Chapter 5

The Media Access Control Sublayer

The Media Access Control (MAC) sublayer is concerned with broadcast networks, also called *multi-access channels* or *random access channels*.

5.1 The Channel Allocation Problem

The bandwidth of a channel can be allocated either statically or dynamically.

5.1.1 Static Channel Allocation

In this case, we can use techniques like:

- FDM
- TDM

Problem

The traffic in a Computer Network is generally bursty in nature. Static allocation is inefficient for such traffic.

5.1.2 Dynamic Channel Allocation

Following assumptions/parameters are considered:

(a) *Station Model:* There are N independent stations or terminals (e.g. PCs). Once a frame is ready, the station is blocked and does nothing until the frame is successfully transmitted.

(b) *Single Channel Assumption:* A single Channel is available for all communication. All stations can transmit and receive from it.

(c) *Collision Assumption:* If two frames are transmitted simultaneously, they overlap in time and the resulting signal is garbled. This event is called collision. All stations can detect Collision. A collided frame must be transmitted again later. There are no errors other than those generated by collision.

(d) *Time:*

   (i) *Continuous Time:* Frame transmission can begin at any instant.

   (ii) *Slotted Time:* Time is divided into discrete intervals or slots. Frame transmission always begins at the start of a slot.

(e) *Carrier:*

   (i) *Carrier Sense:* Stations can tell if the channel is in use before trying to use it.

   (ii) *No Carrier Sense:* Stations can not sense the channel before trying to use it.

5.2 Multiple Access Protocols

These protocols uses dynamic channel allocation technique.

5.2.1 Pure Aloha

- Stations transmits whenever they have data to send.
- If more than one stations transmit at the same time, there will be collision and the frames will be damaged.
- The transmitting station(s) listen to the broadcast channel to find out if the frame was destroyed.
- If station(s) can not listen to the channel while transmitting, acknowledgments are needed.
- If the frame was destroyed, the sender waits a random amount of time and sends it again.
- The maximum channel utilization is 18%.

5.2.2 Slotted Aloha

- Time is divided into discrete intervals called slots — each slot corresponding to one frame.
- One special station emits a short pip at the start of each slot.
- Stations can not send whenever they have data ready. Instead, they must wait for the beginning of the next slot.
- The maximum channel utilization is 37%.

5.2.3 Carrier Sense Multiple Access (CSMA) Protocols

(i) **1-Persistent CSMA**

- When a station has data to send, it checks the channel to see if anyone else is transmitting at that moment.
- If the channel is busy, the station waits until it becomes idle.
- When the station detects an idle channel, it transmits a frame.
- If a collision occurs, the station waits a random amount of time and starts all over again. (Propagation delay plays an important role in this case)

(ii) **Non-persistent CSMA**

- Before sending, a station senses the channel.
- If no one else is sending, the station starts transmission.
- But, if the channel is already in use, it waits a random period of time and then repeats the algorithm.
- This algorithm leads to better channel utilization but longer delays than '1-Persistent CSMA'.

(iii) **p-Persistent CSMA**

- It applies to slotted channels.
- When a station is ready to send, it senses the channel.
- If it is idle, it transmits with a probability 'p'.
- With a probability $q = 1 - p$, it defers until the next slot.
- If that slot is also idle, it either transmits or defers again, with probability 'p' & 'q' respectively.
- This process is repeated until either the frame has been transmitted or another station has begun transmitting.

- In the later case, the station waits a random time and starts again.
- If the station initially senses the channel busy, it waits until the next slot and applies the above algorithm.

Comparison of various Multiple Access Protocols is shown in figure 5.1

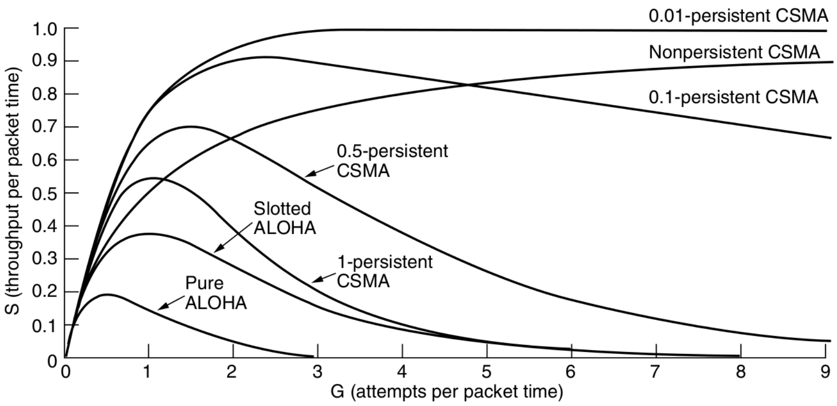

Figure 5.1: Comparison of Channel utilization versus Load for various Multiple Access Protocols (Courtesy: Computer Networks by Tanenbaum, 5^{th} Ed.)

5.2.4 CSMA with Collision Detection (CSMA/CD)

- If two stations sense the channel to be idle and begin transmitting simultaneously, there will be a collision.
- Both stations detect the collision and stops the transmission immediately.
- Quickly terminating damaged frames saves time and bandwidth.
- A station must wait 2τ time units, after starting it's transmission, to make sure that there is no collision in the channel (where τ is the full cable propagation delay time).
- This protocol is the basis of Ethernet LAN.

5.3 Collision-Free Protocols

Following assumptions/parameters are considered:

a) There are exactly N stations, each with a unique address from 0 to $N - 1$.

b) Some stations may be inactive part of the time.

c) Propagation delay is negligible.

5.3.1 A Bit-Map Protocol

The Bit-Map Protocol is show in figure 5.2

- Each contention period consists of exactly N slots.
- If station 0 has a frame to send, it transmits a '1' bit during the zeroth slot. No other station is allowed to transmit during this slot.
- Regardless of what station 0 does, station 1 gets the opportunity to transmit a '1' during slot 1, but only if it has a frame queued.

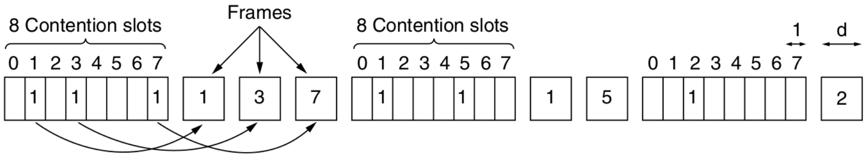

Figure 5.2: The Basic Bit-Map Protocol (Courtesy: Computer Networks by Tanenbaum, 5^{th} Ed.)

- In general, station j may announce that it has a frame to send by inserting a '1' bit into slot j.
- After all N slots have passed by, each station has complete knowledge of which station wish to transmit.
- At that point, they begin transmitting in numerical order.
- After the last ready station has transmitted it's frame, another N-bit contention period begins.
- If a station becomes ready just after it's bit slot has passed by, it must wait till the next contention period has come up again.
- Protocols like this, in which the desire to transmit is broadcast before the actual transmission, are called 'Reservation Protocols'.

5.3.2 Binary Countdown

The Binary Countdown Protocol is shown in figure 5.3

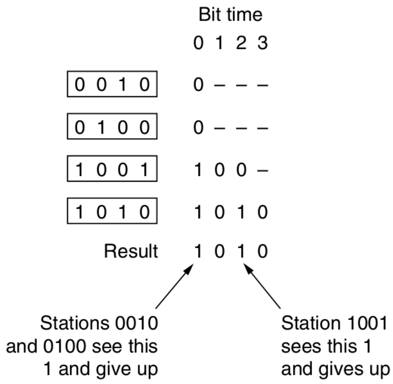

Figure 5.3: The Binary Countdown Protocol. A dash indicates silence. (Courtesy: Computer Networks by Tanenbaum, 5^{th} Ed.)

- As the number of stations grows, the overhead in bit-map protocol also grows significantly.
- Instead of reserving a bit position for all the stations, as in Bit-Map protocol, a binary station address is used in this protocol.
- A station wanting to use the channel now broadcasts it's address as a binary bit string, starting with the high order bit.
- All addresses are assumed to be of same length.
- The bits in each address position from different stations are boolean OR-ed together.
- When a station sees that a high-order bit position that is '0' in it's address has been overwritten with a '1', it gives up.
- After the last bit position is OR-ed, the station whose last bit is same as the OR-ed result wins.
- The winning station can now transmit a frame, after which another bidding cycle starts.

5.3.3 Token Passing

A token ring is shown in figure 5.4

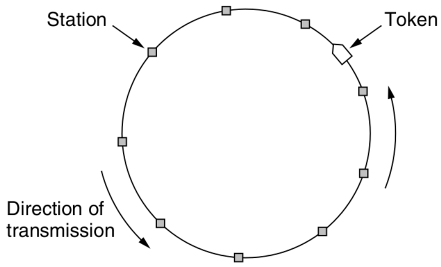

Figure 5.4: Token Ring (Courtesy: Computer Networks by Tanenbaum, 5^{th} Ed.)

- A small message called a 'token' is passed from one station to the next, in a predefined order.
- The token represents permission to send.
- Upon receipt of the token, if a station has a frame to send, it keeps the token and sends the frame in the same predefined direction.
- Once the frame is received by the intended station, and the frame circulates back to the originating station, it removes the frame and releases the token.
- If a station has no frame to send, when it receives the token — it simply forwards the token to the next station in the predefined order or direction.
- The token passing mechanism can be used in protocols like 'Token Ring' and 'Token Bus'.

5.4 Ethernet

The Ethernet was designed to connect isolated computers to form a small network. After it was widely adopted, the IEEE[1] committee was entrusted with the task of standardizing the LANs and MANs with a assigned number 802. The IEEE committee standardized the Ethernet, and called it 802.3. However, nowadays, the terms Ethernet & 802.3 are used interchangeably.

Some popular standards under 802 are:

- 802.3 : Wired LAN
- 802.11 : Wireless LAN
- 802.15 : Wireless PAN (Bluetooth)
- 802.16 : Wireless MAN

Some key points regarding the Ethernet are:

- Broadcast network.
- Single communication channel, that is shared by all the machines/nodes on the network.
- General Rule: Smaller, geographically localized network.
- Short messages sent by any machine are received by all others.
- Shared medium means a single collision domain.

[1] Institute of Electrical & Electronics Engineers

- All machines receives the frames, but one processes it: Mode of operation — Broadcasting.
- Also possible to address a frame to a subset of machines: Mode of operation — Multicasting.
- Bus topology (when a Hub is used, the physical topology is Star, however, the logical topology is Bus).
- Uses the CSMA/CD protocol (Section 5.2.4 on page number 53).
- In case of collision, jamming signal is used to inform all the stations and to stop the ongoing communication.
- The random amount of time to wait, in case of a collision, is given by an algorithm called the Binary Exponential Backoff algorithm (Section 5.4.3 on page number 59).
- Collision detection can take as long as 2τ amount of time (where, τ is the full cable propagation delay time).
- Uses the standard Ethernet frame format (Figure 5.5 on page number 57).
- Unreliable, Connection-less service:
  - *Unreliable:* Receiving adapter does not send any ACK or NACK to sending adapter.
  - *Connectionless:* No handshaking between sending and receiving adapters.
- Ethernet NICs uses a 46-bit (48-bit address field) serial number, which is encoded in the firmware of the card — also called a Hardware address or MAC address.
- The 802.3 CSMA/CD bus LAN is said to be a non-deterministic network: There is no guarantee of a fixed time, within which a station shall be able to send it's frame. As the network becomes busy, more and more time may be required to send each frame.

Ethernet is divided into two broad classes:

- Classic Ethernet
- Switched Ethernet

5.4.1 Classic Ethernet (IEEE 802.3)

SL#	Name	Cable	Max. Segment Length	Nodes/Segment
(i)	10Base5	Thick Coax.	500m	100
(ii)	10Base2	Thin Coax.	185m	30
(iii)	10BaseT	Twisted Pair	100m	1024
(iv)	10BaseF or FL	Fibre Optics	2000m	1024

Table 5.1: Classic Ethernet Cabling

a) *Cabling:* The classic Ethernet cabling schemes are shown in table 5.1

(i) 10Base5:
- Uses thick coaxial cable.
- For connecting the nodes, Vampire Tap is used.
- 10 Mbps data rate.
- Uses base-band signaling.
- Maximum four (4) repeaters can be used to extend the network.

(ii) 10Base2:
- Uses thin coaxial cable.

- Uses BNC connectors for connecting the nodes.
- 10 Mbps data rate.
- Uses base-band signaling.
- Maximum four (4) repeaters can be used to extend the network.

(iii) 10BaseT:

- Uses UTP cable (CAT3).
- Needs a Hub for connecting more than two (2) nodes.
- Uses RJ45 connectors for connecting the nodes.
- 10 Mbps data rate.
- Uses base-band signaling.
- Maximum four (4) repeaters can be used to extend the network.

b) *Encoding:* Uses Manchester Encoding.

c) *Frame Format:* The frame format for the Ethernet is shown in figure 5.5(a) & the IEEE 802.3 frame format is shown in figure 5.5(b).

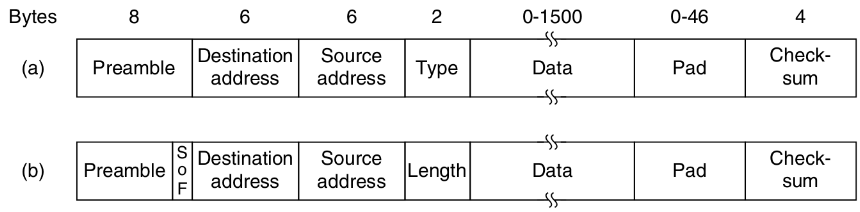

Figure 5.5: Ethernet Frame Format (Courtesy: Computer Networks by Tanenbaum, 5^{th} Ed.)

- *Preamble:*
  - Used to synchronize the source and the destination station.
  - Consists of the byte pattern '10101010', which is repeated eight (8) times, in case of the 'Ethernet' frame.
  - In case of the 802.3 frame, the same byte pattern (i.e. 10101010) is repeated seven (7) times.
- *Addresses:*
  - The high-order bit of the destination address has special meaning. If it is '0', it is a normal address. If it is '1', it is a group or multicast address.
  - If all the bits of the destination address are '1', it is a broadcast address.
  - The next bit to MSB (i.e. the 46^{th} bit) is used to specify either local address (if the bit is '0') or global address (if the bit is '1').
  - The addresses used in this frame format is known as Hardware or MAC address.
  - The MAC address is embedded into the NIC card or any other network device at the time of manufacturing, in the device firmware.
  - MAC addresses must be unique.
  - To maintain uniqueness, the 6-byte MAC address is divided into two parts of 3-bytes each. The first 3-bytes (minus the leading 2-bits) are unique for each manufacturer called the OUI[2]. The next 3-bytes are managed by the manufacturers themselves.
  - In some implementation, the addresses may be 2-bytes long.
- *Type:*
  - indicates the higher layer protocol used.
  - Mostly 'IP', but others may also be supported, such as Novell IPX/SPX or AppleTalk.
- *Data:*

[2] Organizationally Unique Identifier

- The actual data that we want to send as part of the communication i.e. the payload.
- It can vary from 0 – 1500 bytes (i.e. it can also be empty, upper size limit is 1500 bytes).

- *Pad:*
  - Used to maintain a minimum size of the frame. The minimum allowed size of an Ethernet frame is 64 bytes.
  - It can vary from 0 – 46 bytes.
  - In case of absence of data or less amount of data, padding bytes are used to make the minimum size of the frame 64 bytes.
- *Checksum:*
  - Used for error detection.
  - The 32-bit CRC method is used.
- *SOF:*
  - Stands for Start of Frame.
  - Uses the 1-byte bit pattern '10101011' for this purpose.
- *Length:*
  - Specifies the length (size in bytes) of the variable 'Data' field.
  - However, to identify the higher layer protocol, the 'Data' field now carries this information.

5.4.2 Switched or Modern Ethernet

Modern Ethernet has gone through many revisions, such as Fast Ethernet, Gigabit Ethernet, 10-Gigabit Ethernet etc. The primary goal of all these revisions were to increase the throughput by ten times (compared to the previous revision), while maintaining backward compatibility.

Fast Ethernet (802.3u)

The cabling schemes for Fast Ethernet is shown in table 5.2

SL#	Name	Cable	Max. Segment Length	Advantage
(i)	100Base-T4	UTP	100m	Uses CAT3/CAT4 UTP cable
(ii)	100Base-TX	UTP	100m	Full Duplex at 100Mbps
(iii)	100Base-FX	Fibre Optics	2000m	Full Duplex, Long run

Table 5.2: Fast Ethernet Cabling

(i) *100Base-T4:* With this cabling scheme, all the organizations who already had their cabling done using CAT3 cables, could upgrade to 100Mbps speed by upgrading their Hubs or Switches and NICs. The major rewiring cost could be avoided.

(ii) *100Base-TX:*

- Most popular cabling scheme.
- Uses CAT5 UTP.
- Uses base-band signaling.
- 100m segment length.
- An encoding scheme called 'Multi-Level Transmit (MLT-3)' is used. In this scheme, three (3) voltage levels are used to represent the binary bits. To represent binary '1', transitions from $Low \rightarrow 0, High \rightarrow 0, 0 \rightarrow Low, 0 \rightarrow High$ are used. To binary '0' is represented without any transitions. An example of MLT3 encoding is shown in figure 5.6
- Bandwidth requirement for MLT3 is 1/2 the bandwidth required for two-level scheme.
- However, long stream of zeros may lose clock synchronization.
- 100m maximum distance between Hub-to-Station.
- Limit of two (2) hubs.

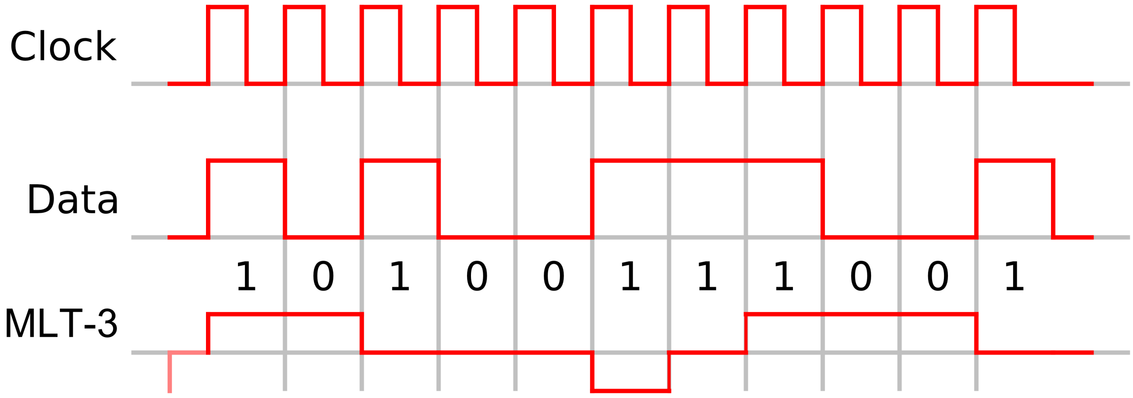

Figure 5.6: MLT3 Encoding Example (Courtesy: www.wikipedia.org)

Gigabit Ethernet (IEEE 802.3z)

The cabling schemes for Gigabit Ethernet is shown in table 5.3

SL#	Name	Cable	Max. Segment Length	Comment
(i)	1000Base-SX	Fibre	550m	Multimode Fibre
(ii)	1000Base-LX	Fibre	5000m	Single/Multimode Fibre
(iii)	1000Base-CX	2-pairs of STP	25m	Shielded Twisted Pair
(iv)	1000Base-T	4-pairs of UTP	100m	Standard CAT5/5e/6 Cable

Table 5.3: Gigabit Ethernet Cabling

- Allows for point-to-point links and shared broadcast channels.
- In shared mode, CSMA/CD is used.
- Uses standard Ethernet frame format (IEEE 802.3z standard).
- The normal mode is full-duplex mode, with a central *Switch* connected to computers. All lines are buffered.

5.4.3 The Binary Exponential Backoff Algorithm

In case of a collision under the CSMA/CD protocol, each affected station must wait a random amount of time before retrying again. The binary exponential backoff algorithm is used to get the random amount of time to wait, after every collision. Apart from placing an upper limit on the number of retry allowed, this algorithm also adjusts the wait time to suit the data transmission load in the network.

- Time is divided into discrete slots whose length is equal to the worst-case round-trip propagation time of the media.
- After the first collision, each station waits either 0 or 1 slot time before trying again.
- If they chose the same number, the frame will collide again.
- After the second collision, each station picks a number from 0, 1, 2, or 3 at random, and waits that number of slot time(s) before retrying.
- After the third collision, the wait time ranges from 0 to $(2^3 - 1)$ slot times.
- In general, after i collision, a random number between 0 and $(2^i - 1)$ is chosen.

- However, after ten (10) collisions, the maximum wait time is kept constant at 1023 slot times (i.e. the random wait time ranges from 0 to 1023 slot times).
- As such, after the eleventh collision also, the random wait time ranges from 0 to 1023 slot times.
- However, after sixteen (16) collisions, the station reports a failure, and gives up.

Review Questions

1. Under which layer of the ISO/OSI Reference Model, you can find the MAC Sublayer? What is the main function of this sublayer?
2. What is the name of the other sublayer present in this layer? What is the main function of that sublayer?
3. What are the other names of MAC Sublayer?
4. In the context of Computer Networks, what is meant by Multiplexing?
5. How does the FDM work?
6. What are various types of TDM? How do they work?
7. What is the meaning of 'Collision' in Computer Network? What is the effect of collision?
8. What is 'Slotted Time'?
9. What is the significance of 'Random Wait Time' in the ALOHA protocols?
10. How does the 'Slotted ALOHA' differs from the 'Pure ALOHA' protocol? What do you think is the reason for increased channel utilization in case of Slotted ALOHA, compared to the Pure ALOHA protocol?
11. What is the basic difference between the '1-Persistent' & 'Nonpersistant' CSMA protocols?
12. In the CSMA protocols, what does the '1', 'Non', and 'p' signifies?
13. In the 'p-Persistent CSMA', what is the relation between 'p' & 'q'? What is their purpose?
14. In the CSMA/CD protocol, what does the 'CD' part stands for? What is the importance of the 'CD', in this protocol?
15. In the CSMA/CD protocol, why should a station wait twice the full cable propagation delay time, before it is sure that no collision has occurred? Is there any best-case or worst-case kind of scenario?
16. In the Bit-Map protocol, what is done during the 'Contention Slots'?
17. In the Bit-Map protocol, what happens to the contention slots when the number of stations increases in the Network? How does it effect the overall performance of the protocol?
18. In the Bit-Map protocol, what is done if a frame becomes ready in a station just after it's bit-slot has passed by?
19. What are 'Reservation Protocols'?
20. How does the bidding process works in a 'Binary Countdown' protocol?
21. In terms of overhead, how does the Binary Countdown protocol differs from the Bit-Map protocol?
22. Does the Binary Countdown protocol implicitly offers more preference to some stations compared to others? If so, how?
23. In a 'Token Passing' protocol, what is the significance of the 'Token'?

24. In a practical implementation like Token Ring or Token Bus, who is responsible for generating and maintaining the token? What happens when the token is damaged or lost?
25. If the number of stations in a Token Ring or Token Bus increases, does it effect the overall performance of the Network?