Data-Link Layer II

Multiple Access

Agenda

- Multiple Access Protocols

Data-Link Layer II

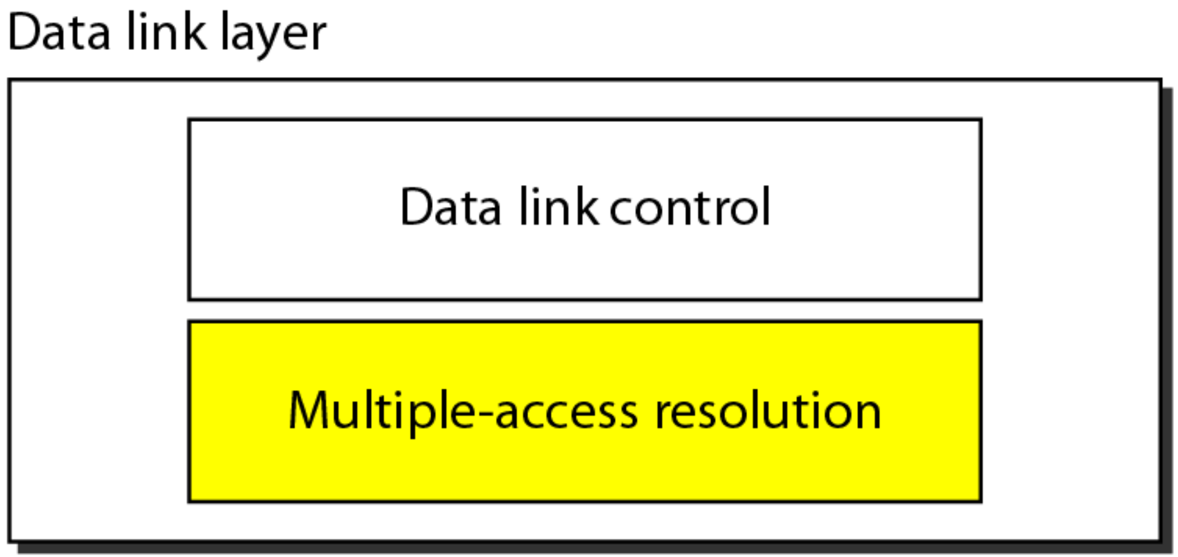
Our goals:

Understand principles behind link layer services:

- Introduction, Services
- Error detection, correction
- Multiple access protocols
- Sharing a broadcast channel: multiple access
- Data-Link Layer Addressing
- ARP/RARP
- LAN: Ethernet
- LAN: Switches
- LAN: VLANS
- Simple web request description

Implementation of various link layer technologies

Data link layer divided into two functionality-oriented sublayers



Multiple Access

The Channel Allocation Problem

Central Q. How to allocate a single broadcast channel among concurrent work users?

Static Access (Multiplexing with Channelization)

FDM/TDM/WDM/CDM (Frequency/Wave/Time/Code Division Multiplexing)

- FDM: Radio/TV broadcasts
- WDM: is a form of FDM used for optical fiber
- TDM: POTS (Plain Old Telephone System)
- CDM: used in cell phone

Controlled Access

- Reservation
- Polling (опрос)
- Token passing (ex. Token Ring)

Dynamic Access (Random)

- ALOHA Pure/ Slotted
- CSMA Carrier Sense Multiple Access (CSMA) Protocols
- CSMA/CD CSMA Collision Detection
- CSMA/CA Collision free protocols
- Switching

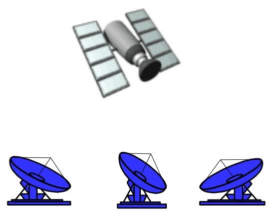
Multiple access links, protocols

two types of "links":

- point-to-point
  - PPP for dial-up access
  - point-to-point link between Ethernet switch, host
- *broadcast (shared wire or medium)*
  - old-fashioned Ethernet
  - upstream HFC
  - 802.11 wireless LAN

shared wire (e.g., cabled Ethernet)

shared RF (e.g., 802.11 WiFi)



shared RF (satellite)

humans at a cocktail party (shared air, acoustical)

Multiple access protocols

- single shared broadcast channel
- two or more simultaneous transmissions by nodes: interference
  - *collision* if node receives two or more signals at the same time

multiple access protocol

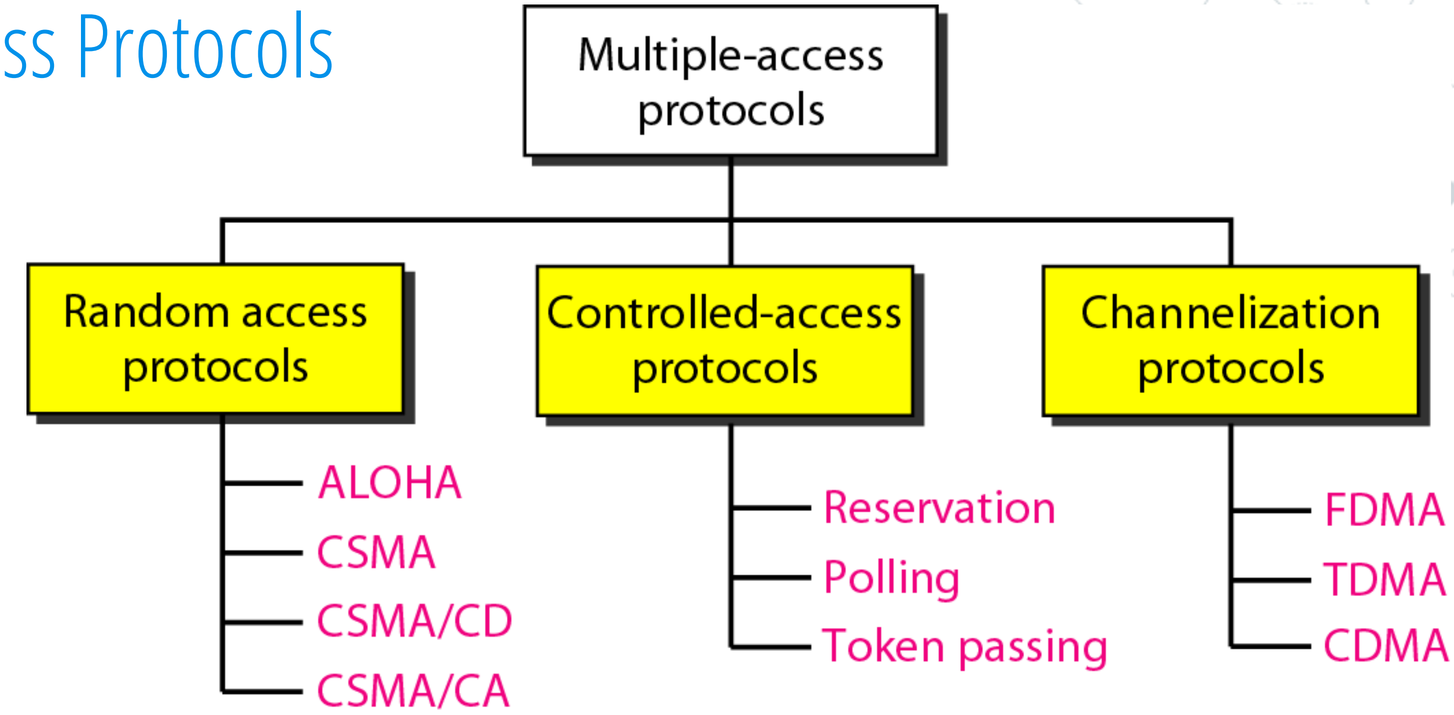
- distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination

An ideal multiple access protocol

given: broadcast channel of rate R bps
desiderata:
1. when one node wants to transmit, it can send at rate R.
2. when M nodes want to transmit, each can send at average rate R/M
3. fully decentralized:
   - no special node to coordinate transmissions
   - no synchronization of clocks, slots
4. simple

Multiple Access

Multiple Access Protocols

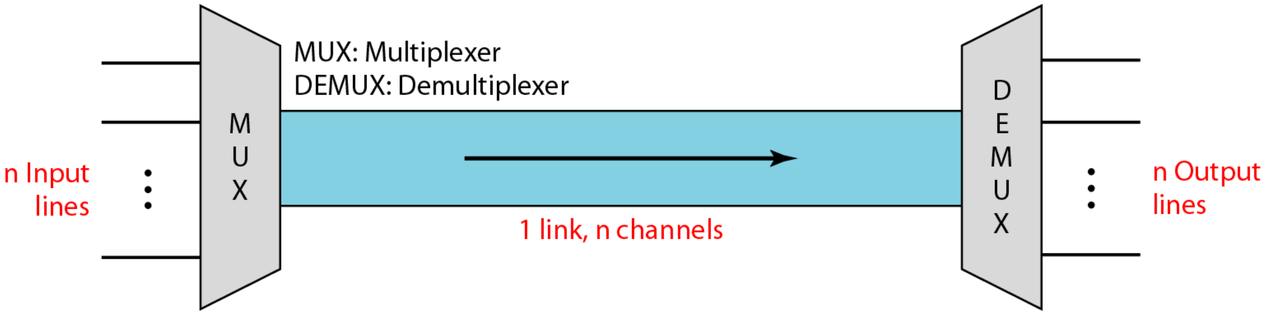


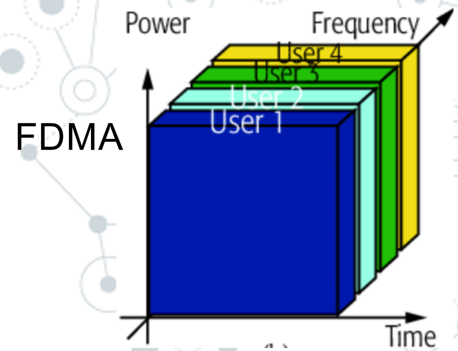
Mobile History

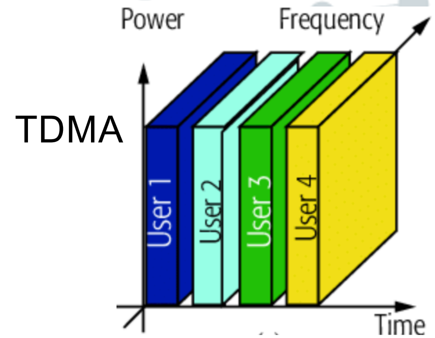
1G – 1982, AMPS, Bell Labs
2G – 1988, European, ETSI
2.1G – 1991, GSM, Finland
2.5G – 1995, GPRS
2.7G – 1997, EDGE
3G – 1999, UMTS
4G – 2004, LTE
5G – 2018,

Multiple Access

Channelization: Multiplexing Types







Motivation - 1 link n channels

DMA - Division Multiple Access - used to allow many users to share simultaneously a finite amount of radio spectrum

FDMA — frequency (Radio/TV broadcasts) 1G (AMPS - Advanced Mobile Phone System)

WDMA — wave (is a form of FDMA used for optical fiber)

TDMA — time (POTS - Plain Old Telephone System) 2G (GSM – Global Mobile System)

CDMA — code (spread spectrum) 3G (UMTS – Universal Mobile Telecommunication System)

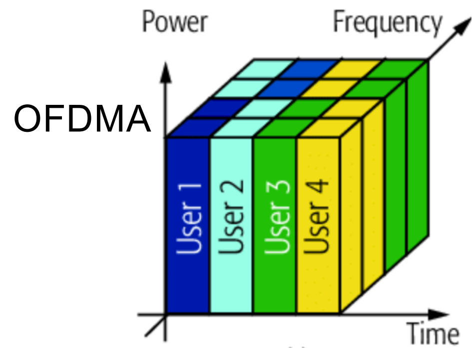
SDMA — space (cell phone and WiFi)

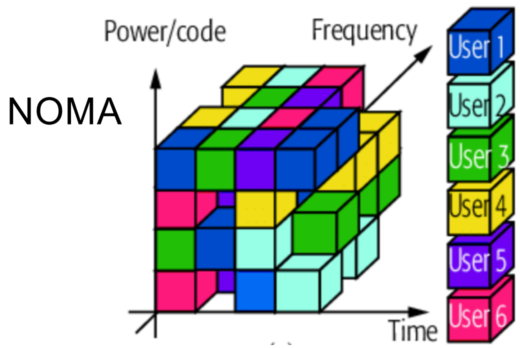
OFDMA — orthogonal fdma+tdma – many subF (WiMAX) 4G (LTE – Long Term Evolution)

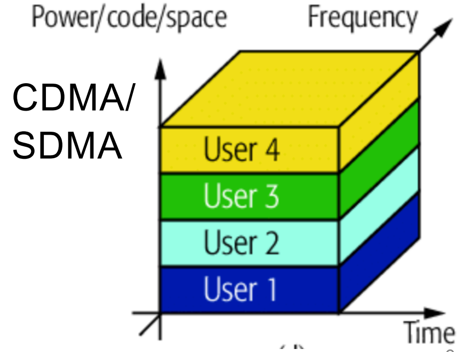
NOMA — Non-Orthogonal Multiple Access = 5G

+ SDMA elements,
+ OFDMA elements,
+ PAA – phased array antenna
+ Massive MIMO – multiple input output over 2-256 antennas

https://www.youtube.com/watch?v=rKy5dOl3Et4

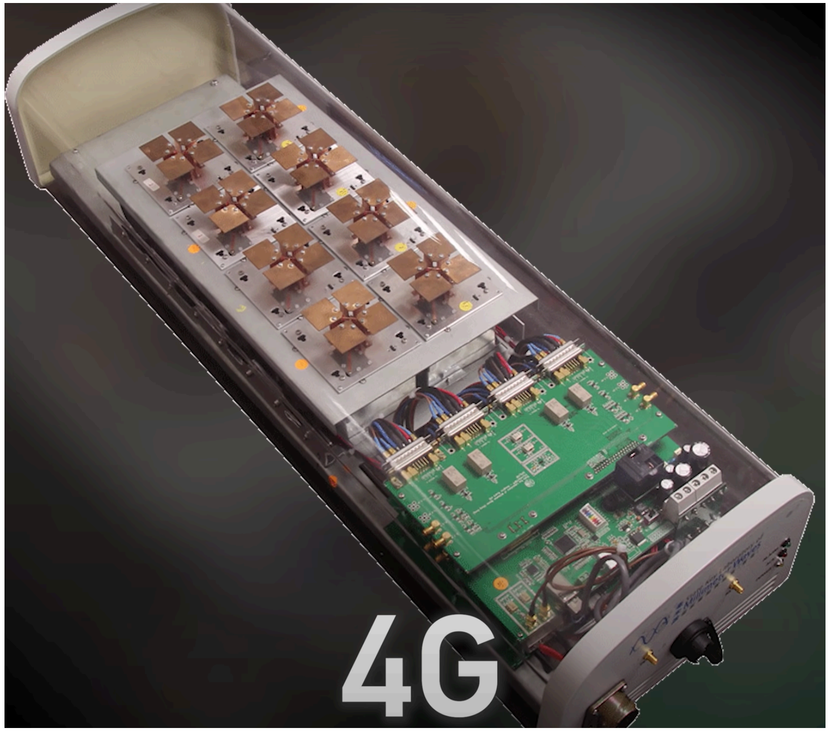


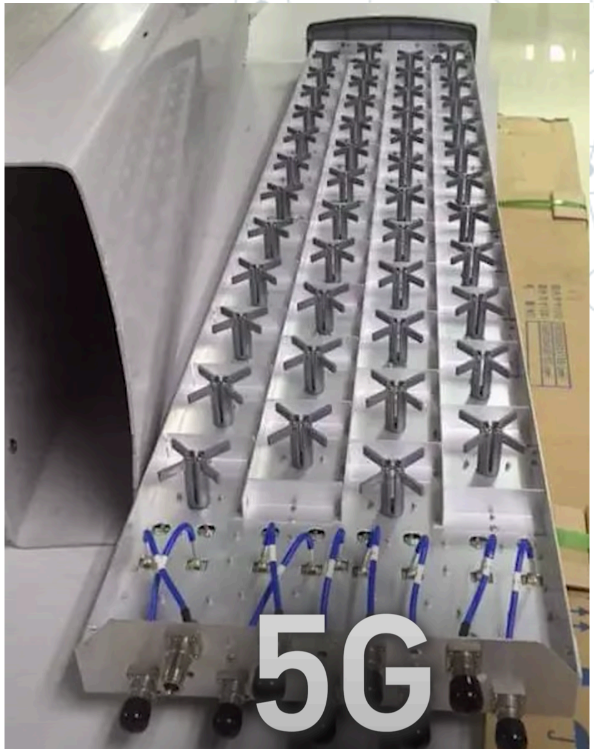


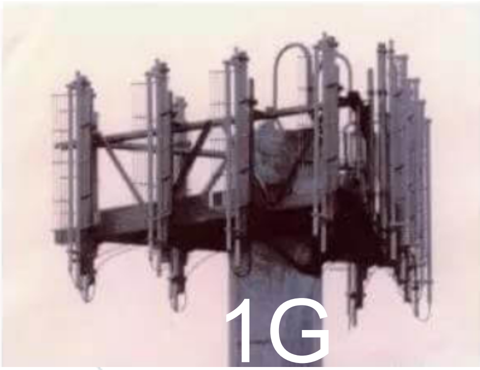


Multiple Access

Channelization: 1G, 2G, 3G, 4G, 5G Base Station Antennas





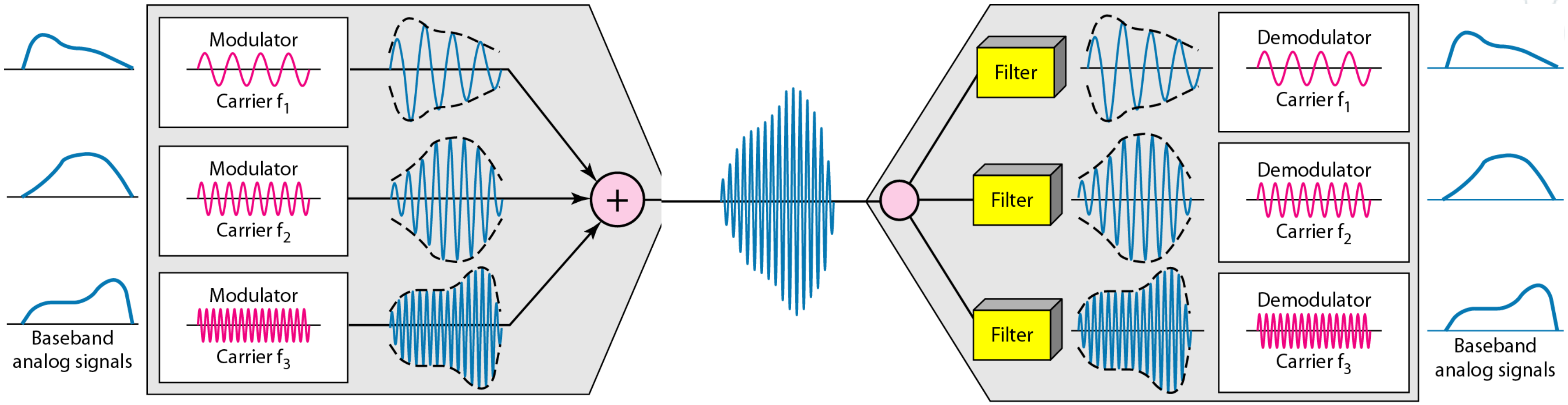


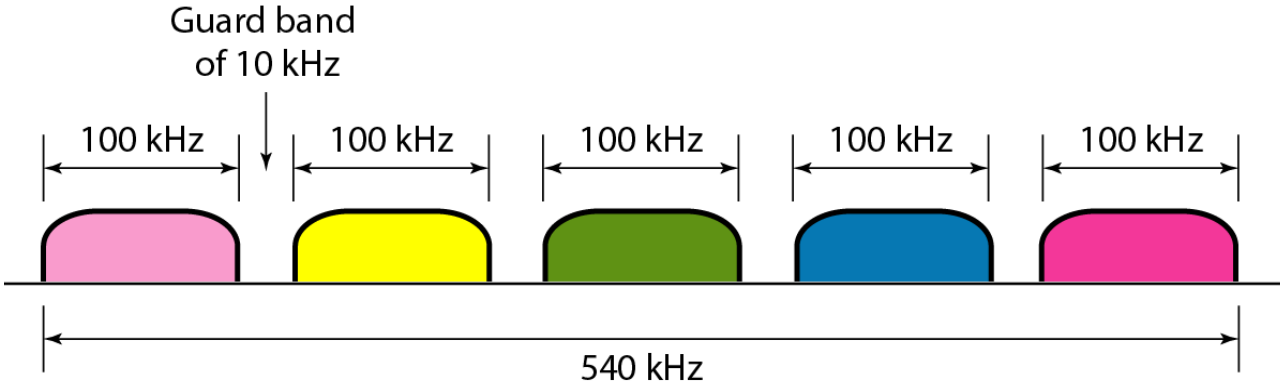
Phased Array Antenna use wave interference

Multiple Access

Channelization: FDMA - Frequency Division Multiple Access

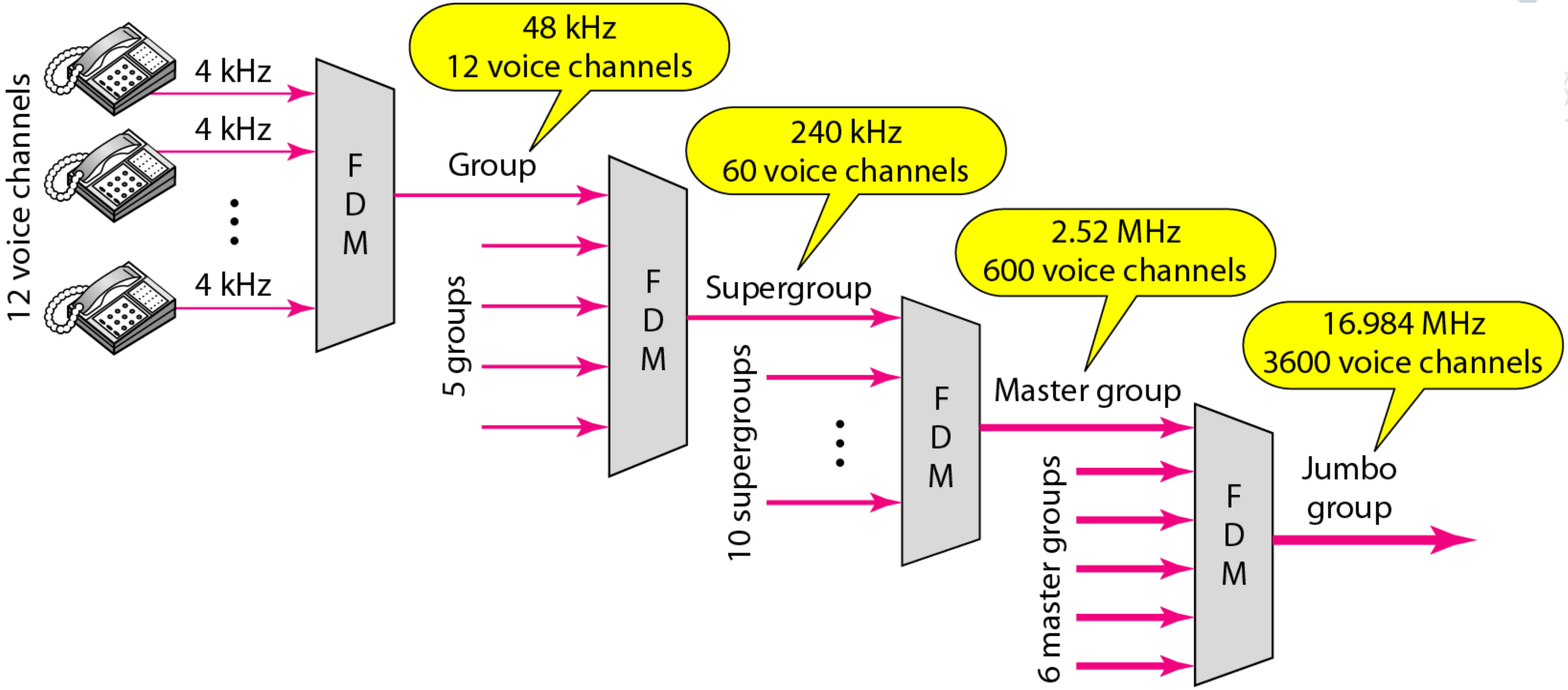
FDM is an analog multiplexing technique that combines analog signals.





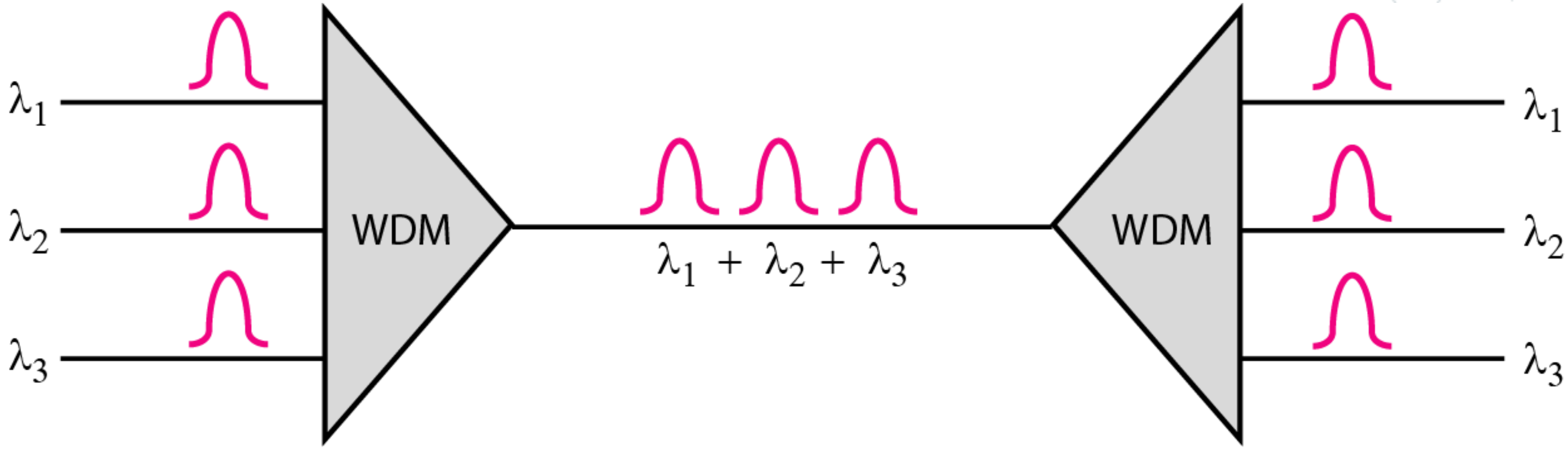
Multiple Access

Channelization: FDMA - Analog Hierarchy

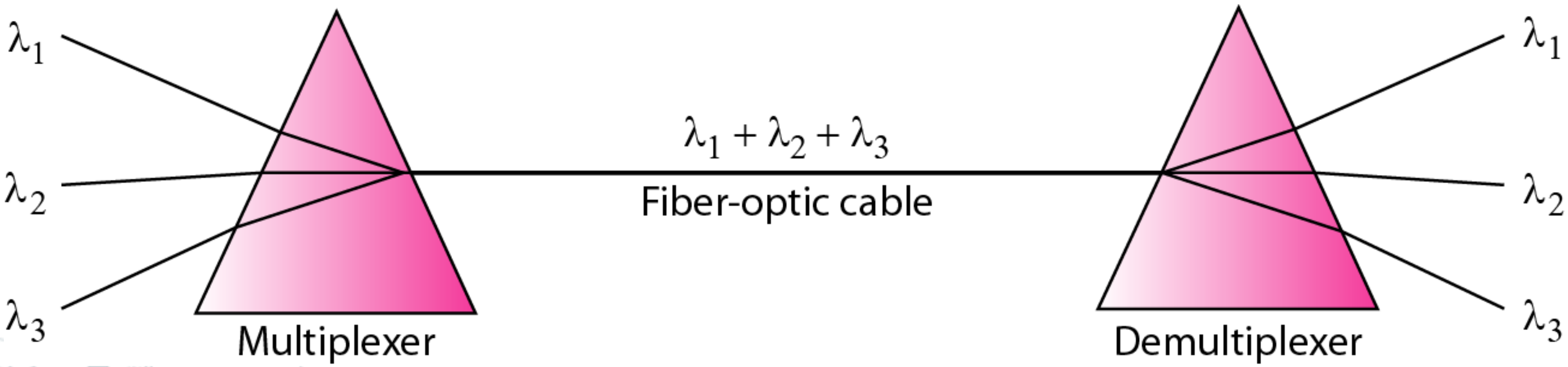


Multiple Access

Channelization: WDMA - Wavelength Division Multiple Access



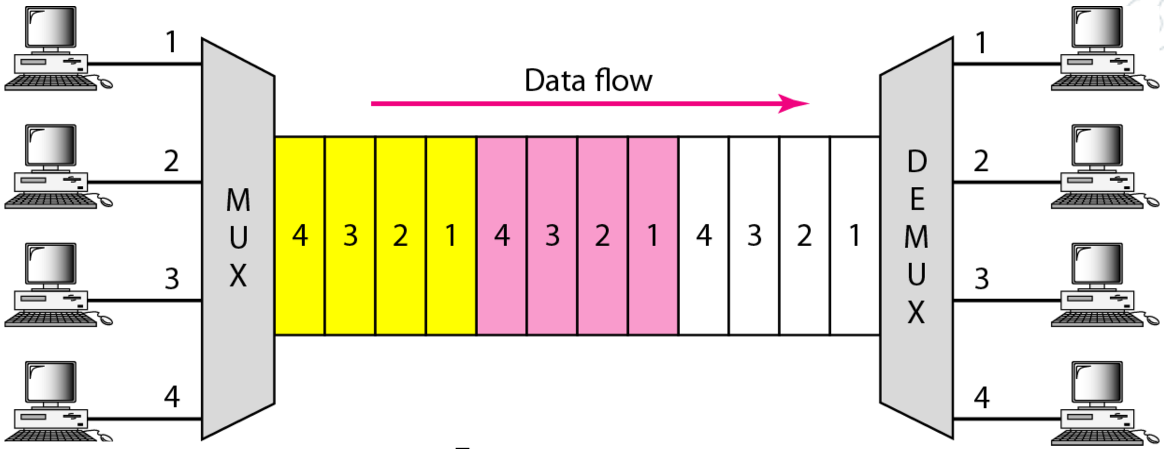
Prisms in wavelength-division multiplexing and demultiplexing

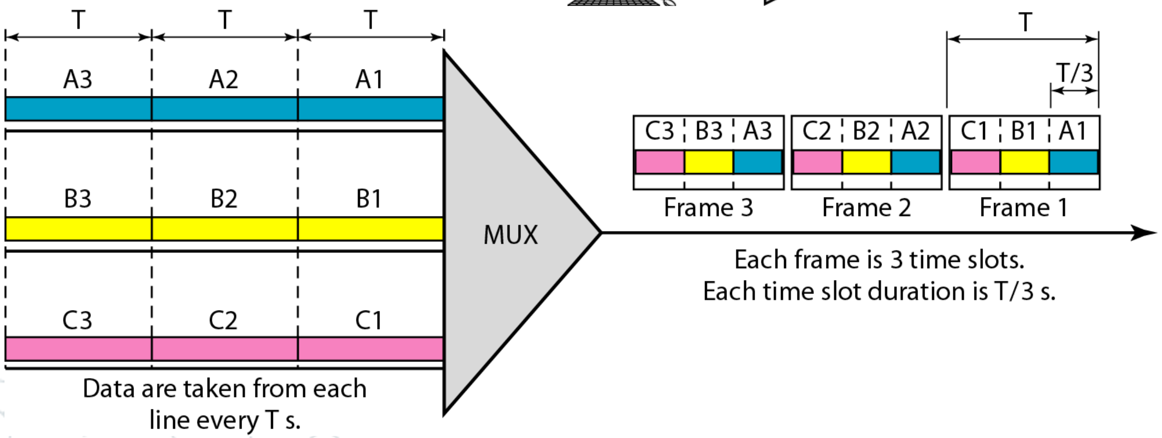


Multiple Access

Channelization: TDMA - Time Division Multiple Access

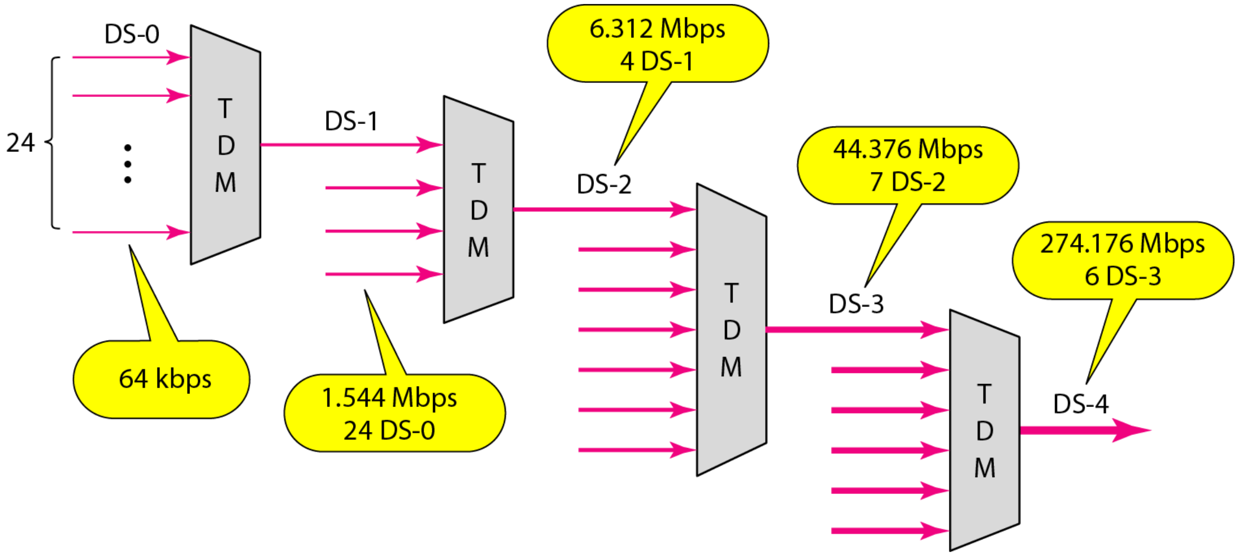
TDM is a digital multiplexing technique for combining several low-rate digital channels into one high-rate one.





Multiple Access

Channelization: TDMA - Digital Hierarchy



DS and T line rates

Service	*Line*	*Rate (Mbps)*	*Voice Channels*
DS-1	T-1	1.544	24
DS-2	T-2	6.312	96
DS-3	T-3	44.736	672
DS-4	T-4	274.176	4032

Multiple Access

Channelization: CDMA – Code Division Multiple Access

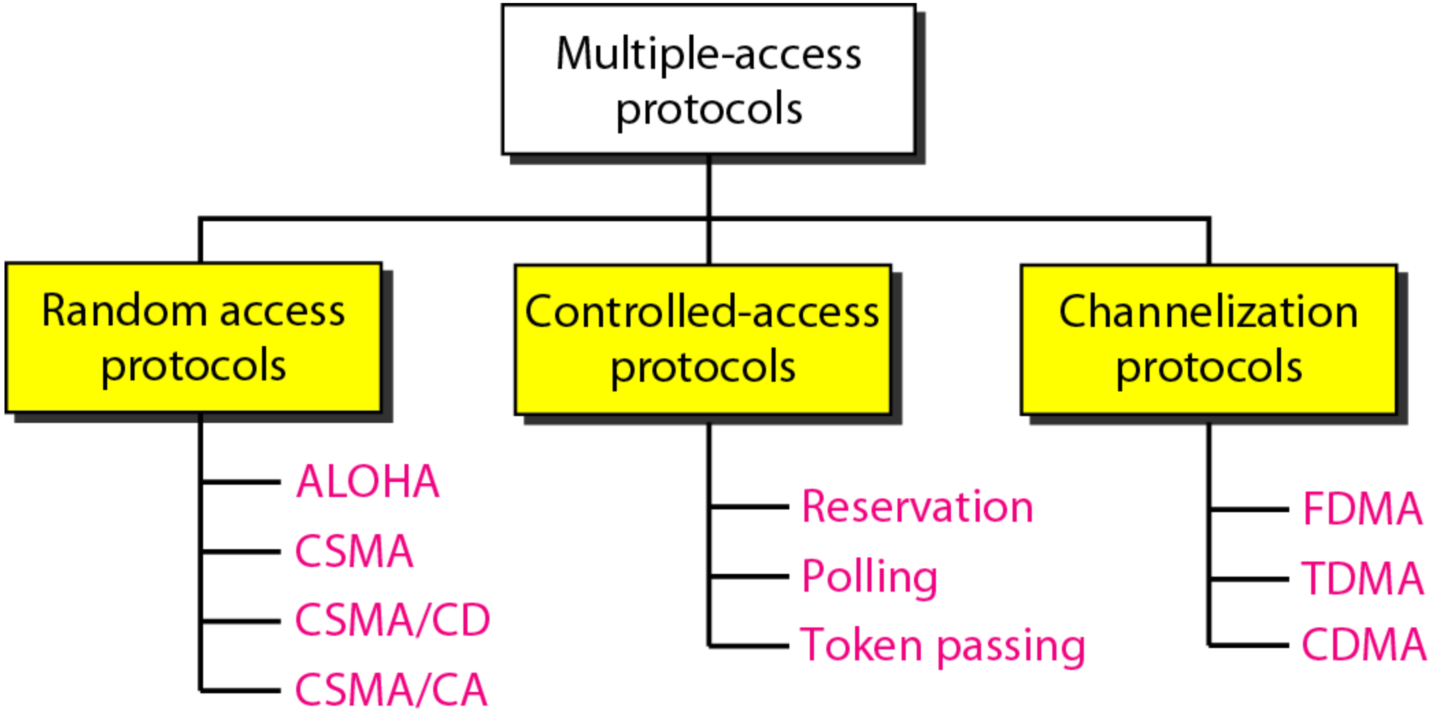
CDMA - code division multiple access, used in 3G mobile communications, the principle was first described in 1935 by the Soviet scientist D. Ageev.

CDM is used in parts of the cellular telephone system and for some satellite communication
– Cell phone version called Code Division Multi-Access (CDMA)
CDM does not rely on physical properties – such as frequency or time
CDM uses mathematical ideas based on orthogonal vectors

CDMA phones have a lower peak radiation power and therefore allow more economical battery consumption and are safer than GSM.

Multiple Access

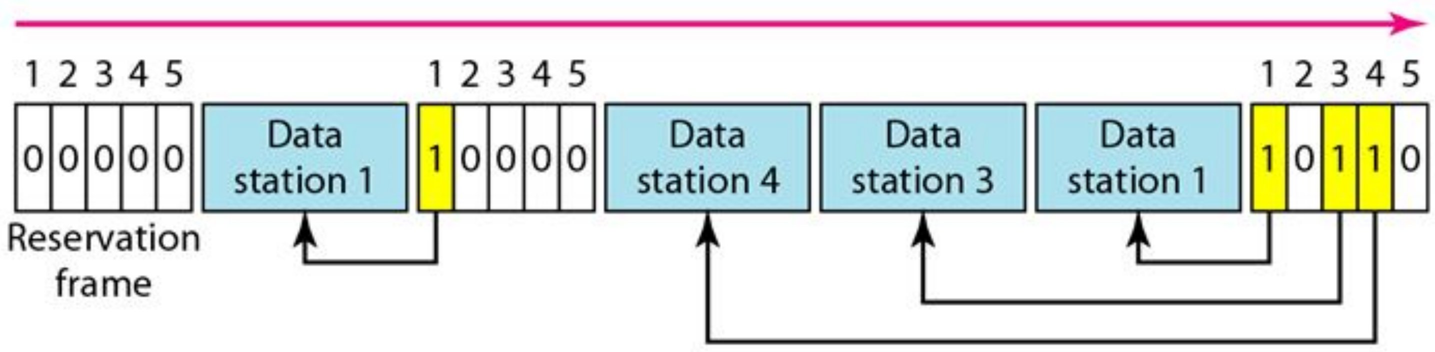
Multiple Access Protocols



Multiple Access

Controlled Access: Reservation

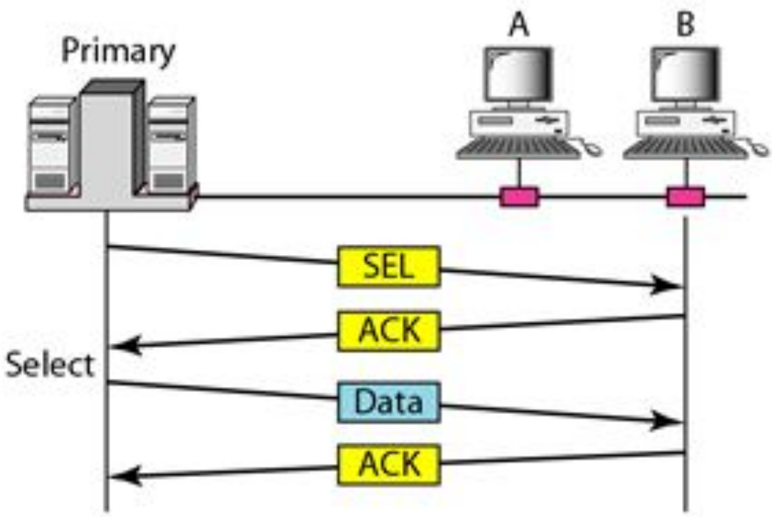
When a node needs to transmit data to the transmission medium, it places a bit in the mini-slot.
After a redundant frame, the node has the right to send data.
Reservation-station needs to make a reservation before sending data



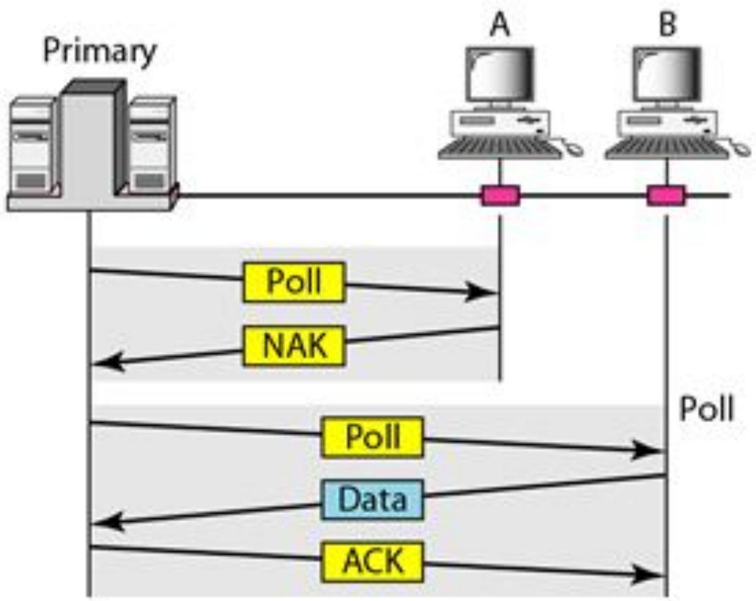
Multiple Access

Controlled Access: Polling

One device (primary, master, controller) polls and monitors the access of the other network devices.
Usually the topology of the network is a star or a bus.



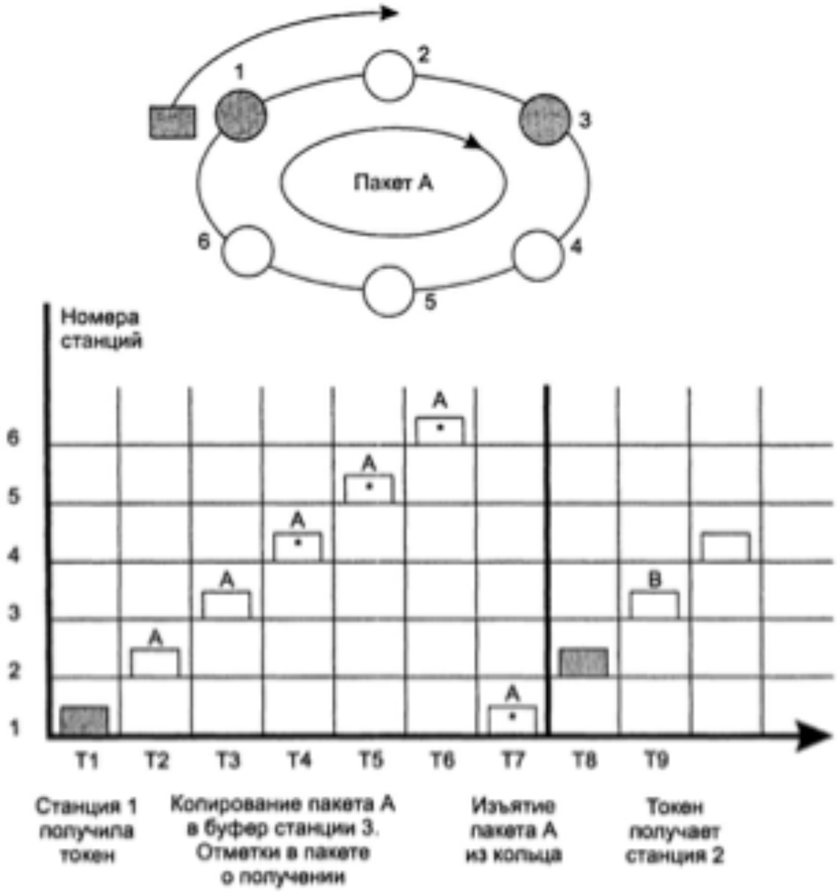
Transfer to the end node

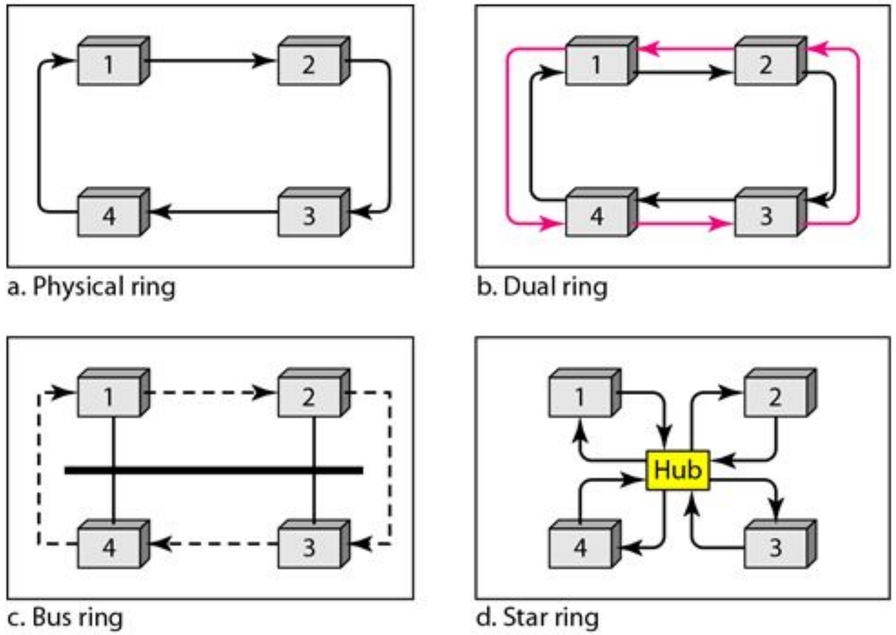


Requesting data from the node

Multiple Access

Controlled Access: Token Passing

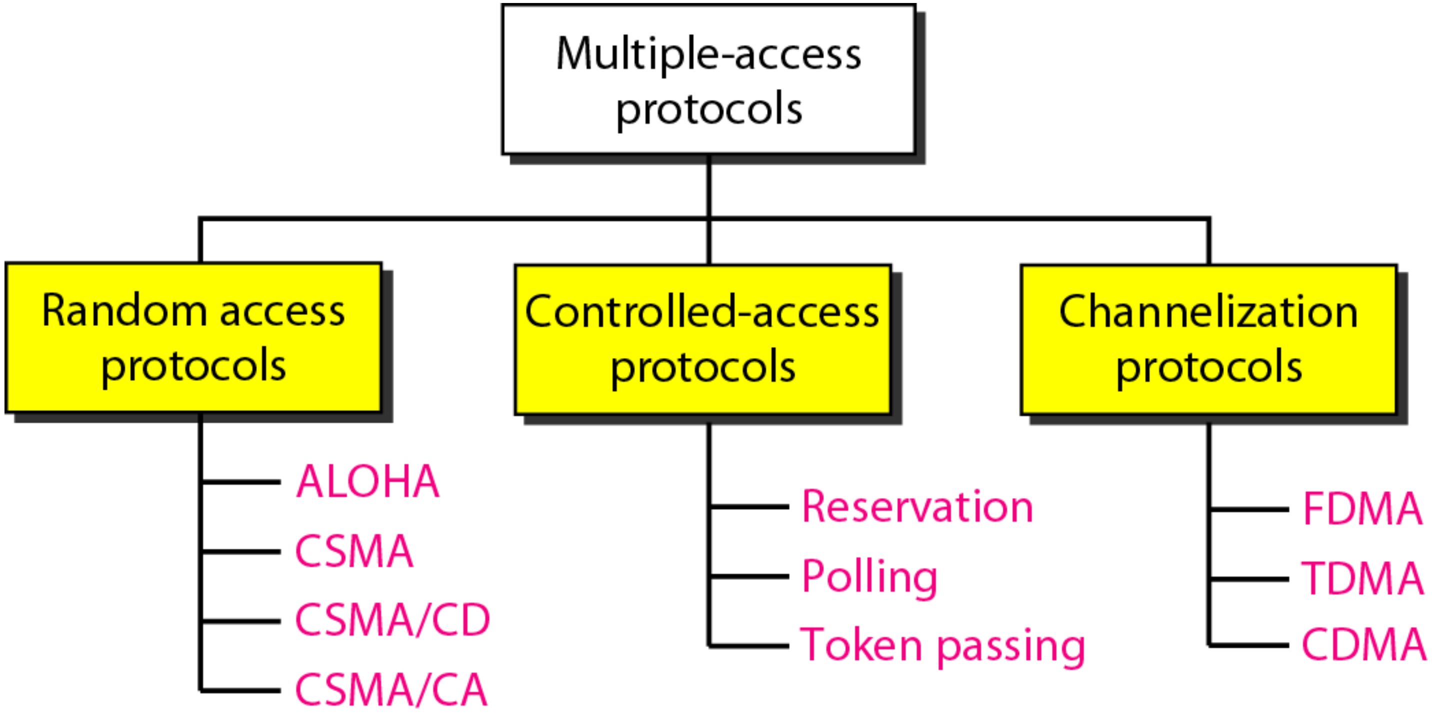




Chanel Throughput Utilization < 99 %.

Multiple Access

Multiple Access Protocols



Multiplexing & Medium Access

Dynamic Channel Allocation Technologies

1. Pure ALOHA
2. Slotted ALOHA
3. CSMA
4. CSMA/CD (old ETHERNET)
5. Switching (Fast ETHERNET)

Multiple Access

Random Access: ALOHA Protocols

Back in 1970, the University of Hawaii built a network out of radios that broadcast signals.

Basic idea

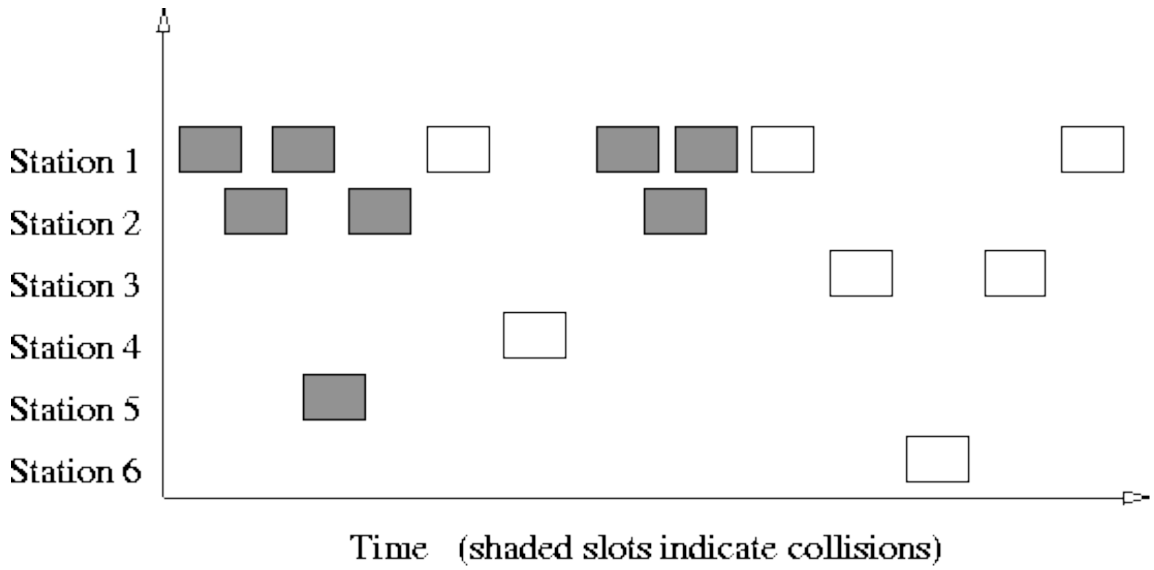
- Anyone may transmit whenever they want. (Continuous time model.)
- Each radio detects collisions by listening to its own signal. A collision is detected when a sender doesn't receive the signal that it just sent.
- After a collision, wait a random amount of time and transmit the same frame again. This technique is known as *backoff*.

Multiple Access

Random Access: Pure ALOHA

Rules

- If you have a packet, just send it.
- If is collision, then try resending it later!



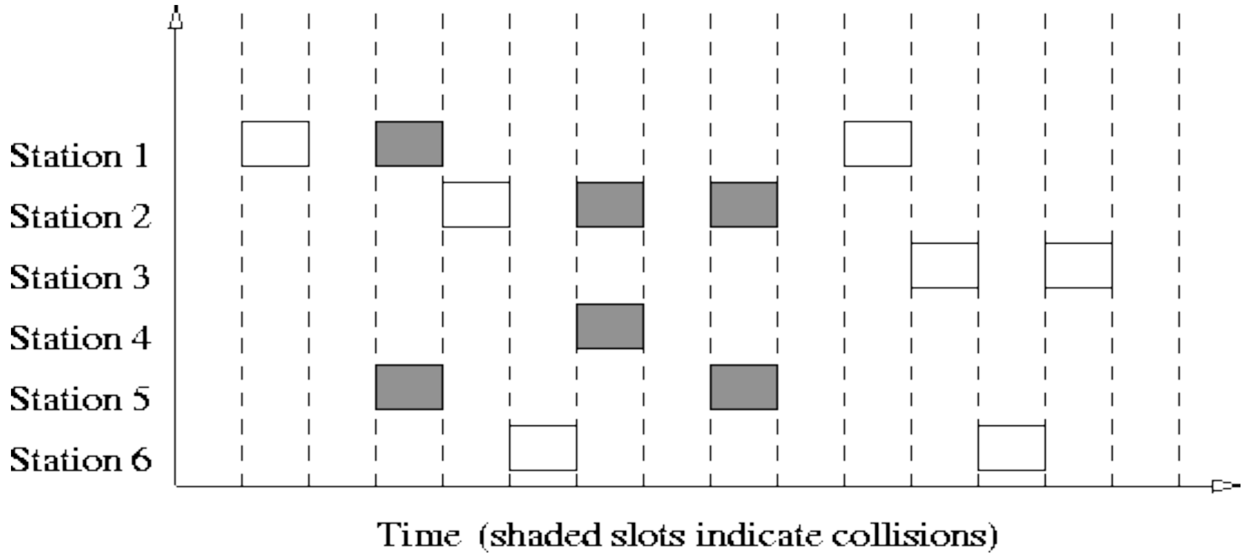
Chanel Utilization < 18,4 %.

Multiple Access

Random Access: Sloted ALOHA

Rules

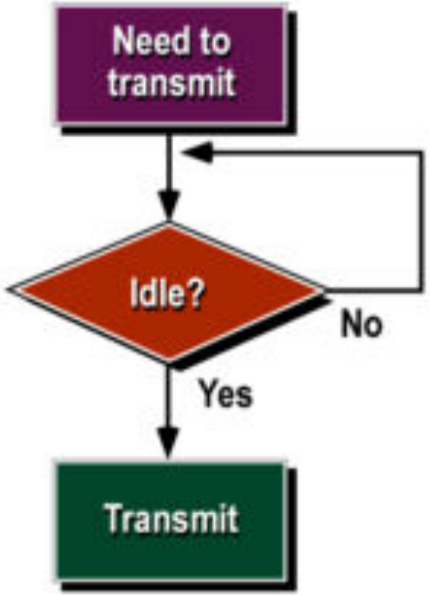
- Time is divided into slots… can only transmit at start of slot
- Vulnerable period halved => max. efficiency is doubled
- Requires sync of clocks
- Still poor at hi-loads



Chanel Utilization < 36,5 %.

Multiple Access

Random Access: CSMA - Carrier Sense Multiple

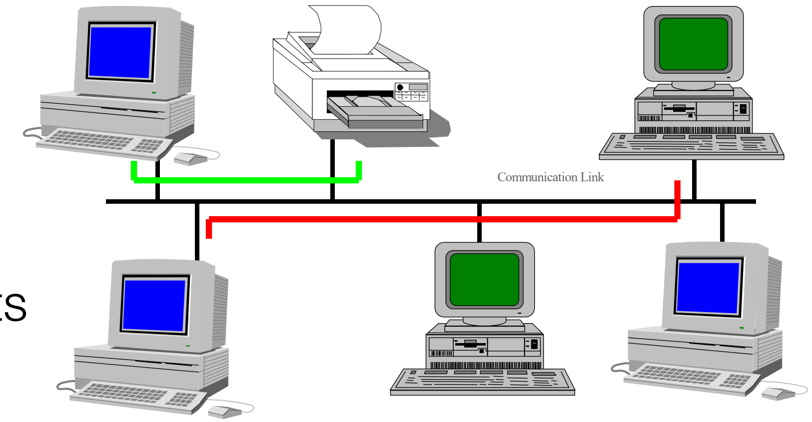


Idea

We can improve the performance of our simple network greatly if we introduce **carrier sensing** (CS).

Rules

- Ethernet uses cable as a shared medium
  – Nothing controls access to the medium.
- CSMA: listen before transmitting. A host will only transmit its own frames when it cannot hear any data being transmitted by other hosts.
  – If cable sensed idle: transmit a frame
  – If cable sensed busy: wait
- When a frame finishes, an interframe gap of about 9.6 μsec (microsecond) is allowed to pass before another host starts transmitting its frame.



Chanel Utilization < 30 %.

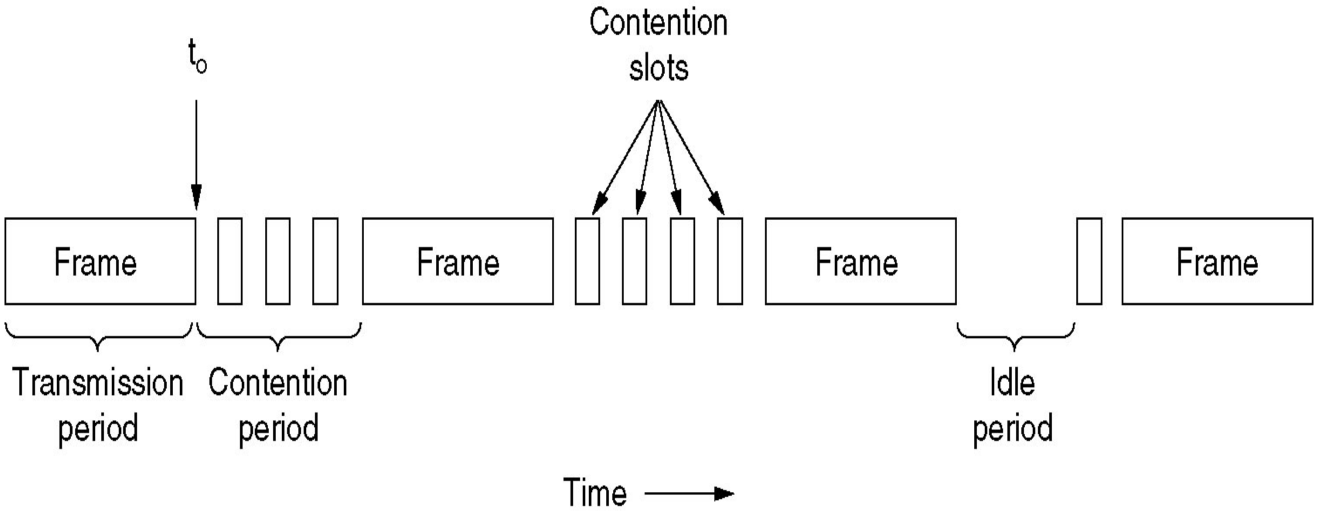
Multiple Access

Random Access: CSMA/CD - CSMA with Collision Detection

Problem CSMA: A collision can occur if two stations find the cable idle, and both start transmitting.

Rules CSMA/CD

- If adapter detects another transmission while transmitting, it aborts and sends jam signal
- Each adapter waits a random time and retransmits
- If another collision occurs, they double the maximum time and try again (*binary exponential backoff*)
- After 16 consecutive collisions, the network is considered faulty



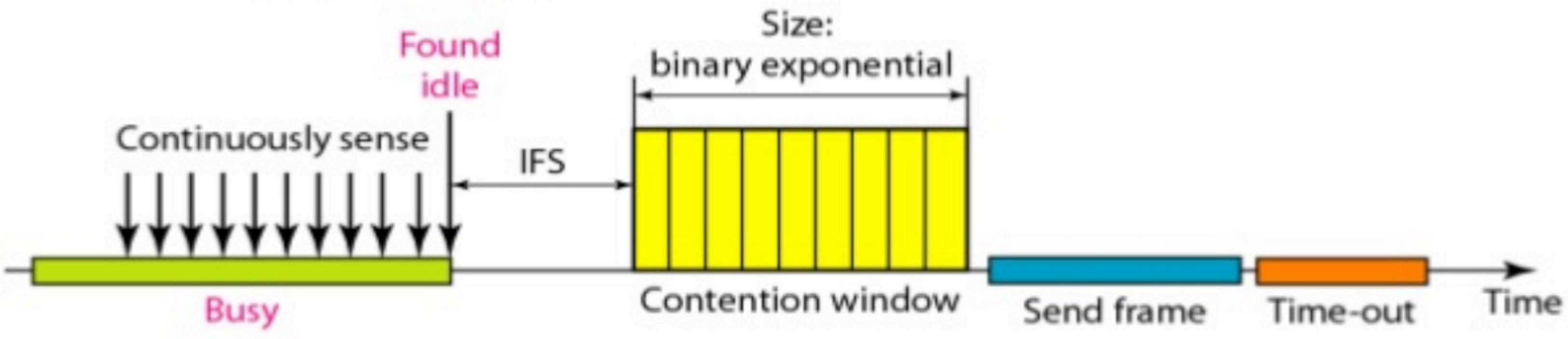
CSMA/CD can be in one of three states: contention, transmission, or idle.

Multiple Access

CSMA/CA – CSMA with Collision Avoidance

Used in a network where collision cannot be detected (example, wireless LAN IEEE802.11).
Collisions are avoided through following strategy:

- a carrier wave listening circuit is used
- the station that is about to start transmitting sends a jam-signal
- the station starts transmitting the frame
- if during transmission the station detects a jam-signal from another station, it stops the transmission for a period of time of a random length and then retries



IFS – Interframe Space

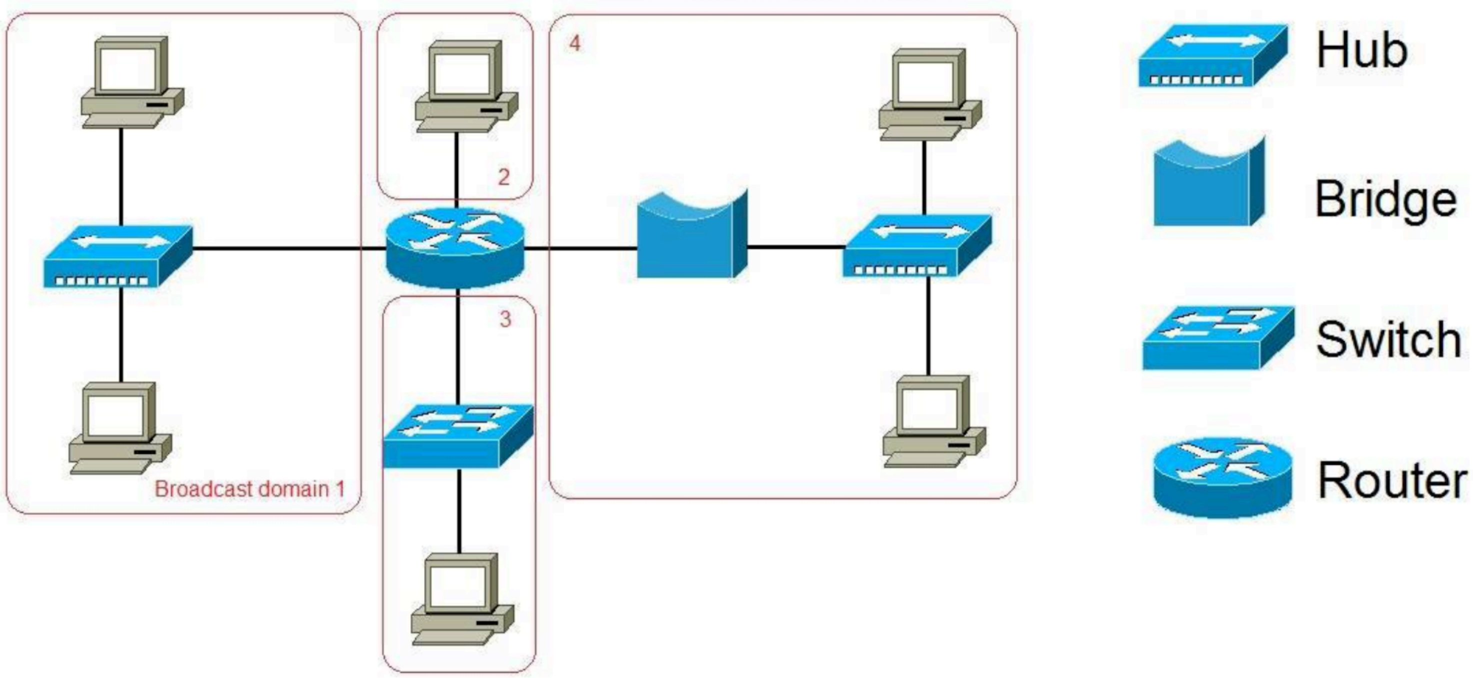
- CSMA CD takes effect after a collision while CSMA CA takes effect before a collision.
- CSMA CA reduces the possibility of a collision while CSMA CD only minimizes the recovery time

Multiple Access

Switching: no Collision Domain – no Problem

Concurrent media access systems (Ethernet LAN with hubs or wireless LAN) do not scale well with intensive use of the transmission medium.

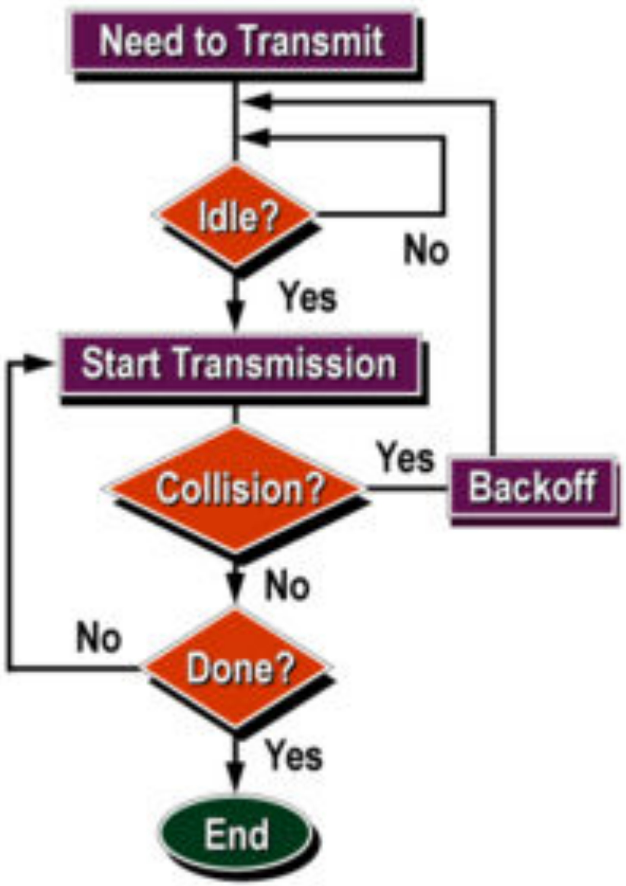
In new Ethernet networks with switches, concurrent media access is not used, since the switch and the host network card operate in full duplex mode and do not have other participants in the collision domain.



Multiple Access

Random Access: CSMA/CD - IEEE 802.3: Ethernet

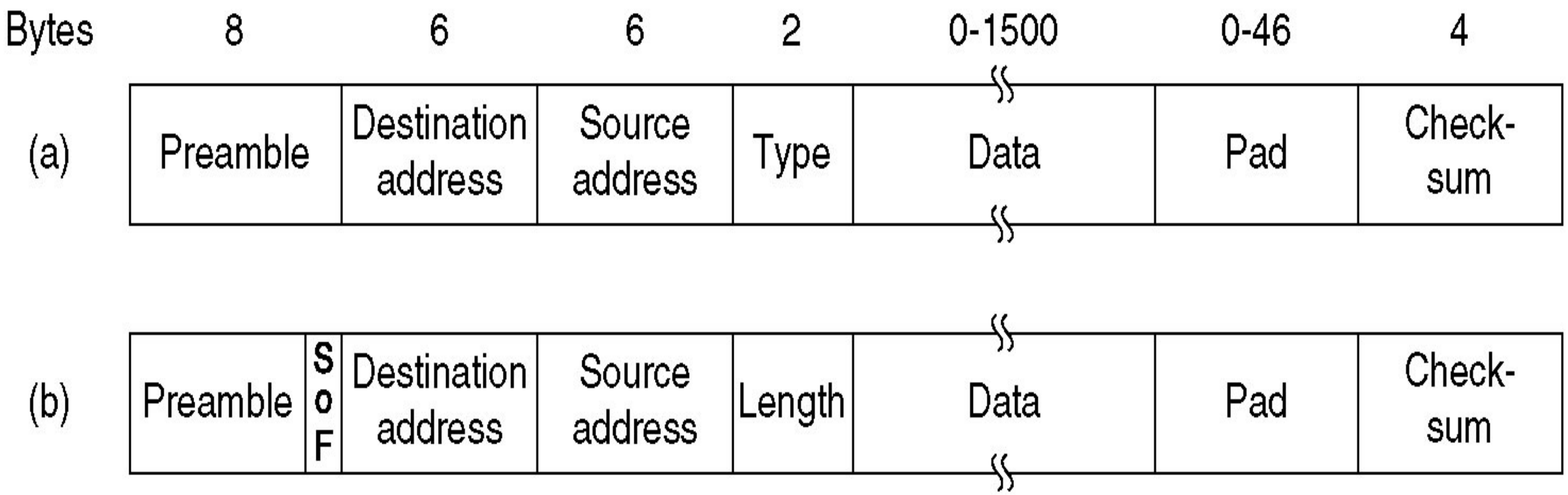
- The 802.3 standard describes the operation of the MAC sub-layer in a bus LAN that uses carrier sense, multiple access with collision detection (CSMA/CD).
- Beside carrier sensing, collision detection and the binary exponential back-off algorithm, the standard also describes the format of the frames and the type of encoding used for transmitting frames.
- The minimum length of frames can be varied from network to network. This is important because, depending on the size of the network, the frames must be of a suitable minimum length.
- The standard also makes some suggestions about the type of cabling that should be used for CSMA/CD bus LANs.
- *The CSMA/CD Bus LAN is also widely called Ethernet*.



Multiple Access

Random Access: CSMA/CD - IEEE 802.3: MAC Sub-layer Protocol

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



Multiple Access

Random Access: CSMA/CD - IEEE 802.3: MAC Addresses

- Every network card in the world has a unique 46-bit serial number called a MAC address. The IEEE allocates these numbers to network card manufacturers who encode them into the firmware of their cards.

- The destination and source address fields of the MAC frame have 48 bits set aside (the standard also allows for 16-bit addresses but these are rarely used).

- The most significant bit is set to 0 to indicate an ordinary address and 1 to indicate a group address (this is for multicasting, which means that frames are sent to several hosts). If all 48 bits are set to 1 then frames are broadcast to all the hosts.

- If the two most significant bits are both zero then the 46 least significant bits contain the MAC addresses of the source and destination hosts.

Multiple Access

Random Access: CSMA/CD - IEEE 802.3: Minimum Frame Length

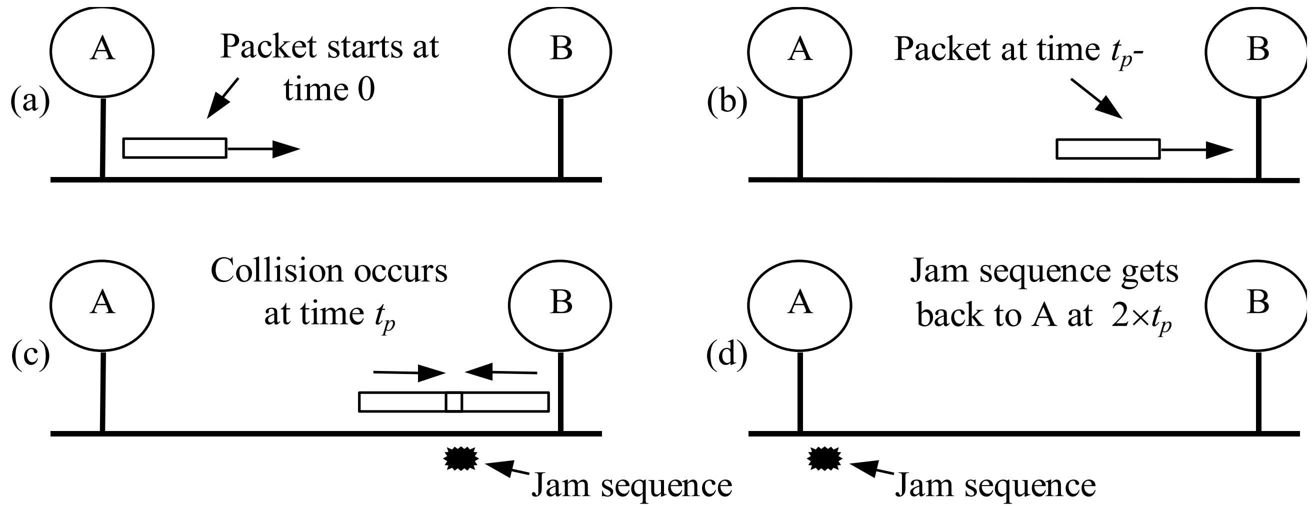
- When a host transmits a frame, there is a small chance that a collision will occur. The first host to detect a collision transmits a 48-bit jam sequence.
- To ensure that any hosts involved with the collision realise that the jam sequence is associate with their frame, they must still be transmitting when the jam sequence arrives. This means that the frame must be of a minimum length.
- The worse case scenario is if the two hosts are at far ends of the cable. If host A's frame is just reaching host B when it begins transmitting, host B will detect the collision first and send a jam signal back to host A.

- To ensure that no node may completely receive a frame before the transmitting node has finished sending it, Ethernet defines a minimum frame size (i.e. no frame may have less than 46 bytes of payload).
- The minimum frame size is related to the distance which the network spans, the type of media being used and the number of repeaters which the signal may have to pass through to reach the furthest part of the LAN.
- Together these define a value known as the Ethernet Slot Time, corresponding to 512 bit times at 10 Mbps.

Multiple Access

Random Access: CSMA/CD - IEEE 802.3: Minimum Frame Length

- The longest time between starting to transmit a frame and receiving the first bit of a jam sequence is twice the propagation delay from one end of the cable to the other.

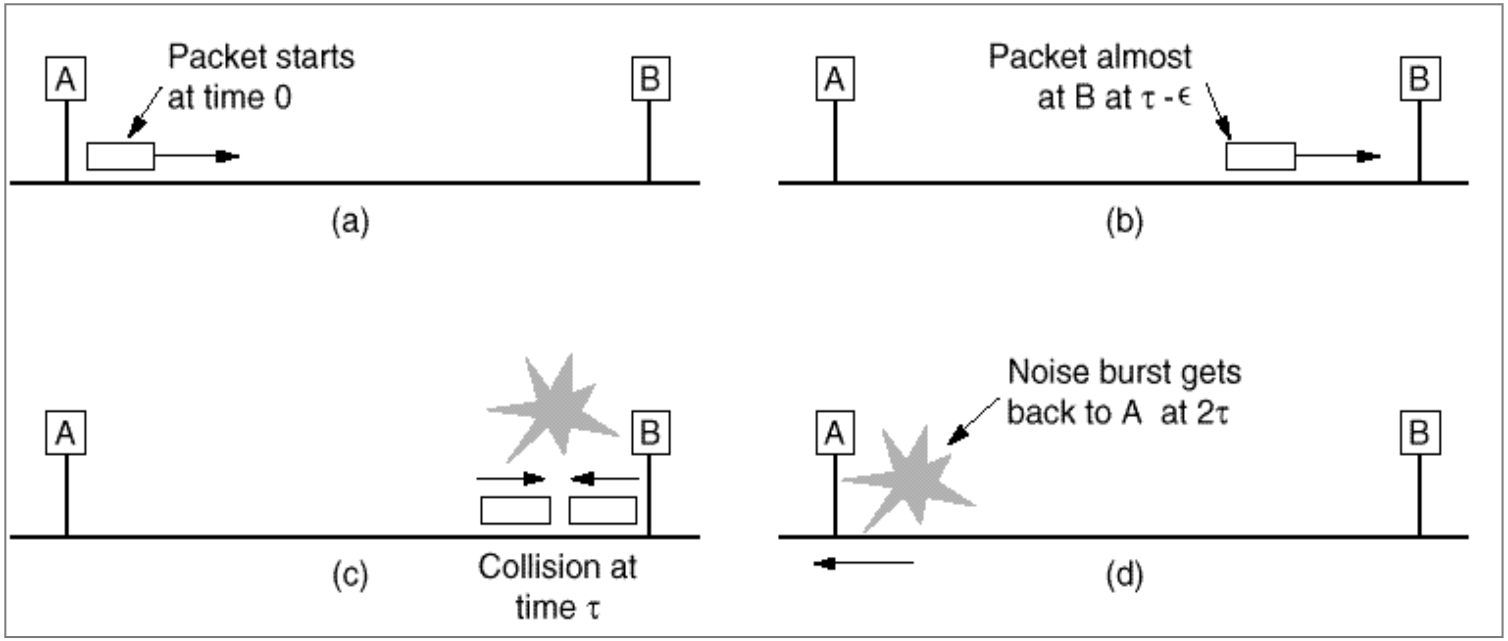


- This means that a frame must have enough bits to last twice the propagation delay.
- The 802.3 CSMA/CD Bus LAN transmits data at the standard rate of r = 10Mbps.
- The speed of signal propagation is about v = 2×108m/s..

Multiple Access

Random Access: CSMA/CD - IEEE 802.3: Minimum Frame Length

- In order to calculate the minimum frame length, we must first work out the propagation delay from one end of the cable to the other.



Collision detection can take as long as 2t

Multiple Access

Random Access: CSMA/CD - IEEE 802.3: Minimum Frame Length

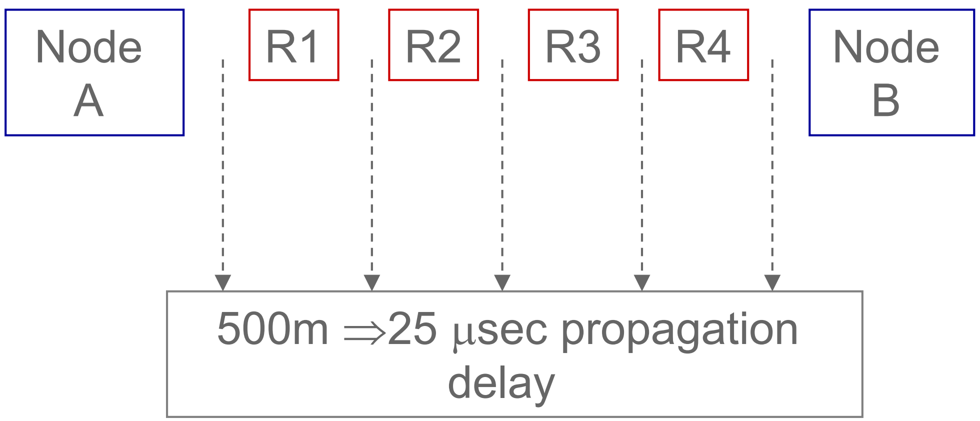
- The standard frame length is at least 512 bits (64 bytes) long, which is much longer than our minimum requirement of 64 bits (8 bytes).
- We only have to start worrying when the LAN reaches lengths of more than 2.5km.

- 802.3 CSMA/CD bus LANs longer than 500m are usually composed of multiple segments joined by in-line passive repeaters, which output on one cable the signals received on another cable.
- When we work out the minimum frame length for these longer LANs, we also have to take the delays caused by the passive repeaters (about 2.5μsec each) into account as well.

Multiple Access

Random Access: CSMA/CD - IEEE 802.3: Shortest Ethernet Frame

Why specify a shortest frame of 64byte?



- 64 bytes sent at 10Mbps ⇒ 51.2 μsec
- 500m/segment, 4 repeaters between nodes ⇒2500m ⇒25 μsec propagation delay
- The frame should be longer enough for sender to detect the collision (2x25 or about 50 μsec)