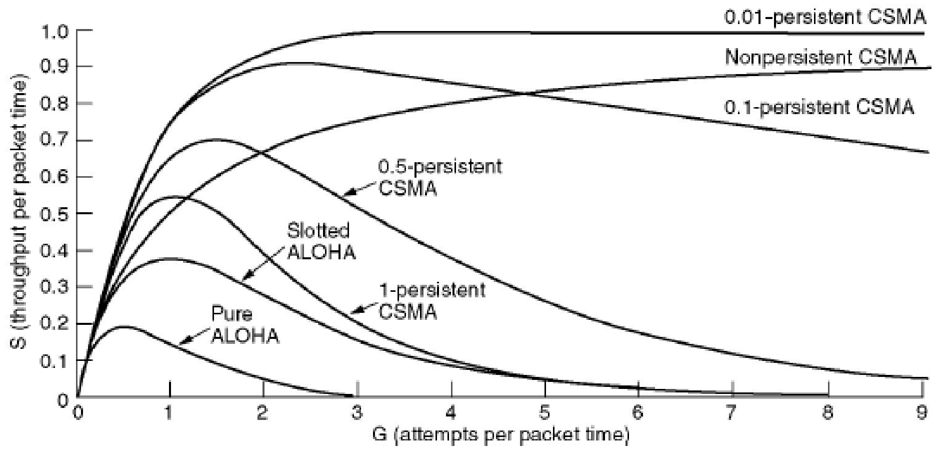
- Before sending, station senses the channel
- If channel is idle, station begins sending else station waits random amount of time (**does not continuously sense channel**) and tries again

Method-III: **P-Persistent CSMA**:

When ready to send, station senses the channel. If channel idle, station transmits with probability p, defers to next slot with probability q = 1-p else station waits until next slot tries again. If next slot idle, station transmits with probability p, defers to next slot with probability q = 1-p.

Performance of ALOHA and CSMA Protocols

Persistent and non-persistent CSMA improve over ALOHA because they ensure that no station starts to transmit when it senses channel is busy.



Ethernet or IEEE 802.3

- The standard issued in 1978 by Xerox Corporation, Intel Corporation and Digital Equipment Corporation, usually called *Ethernet* (or *DIX* Ethernet).
- The international IEEE 802.3 standard, a more recently defined standard.

IEEE Standard 802 For LLC and MAC Layer

- 802.2 LLC
- 802.3 CSMA/CD Ethernet 1-Persistent
- 802.4 Token Bus
- 802.5 Token Ring
- 802.6 Distributed and Dual Bus
- 802.7 Broadband Transmission
- 802.8 Fiber Optics
- 802.9 Voice LANs

- **802.3** **10Base5 (Coaxial Thickwire)**
- **802.3a** **10Base2 (Coaxial Thinwire)**
- **802.3i** **10BaseT (UTP)**
- **802.3j** **10BaseFL (Fiber)**
- **802.3u** **100BaseT (UTP)**
- **802.3z** **100BaseX (Fiber)**

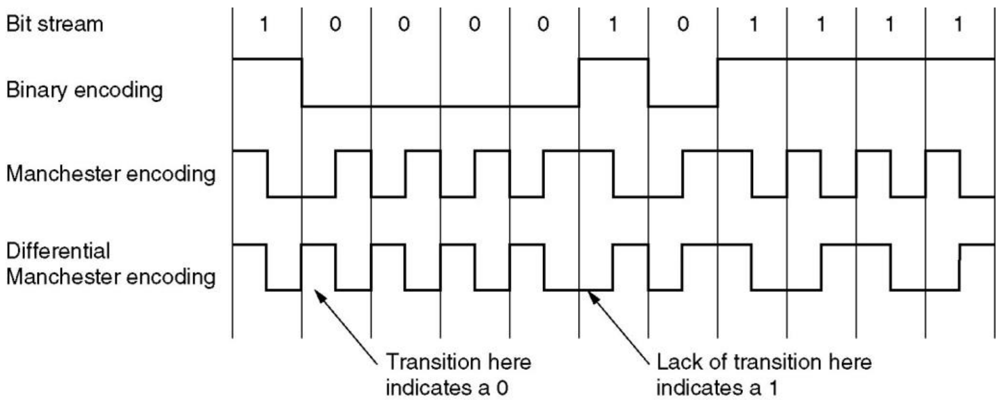
10 Mbps Ethernet

1. 10Base2 (Coaxial – single wire)
2. 10Base5 (Coaxial – signal wire)
3. 10BaseT (UTP- 8 core, Uses two Pair 1-2, and 3-6)

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

4. 10BaseF (Standard)
    4a. 10BaseFL (Fiber Link - Pair)
    4b. 10BaseFB (Fiber Backbone - Pair)
    4c. 10BaseFP (Fiber Passive - Pair)

Encoding:
802.3 baseband systems uses Manchester's encoding
1-bit => 0.85 volt
0-bit => -0.85 volt
Gives DC value => 0 volt
1 => High to Low at middle
0 => Low to High at middle



Frame Format

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

Bytes	7	1	6	6	2	0-1500	0-46	4
(b)	Preamble	SOF	Destination address	Source address	Length	Data	Pad	Check-sum

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

Fig (a) shows original DIX (DEC, Intel, Xerox) frame structure.
Fig (b) shows original IEEE 802.3 frame structure.

Currently it uses **DIX Ethernet** frame format.
Each frame starts with a Preamble of 8 bytes, where first 7 have bit pattern 10101010 and 8th byte has bit pattern 10101011. The Manchester encoding of this pattern allow the receiver's clock to synchronize with the sender's.
10-Mbps baseband standard uses 6-byte destination and source addresses.
The high-order bit of the destination address is a 0 for ordinary addresses and 1 for group addresses.

Group addresses allow multiple stations to listen to a single address. When a frame is sent to a group address, all the stations in the group receive it. Sending to a group of stations is called **multicast**.

The address consisting of all 1 bits is reserved for **broadcast**. A frame containing all 1s in the destination field is accepted by all stations on the network.

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Another interesting feature of the addressing is the use of bit 46 (adjacent to the high-order bit) to distinguish local from global addresses. Local addresses are assigned by each network administrator and have no significance outside the local network. Global addresses, in contrast, are assigned centrally by IEEE to ensure that no two stations anywhere in the world have the same global address. With 48 - 2 = 46 bits available, there are about 7×10^{13} global addresses. The idea is that any station can uniquely address any other station by just giving the right 48-bit number. It is up to the network layer to figure out how to locate the destination.

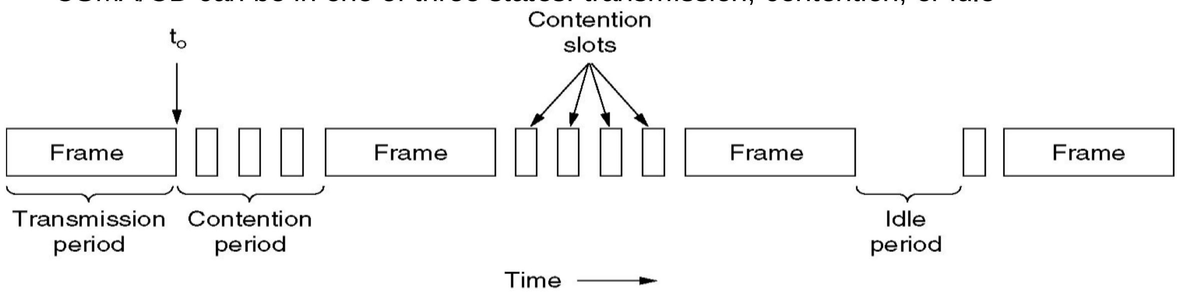
Next comes the Type field, which tells the receiver what to do with the frame. Multiple network-layer protocols may be in use at the same time on the same machine, so when an Ethernet frame arrives, the kernel has to know which one to hand the frame to. The Type field specifies which process to give the frame to.

Next come the data, up to 1500 bytes. This limit was chosen somewhat arbitrarily at the time the DIX standard was cast in stone, mostly based on the fact that a transceiver needs enough RAM to hold an entire frame and RAM was expensive in 1978. A larger upper limit would have meant more RAM, hence a more expensive transceiver.

Padding Bits : To maintain the minimum frame size

CSMA with Collision Detection

- If two stations start transmitting simultaneously, both detect collision and stop transmitting immediately
- Minimum time to detect collision = time for signal to propagate
- CSMA/CD can be in one of three states: transmission, contention, or idle



CSMA/CD can be in one of three states: contention, transmission, or idle.
For station to be sure it has channel and other stations will not interfere, it must wait 2t without hearing a collision (not t as you might expect)

At t0, station A begins transmitting

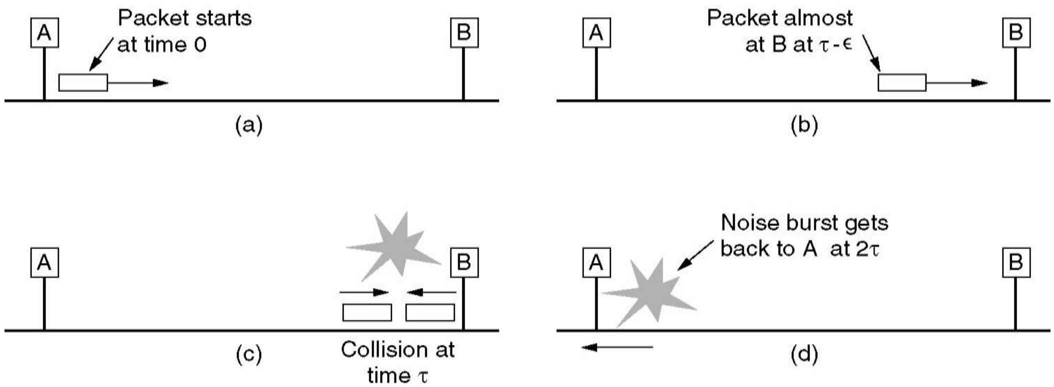
At t0+t**-ε, B begins transmitting, just before A's signal arrives**

B detects collision and stops

At t0+t**- ε +**t **(= t0+2**t**- ε), A detects collision**

Collision detection is analog process; signal encoding must allow collision detection

Collision Detection



Minimum Frame Size:

Network: 10Base5
DTR = 10 Mbps
Diameter = 2500 m
Propagation Speed = 2.3 x 10^8 m/s
Time required for 2500 m = 10.8 microseconds
RTT = 21.6 microseconds
Time for 1 bit= 1/10 Mbps = 100 ns
RTT 21.6 comes out to be 216 bits = 27 bytes
Repeater delay is = 8 bit time
8x8 = 64 bit
Therefore = 27+8 = 35 bytes

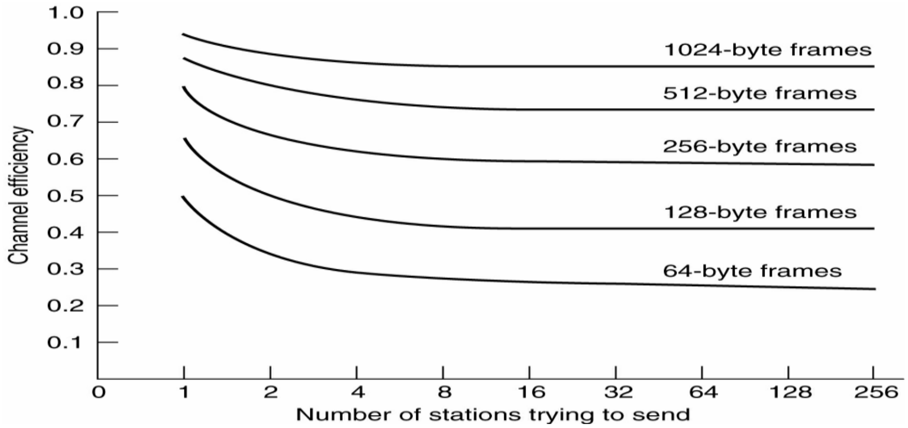
The worst case RTT including four repeaters is 50 microseconds which is 500 bits and hence for the Ethernet minimum frame size is chosen as 64 bytes which is 512 bits.
So, there is plenty of time to detect the collision

Binary Exponential Back-off Algorithm

- If a collision is detected, delay and try again
- Delay time is selected using binary exponential back-off
  - 1st time: choose K from {0,1} then delay = K * 51.2us
  - 2nd time: choose K from {0,1,2,3} then delay = K * 51.2us
  - *nth* time: delay = K x 51.2us, for K=0..$2^n - 1$
    - Note max value for k = 1023
  - give up after several tries (usually 16)
    - Report transmit error to host

Backoff Limit : 10

Ethernet Performance



Interframe Gap and Bandwidth Loss

Minimum Frame = 72 bytes x 8-bits = 576 bits
Interframe Gap = 9.6 micros = 9.6 / 100 ns/bit = 96 bits
Frames for 10 Mbps = 10000000 / 576 = 17361
Followed by 96 bit Interframe gap = 96 x 17361 = 1666656 bits
Bandwidth loss = (1666656 / 10000000)x100 =16.66%

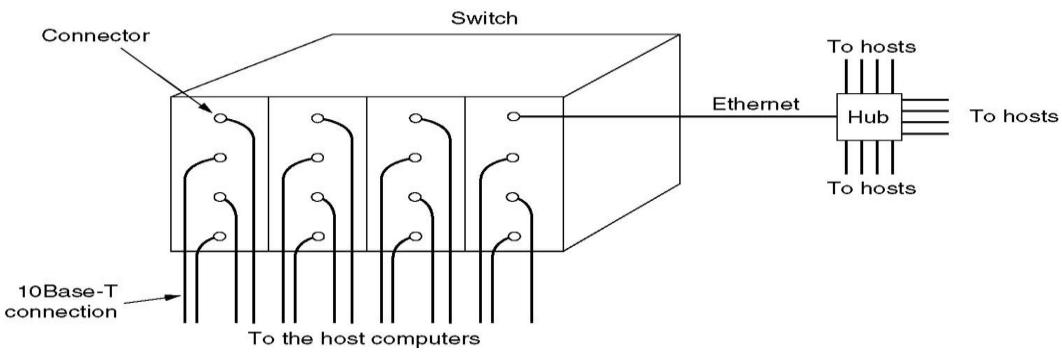
lly
for Frame = 1500 bytes
Frames for 10 Mbps = 10000000 / 1500 x 8 bits = 833
Followed by 96 bit Interframe gap = 96 x 833 = 79968 bits
Bandwidth loss = (79968 / 10000000)x100 =07.99%

10Base2 Ethernet Networks

10Base2(Obsolete)	10Base5(Obsolete)	10BaseT(Legacy)
Media : Thin wire Coaxial Cable Standard : RG-58 Cable Diameter : 0.25” Propagation Velocity : 0.65c Impedance : 50 ohms Connector : BNC T Segment Length : 185 m Maximum Nodes/segment : 30 Maximum Stations : 90 Node Spacing : 0.5 meters Topology : Bus Network Diameter : 0.925 km Encoding : Manchester Propagation Delay : 512 bit Interframe Gap : 9.6 micros Backoff Limit : 10 Jam Size : 48-	Media : Thickwire Coaxial Cable Standard : RG-8 Cable Diameter : 0.4” Propagation Velocity : 0.77c Impedance : 50 ohms Connector : Vampire Tap Segment Length : 500 m Maximum Nodes/segment : 100 Maximum Stations : 300 Node Spacing : 2.5 meters Topology : Bus Network Diameter : 2.5 km Encoding : -- Propagation Delay : -- Interframe Gap : -- Backoff Limit : --- Jam Size : --- Maximum Size : --- Minimum Frame Size : ---	Media : UTP Cable Cable Standard : EIA Cat-3,4 or 5 Cable Diameter : 0.5 mm Propagation Velocity : 0.585c Impedance : 100 ohms Connector : RJ-45 Segment Length : 100 m Maximum Nodes/segment : 2 Node Spacing : NA Topology : Star Network Diameter : 0.5 km Encoding : --- Propagation Delay : --- Interframe Gap : --- Backoff Limit :--- Jam Size : ---

bits Maximum Size : 1526 bytes Minimum Frame Size : 64 bytes		Maximum Size : --- Minimum Frame Size : ---

Switched Ethernet
When the load increases in terms of the station 5-4-3 is the limitation. Solution is to go for switched Ethernet



High Speed Standards:
Fast Ethernet:

- DTR : 100 Mbps
- Uses low as well as high frequencies
- Small Diameter
- Sometime uses extension bit to maintain frame time
- Multilevel signaling
- Reduced inter-frame gap
- No Manchester encoding
- Separate wires for Tx and Rx
- Possible on Low grade cables
- Work with half as well as full duplex
- Inter-frame gap = 0.096 microsecond = 96 bits
- Minimum frame = 512 bytes

IEEE Standards for 100Mbps

1. 100BaseT4 (4-pair UTP-Cat-3) (Phase-out)
2. 100BaseTx (2-pair UTP-Cat-5) Current
3. 100BaseFX (Single / Multimode Fiber) (Legacy)
4. 100BaseT2 (Two Cat-3 Cables) (Phase-out)

1000 Mbps Ethernet

- DTR : 1000Mbps
- Alternative to ATM and FDDI
- Inter-frame gap = 0.096 microseconds (96 bits)
- Single repeater type (10/100/1000)
- Full Duplex Communication
- IEEE 802.3$_{xx}$ Standard

- Uses 0-448 byte extension

IEEE Standards for 1000Mbps

1. 1000BaseT (4-pairs of UTP Cat-5)
2. 1000BaseCX (Balanced Copper – Twinax)
3. 1000BaseSX (Multimode Fiber)
4. 1000BaseLX (Multimode Fiber)

Wireless LANS

WLAN are very popular nowadays for Hotel, Buildings, Airport, and Garden

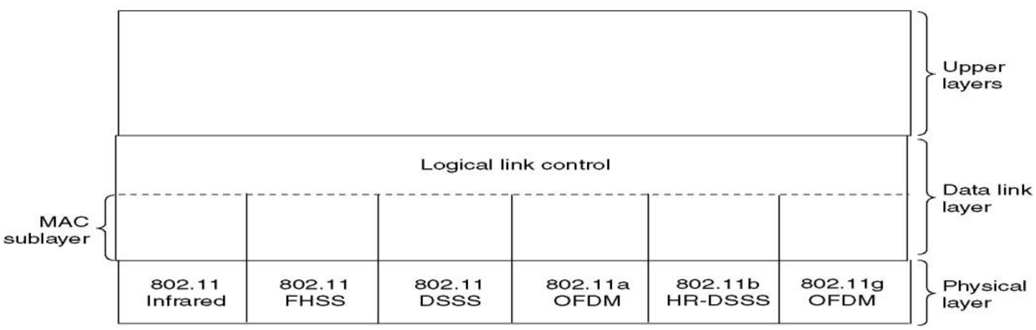
Advantages

- Very flexible within the reception area
- Ad-hoc networks without previous planning possible
- Almost no wiring difficulties
- More robust against disasters like earthquakes, fire or users pulling a plug...

Disadvantages

- typically very low bandwidth compared to wired networks (1-10 Mbit/s)

The 802.11 Protocol Stack



The 802.11 Physical Layer
802.11 Infrared

- Uses IR diodes
- Diffuse light(not line of sight)
- Multiple reflections (walls, furniture etc.)
- Transmission at 0.85 microns or 0.95 microns
- Speeds : 1 Mbps and 2 Mbps
- Encoding:
  I. Grayscale: 4 bits are encoded in 16 bits codes with fifteen 0s and single 1. It is good for synchronization. Results in single bit error only.

  II. 2 bits to 4 bits for 2 Mbps

Advantages

- Simple, cheap, available in many mobile devices
- No licenses needed
- Simple shielding possible

Disadvantages

- Interference by sunlight, heat sources etc.
- Many things shield or absorb ir light
- Low bandwidth
- Cannot penetrates the walls
- (adv – cells can be well isolated from each other in rooms)

Example

- IrDA (Infrared Data Association) interface available everywhere

802.11a High Speed WLAN using OFDM
(Orthogonal Frequency Division Multiplexing)

- Operates in the 5.15GHz to 5.35GHz radio spectrum.
- Speed: Up to 54Mbps (actual throughput is closer to 22Mbps)
- Range: 50 feet
- Less prone to interference.
- More expensive.
- Because 802.11b and 802.11a use different radio technologies and portions of the spectrum, they are incompatible with one another.

- Uses 52 frequencies : 48 for data and 4 for synchronization
- Modulation : PSK QAM

802.11b High Rate DSSS (HR-DSSS) (Wi_Fi Year Mid 1999)

- Point to Multipoint Configuration
- Uses 11 million chips/sec to achive raw Data rate 11 Mbps
- Data rates supported are 1,2,5.5 and 11 Mbps
- 5.9 Mbps over TCP and 7.1 Mbps over UDP
- Uses CSMA/CA
- Complementary Code Keying as a Modulation Technique
- Range is 7 times grater than 802.11a
- Operates in the 2.4GHz radio spectrum.
- Frequency Bandwidth = 5 GHz
- Range: 100 feet
- Prone to interference (it shares airspace with cell phones, Bluetooth, security radios, and other devices).
- Least expensive wireless LAN specification.
- The Wireless Ethernet Compatibility Alliance (WECA) has done its part by certifying hundreds of products to make sure they work together.

802.11g OFDM 54 MBps

- Operates in the 2.4GHz radio spectrum.
- Speed: Up to 54Mbps
- Range: 100 feet
- Prone to interference (it shares airspace with cell phones, Bluetooth, security radios, and other devices)
-

- **802.11n : (600-700 Mbps)** In our Lab we have 600Mbps
  - Operates in the 2.4 or 5GHz radio spectrum
  - Speed: Up to 700Mbs
  - Range: 50 feet
  - Because 802.11b and 802.11g use the same radio technologies and portions of the spectrum, they are compatible with one another. But because the 802.11n standard has yet to be ratified by WECA, it may not be completely compatible with 802.11b and 802.11g.

	IEEE 802.11a	IEEE 802.11b	IEEE 802.11g
Year	Sep 1999	Sep 1999	May 2003
Raw DTR	54 Mbps	11 Mbps	54 Mbps
Avg. Throughput	22 Mbps	27 Mbps	20-25 Mbps
Range	50 feet	100/300 feet	50/100 feet
Frequency	5 GHz	2.4 Ghz	2.4 Ghz
Spectrum	300 MHz	83.5 MHz	83.5 MHz
Modulation	OFDM	DSSS/CCK	OFDM/DSSS
Channels	12	11	11
Cost	Costly	Low Price	Less Expensive

The 802.11 MAC Sub layer Protocol

Hidden station problem (a)

A transmits to B

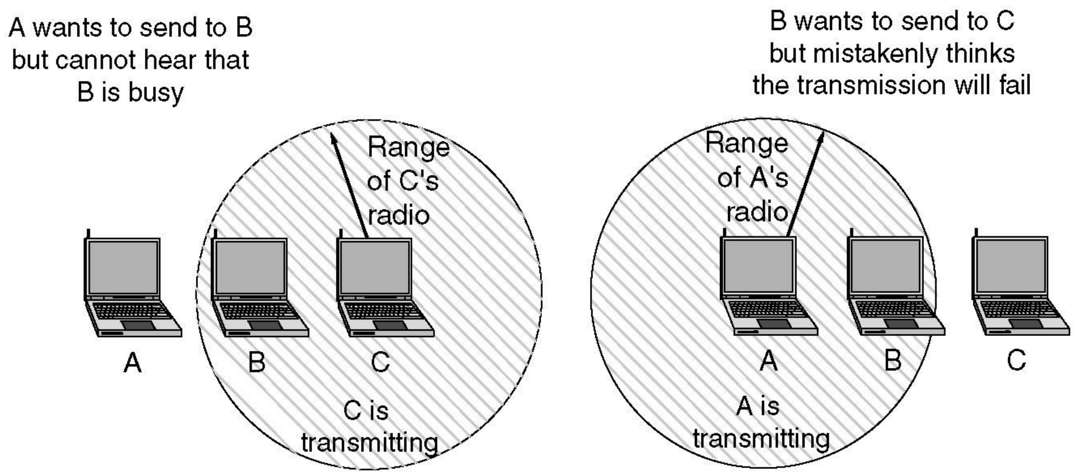
C out of range of A, thinks OK to transmit to B

C transmits to B, interference occurs at B

Exposed station problem (b)

B transmits to A

C senses transmission, concludes can't send to D when

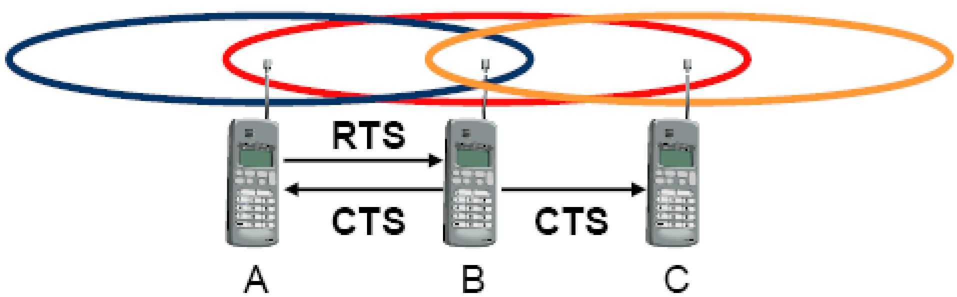


(a) (b)

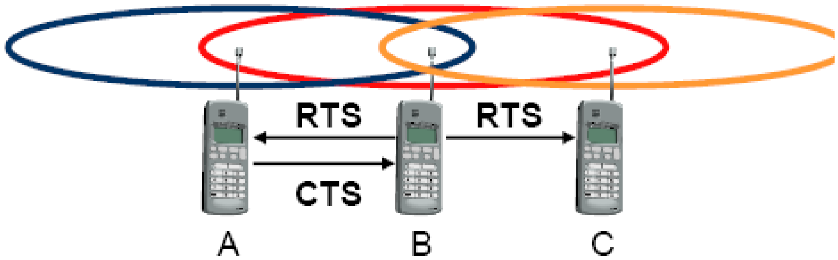
CSMA/CA Collision Avoidance protocol

Sends RTS(request to send) and wait for to receive CTS (clear to send)

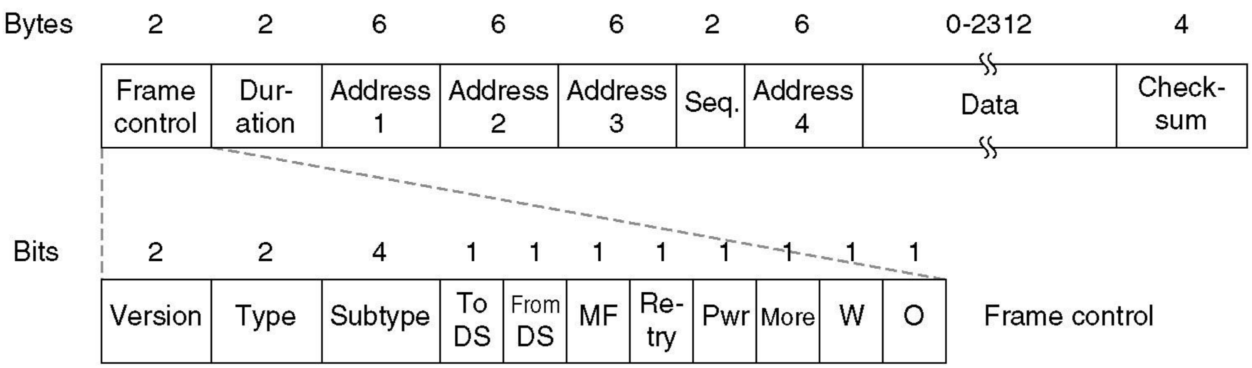
- MACA avoids the problem of hidden terminals
    - A and C want to
      send to B
    - A sends RTS first
    - C waits after receiving
      CTS from B



- MACA avoids the problem of exposed terminals
    - B wants to send to A, C
      to another terminal
    - now C does not have
      to wait for it cannot
      receive CTS from A



The 802.11 Frame Structure



Types

- control frames(01), management frames(00), data frames(10) Sequence numbers
- important against duplicated frames due to lost ACKs Addresses
- receiver, transmitter (physical), BSS identifier, sender (logical) Miscellaneous
- sending time, checksum, frame control, data

scenario	to DS	from DS	address 1	address 2	address 3	address 4
ad-hoc network	0	0	DA	SA	BSSID	-
infrastructure network, from AP	0	1	DA	BSSID	SA	-
infrastructure network, to AP	1	0	BSSID	SA	DA	-
infrastructure network, within DS	1	1	RA	TA	DA	SA

AP: Access Point
DA: Destination Address
SA: Source Address
BSSID: Basic Service Set Identifier
RA: Receiver Address
TA: Transmitter Address
Subtype: For CSMA/CA or

802.16 Broadband Wireless

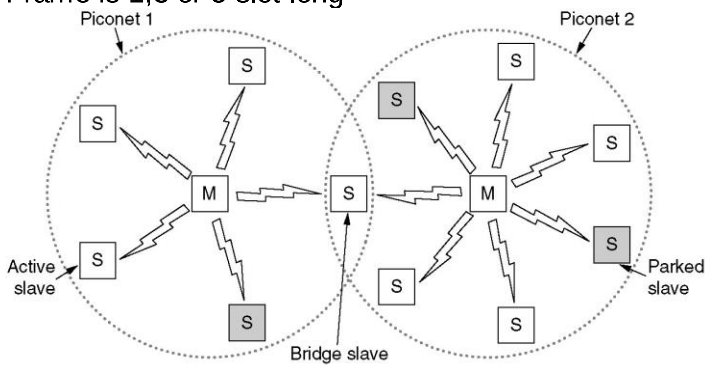
- Goal : To cover the city area
- Operating Frequency: 10 to 66 GHz
- Modulations : QAM-16, QAM-64 , QPSK
- Speeds : 100 Mbps, 150 Mbps , 50 Mbps
- Used : TDD and FDD

Bluetooth

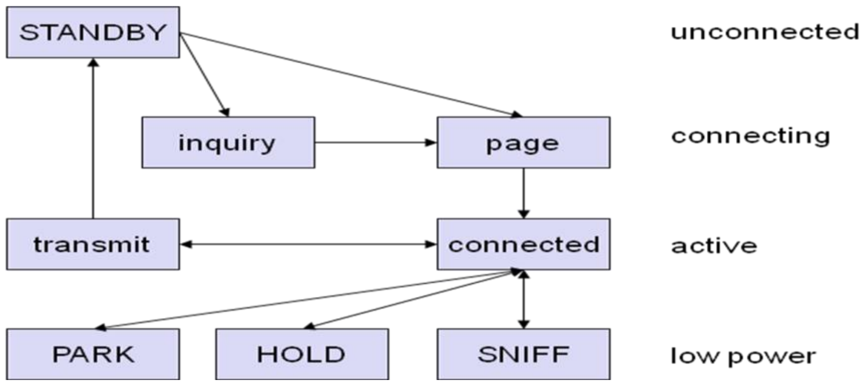
- In 1994 started by Ericsson, IBM, Intel, Nokia and Toshiba for connections of peripheral devices
- 802.15 July 1999 released
- Wireless standard for short range low power, inexpensive devices
- Only physical and data link layer
- Consortium: Ericsson, Intel, IBM, Nokia, Toshiba - many members
- Scenarios
- connection of peripheral devices
  - loudspeaker, joystick, headset
- support of ad-hoc networking
  - small devices, low-cost
- bridging of networks
  - e.g., GSM via mobile phone - Bluetooth - laptop
- Simple, cheap, replacement of IrDA, low range, lower data rates

Bluetooth Architecture

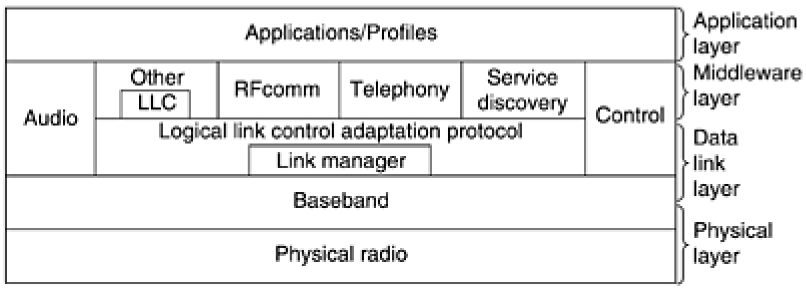
- Basic unit is piconet
- Piconet consists one master node and 7 active slave nodes
- Perimeter is 10 meters
- Multiple piconets can be formed via bridge node
- Interconnected piconets are called scatternet
- Parked slave for responding to the activation/becon from the master
- There can be 255 parked nodes
- Uses TDM
- Communication between master slave only and not slave to slave
- 2.4 GHz, FHSS, TDD, CDMA
- 79 channels of 1 MHz each
- Modulation FSK, 1-bit per Hz gives 1 Mbps datarate
- 625 microsec timeslot
- Frame is 1,3 or 5 slot long



States of the Bluetooth (Physical Layer)



The 802.15 Version of The Bluetooth Protocol Architecture



Physical radio layer: corresponds fairly well to the physical layer in the OSI and 802 models. It deals with radio transmission and modulation.

The baseband layer: is analogous to the MAC sublayer but also includes elements of the physical layer. It deals with how the master controls time slots and how these slots are grouped into frames.

The link manager: handles the establishment of logical channels between devices, including power management, authentication, and quality of service.

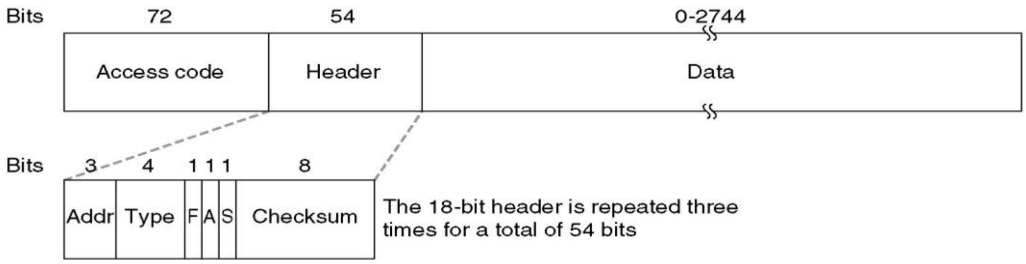
The logical link control adaptation protocol (L2CAP): shields the upper layers from the details of transmission. It is analogous to the standard 802 LLC sublayer, but technically different from it.

As the names suggest, the audio and control protocols deal with audio and control, respectively. The applications can get at them directly, without having to go through the L2CAP protocol.

The next layer up is the middleware layer, which contains a mix of different protocols. The 802 LLC was inserted here by IEEE for compatibility with its other 802 networks.

The top layer is where the applications and profiles are located. They make use of the protocols in lower layers to get their work done. Each application has its own dedicated subset of the protocols.

Frame Format



An access code identifies the master so that slaves within radio range of two masters can tell which traffic is for them.

Next comes a 54-bit header containing typical MAC sublayer fields. Then comes the data field, of up to 2744 bits (for a five-slot transmission). For a single time slot, the format is the same except that the data field is 240 bits.

The *Address* field identifies which of the eight active devices the frame is intended for.

The *Type* field identifies the frame type (ACL, SCO, poll, or null), the type of error correction used in the data field, and how many slots long the frame is.

The *Flow* bit is asserted by a slave when its buffer is full and cannot receive any more data. This is a primitive form of flow control.

The *Acknowledgement* bit is used to piggyback an ACK onto a frame.

The *Sequence* bit is used to number the frames to detect retransmissions. The protocol is stop-and-wait, so 1 bit is enough.

Then comes the 8-bit header *Checksum*. The entire 18-bit header is repeated three times to form the 54-bit header.