Wireless Technology

Wireless Communications

Basics – Part 2

Duplexing Scheme

- Point-to-point system of communication
  - Simplex
  - Half-duplex
  - Full-duplex
- Provide a separation of the send and receive signals
- Prohibits the self-interference

Time Division Duplex

- Alternate transmitting and receiving of data on a single frequency channel
- Times for transmitting and receiving are periodically alternating
- Separate uplink (UL) and downlink (DL) in time domain
- Asymmetric services using guard time

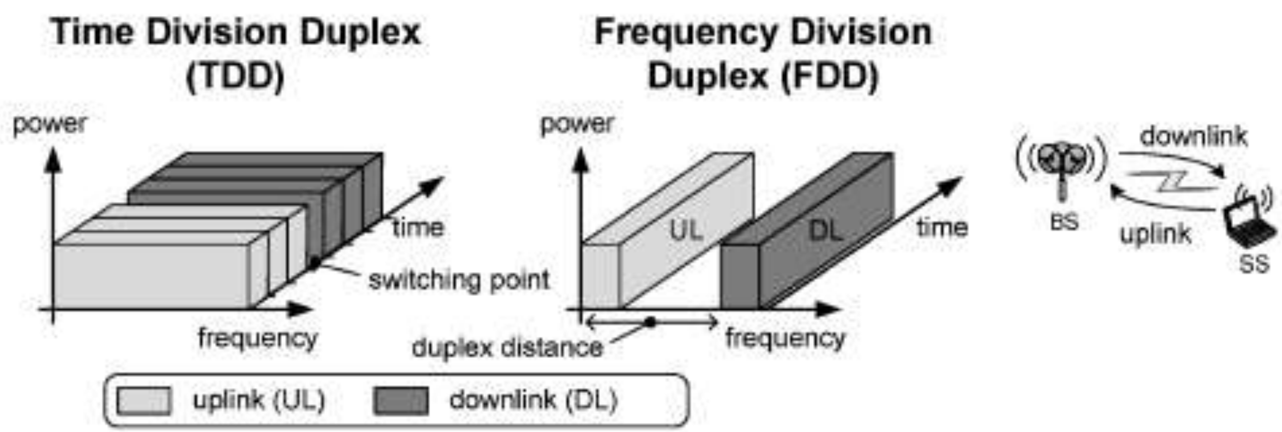
Frequency Division Duplex

- UL and DL are separated in the freq. domain
- Transmit and receive in different freq. band
- The frequency channel used by one station for transmitting is used by another station for receiving and vice versa.
- Upper frequency band is usually assigned to the base station to transmit in DL direction, as the pathloss of radio signals increases with frequency.

- The distance in MHz between paired frequency bands used with FDD is referred to as duplexing distance.
- Symmetric services
- GSM, UMTS, CMDA200, IEEE 802.16

Time/Freq. Division Duplex

Duplexing Schemes

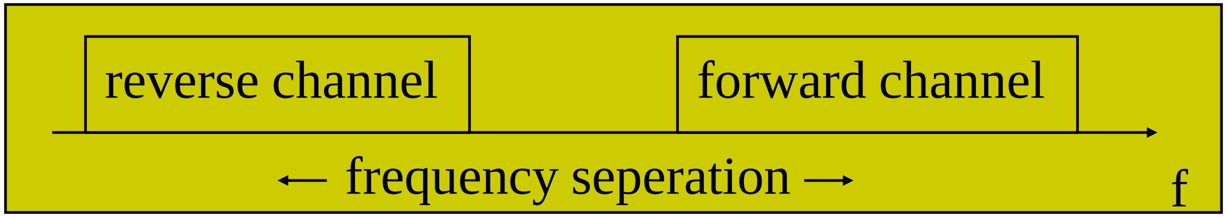


- Time Division Duplex: Switching point periodically separates a single frequency channel into UL and DL period – ideal for asymmetric services
- Frequency Division Duplex: DL and UL have different frequency bands of equal size – suitable for symmetric services but requires paired frequency bands

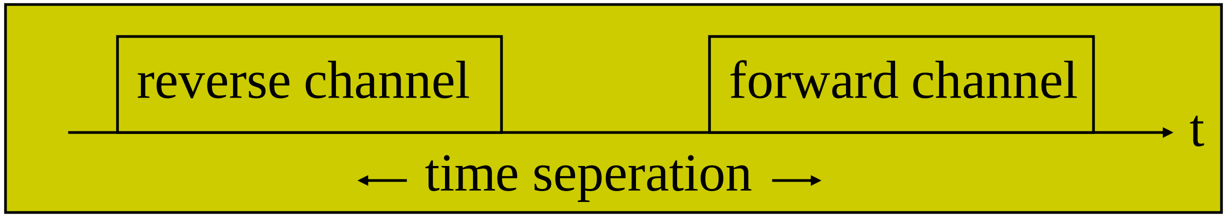
Figure 2.10 Duplexing schemes of time division and frequency division duplex.

Time/Freq. Division Duplex

- Frequency separation



- Time separation



Multiplexing

- Multiplexing serves to share the radio channel capacity between competing stations.
- A multitude of simultaneous transmission requests is multiplexed to a common channel
- A wireless medium → transmission resource, can bedivided into multiple dimensions:
  - Frequency,
  - Time
  - Code
  - Space.

- Access to a multiplexed resource is by means of a multiple access rule
- Multiplexing scheme and the multiple access rule are strongly related.
- IEEE 802.16 → TDD/TDMA/SDMA
- GSM → FDMA/TDMA/FDD
- UMTS → FDMA/CDMA/TDMA/TDD

Freq. Division Multiplex

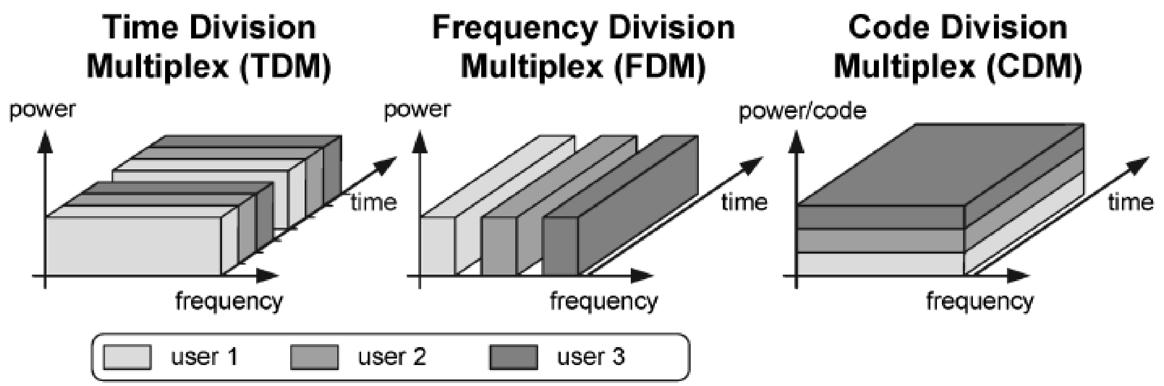
- Spectrum is divided into frequency channels that each may be simultaneously used by multiple users
- The transmission signals of multiple stations are separated in the frequency domain.
- A single station may transmit and receive on a dedicated frequency channel
- Allow multiple access → FDMA

Freq. Division Multiplex

- The partitioning of spectrum into frequency channels → Modulation
- At the receiver, a separation of stations' signals → filtering.
- Guard bands are required between channels in order to avoid adjacent channel interference between neighboring frequency bands.
- Implies many guard bands and thus spectral inefficiency.
- FDM is usually combined with another multiplexing scheme for separating users such as CDM or TDM.

Multiplexing Scheme

Multiplexing Schemes



- Application examples:
- Time Division Multiplex: IEEE 802.16, GSM, DECT
- Frequency Division Multiplex: UMTS
- Code Division Multiplex: UMTS, CDMA 2000

Figure 2.11 Time, frequency and code division multiplexing schemes.

Time Division Multiplex

- The capacity of a frequency channel may be higher than required for a single communication link and therefore may be divided in the time domain among several stations.
- The stations sequentially transmit on a common frequency channel that is separated into periodic time slots forming time channels
- The assignment of time slots to stations may be under central or decentral control according to a multiple access rule (TDMA)
- Time slots might not be periodic in time but might be considered as individual time slots each accessed according to a Medium Access Control (MAC) protocol

TDM

- The complete capacity of a frequency channel may be used by a single station under TDMA, which allows great flexibility in assigning capacity to specific stations.
- The separation of the wireless medium into time slots may lead again to inefficient channel utilization if the data packets do not completely fill a time slot. The available capacity per station is lower than the overall system capacity.

Code Division Multiplex

- Radio signal of small bandwidth is transmitted in a wide frequency channel. The small bandwidth signal is spread through an adequate code to become a wide bandwidth signal.

- User signals are separated at the receiver through correlating the received signal with the channel specific code sequence.
- Access to CDM channels is under control of the CDMA rules specifying the available codes.

- The number of stations transmitting in the same frequency channel is also limited in CDM: With an increasing number of code channels per frequency channel, the signal-to-noise ratio (SNR) is increased and the required threshold for successful decoding at the receiver might not be reached.

Code Division Multiplex

- Each **mobile device** is assigned a unique 64-bit code
- To send a binary 1, a mobile device transmits the unique code
- To send a binary 0, a mobile devices transmits the inverse of the code
- Receiver gets summed signal, multiplies it by receiver code, adds up the resulting values
  - Interprets as a binary 1 if sum is near +64
  - Interprets as a binary 0 if sum is near -64

Code Division Multiplex

- For simplicity, assume 8-bit code
- Example
  - Three different mobile devices use the following codes:
    - Mobile A: 10111001
    - Mobile B: 01101110
    - Mobile C: 11001101
  - Assume Mobile A sends a 1, B sends a 0, and C sends a 1
  - Signal code: 1-chip = +N volt; 0-chip = -N volt

Code Division Multiplex

- Example (continued)
  - Three signals transmitted:
    - Mobile A sends a 1, or 10111001, or +−+++−−+
    - Mobile B sends a 0, or 10010001, or +−−+−−−+
    - Mobile C sends a 1, or 11001101, or ++−−++−+
  - Summed signal received by base station: +3, -1, -1, +1, +1, -1, -3, +3

Code Division Multiplex

- Example (continued)
  - Base station decode for Mobile A:
    - Signal received: +3, -1, -1, +1, +1, -1, -3, +3
    - Mobile A’s code: +1, -1, +1, +1, +1, -1, -1, +1
    - Product result: +3, +1, -1, +1, +1, +1, +3, +3
  - Sum of Products: +12
  - Decode rule: For result near +8, data is binary 1

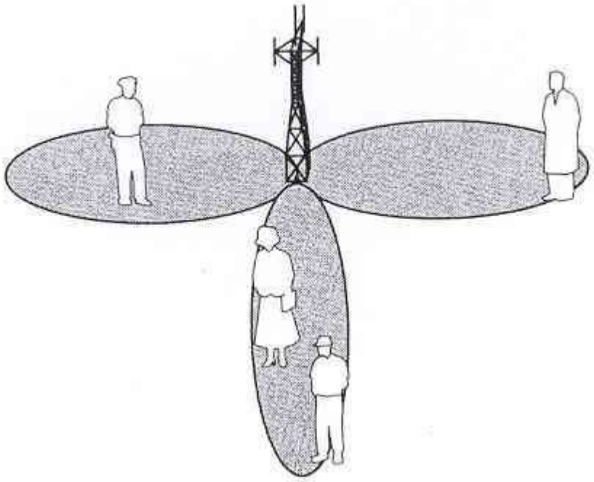
Code Division Multiplex

- Example (continued)
  - Base station decode for Mobile B:
    - Signal received: +3, -1, -1, +1, +1, -1, -3, +3
    - Mobile A’s code: -1, +1, +1, -1, +1, +1, +1, -1
    - Product result: -3, -1, -1, -1, +1, -1, -3, -3
  - Sum of Products: -12
  - Decode rule: For result near -8, data is binary 0

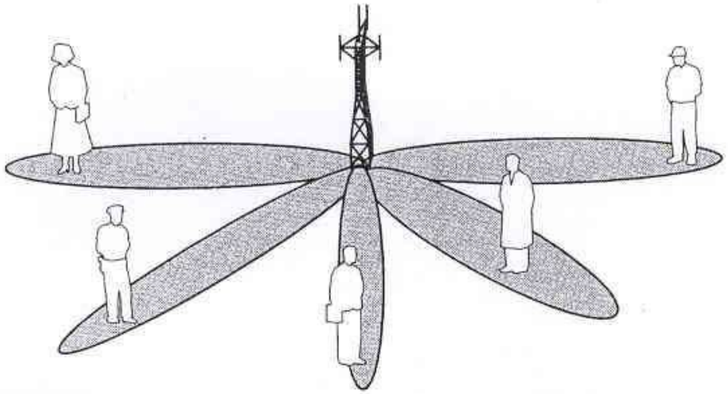
Space Division Multiplex

- Controls radiated energy for each user in space
- using spot beam antennas
- Base station tracks user when moving
- If receive stations are located close by, spatial separation is difficult to realize. Space Division
- Accessed by multiple stations at the same time.

- primitive applications are "Sectorized antennas"



- in future adaptive antennas simultaneously steer energy in the direction of many users at once



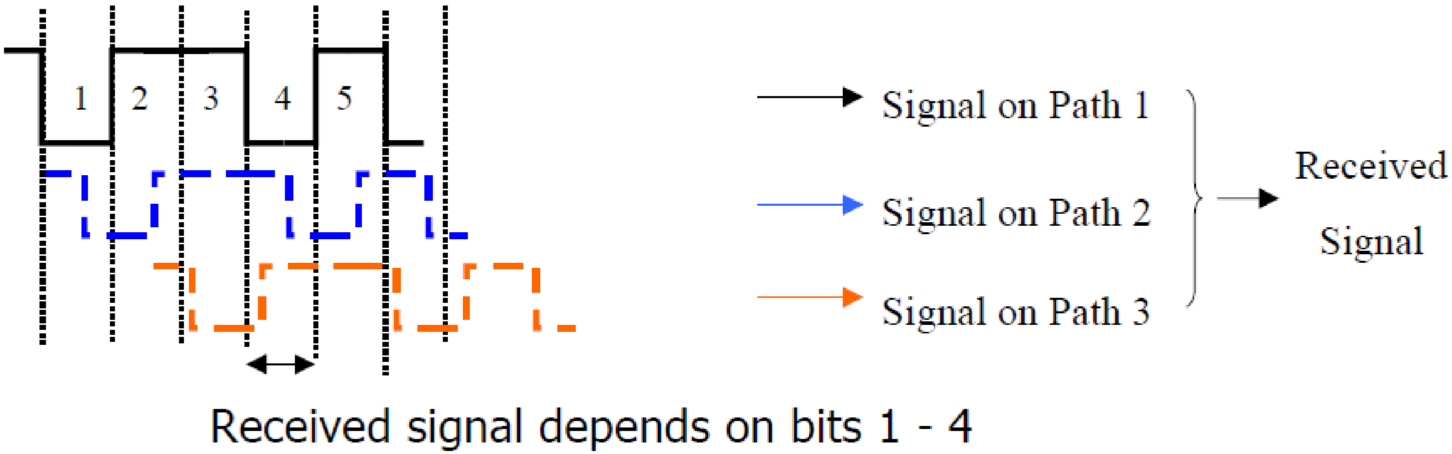
Orthogonal FDM

- The concept of using parallel data transmission by means of frequency division multiplexing (FDM) was published in mid 60s
- Some early development can be traced back in the 50s. A U.S. patent was filled and issued in January, 1970
- In the 1980s, OFDM has been studied for high-speed modems

Orthogonal FDM

- Transmit data by dividing the high symbol rate stream into several parallel low symbol rate streams
- OFDM is the basis for many wireless communication technologies because of its immunity against multipath
- The symbol duration of each substream is aimed to be higher than the channel delay spread and the maximum excess delay of delayed signals, and these parameters define the number of subcarriers to be used in a channel.

Orthogonal FDM

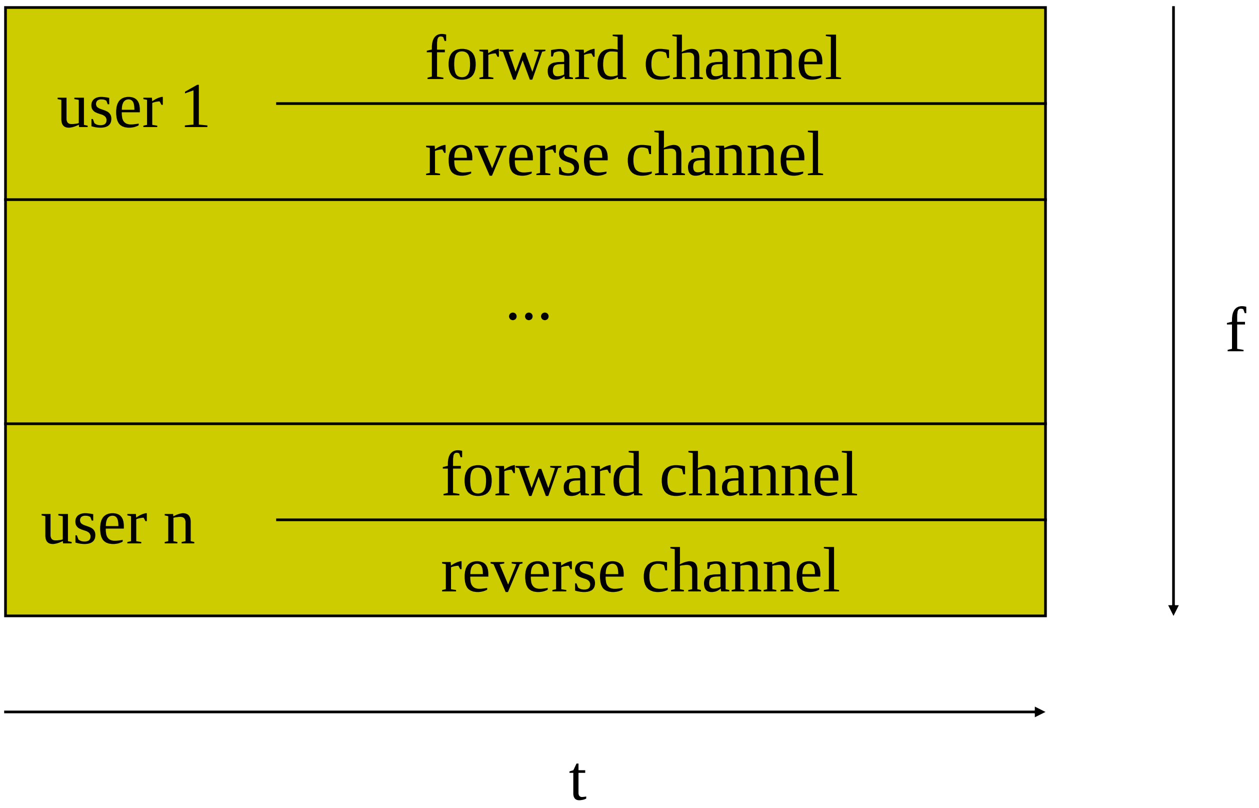


- Received signal at any time depends on a number of transmitted bits
  - Intersymbol Interference (ISI)

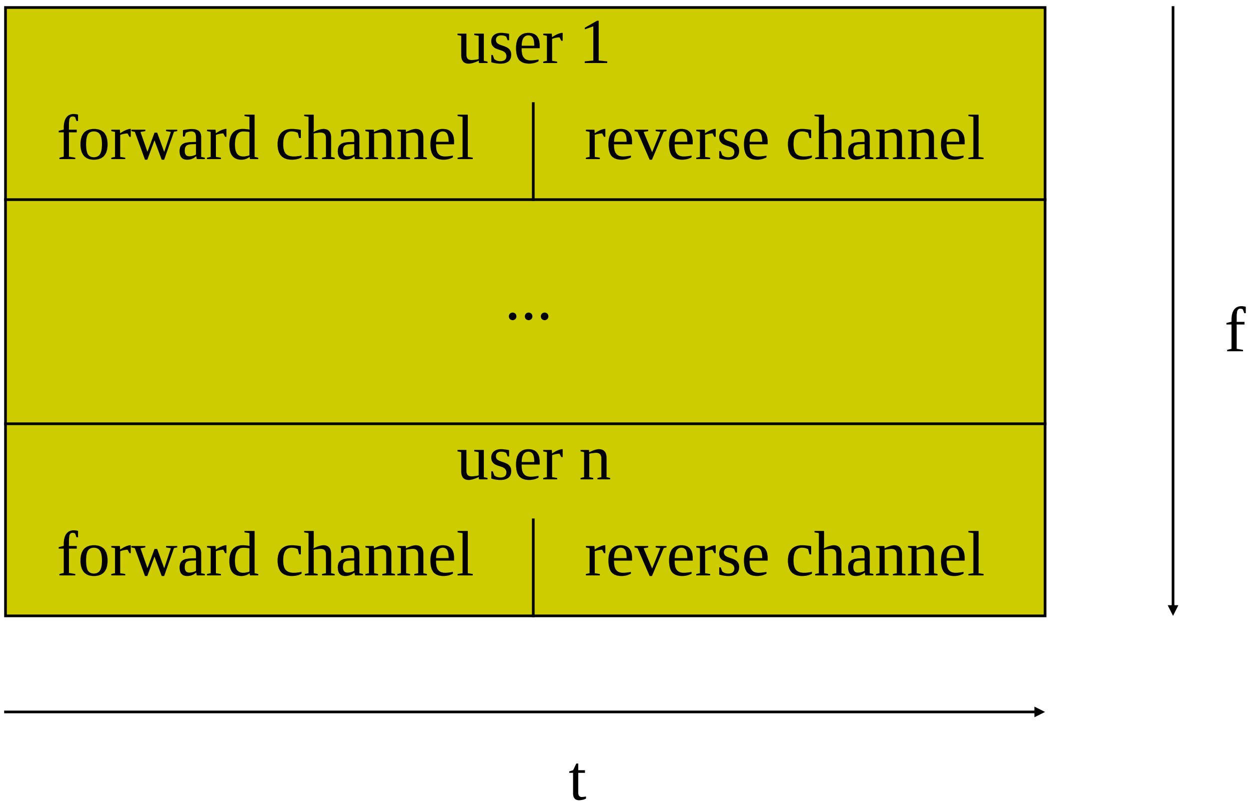
Multiple Access Techniques in use

Cellular System	Multiple Access Technique
Advanced Mobile Phone System (AMPS)	FDMA/FDD
Global System for Mobile (GSM)	TDMA/FDD
US Digital Cellular (USDC)	TDMA/FDD
Digital European Cordless Telephone (DECT)	FDMA/TDD
US Narrowband Spread Spectrum (IS-95)	CDMA/FDD

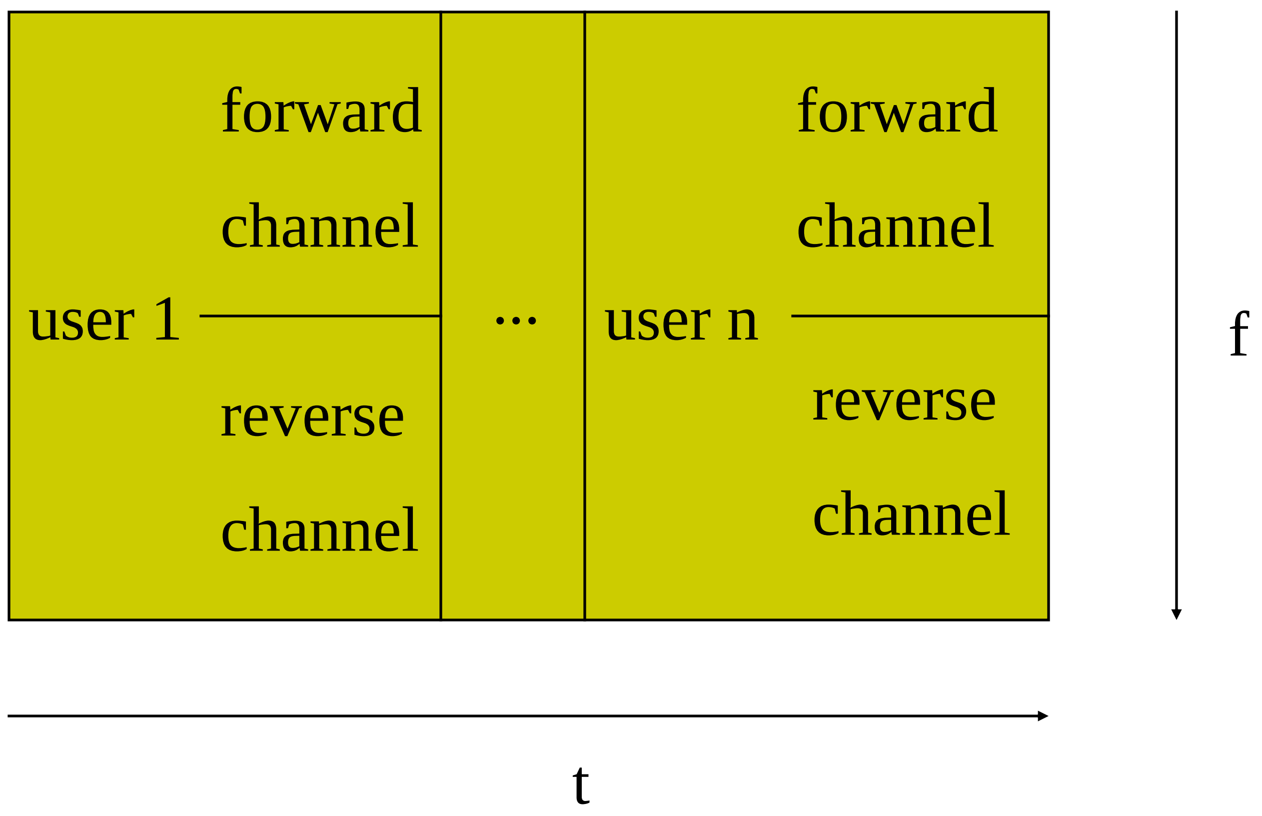
Logical separation FDMA/FDD



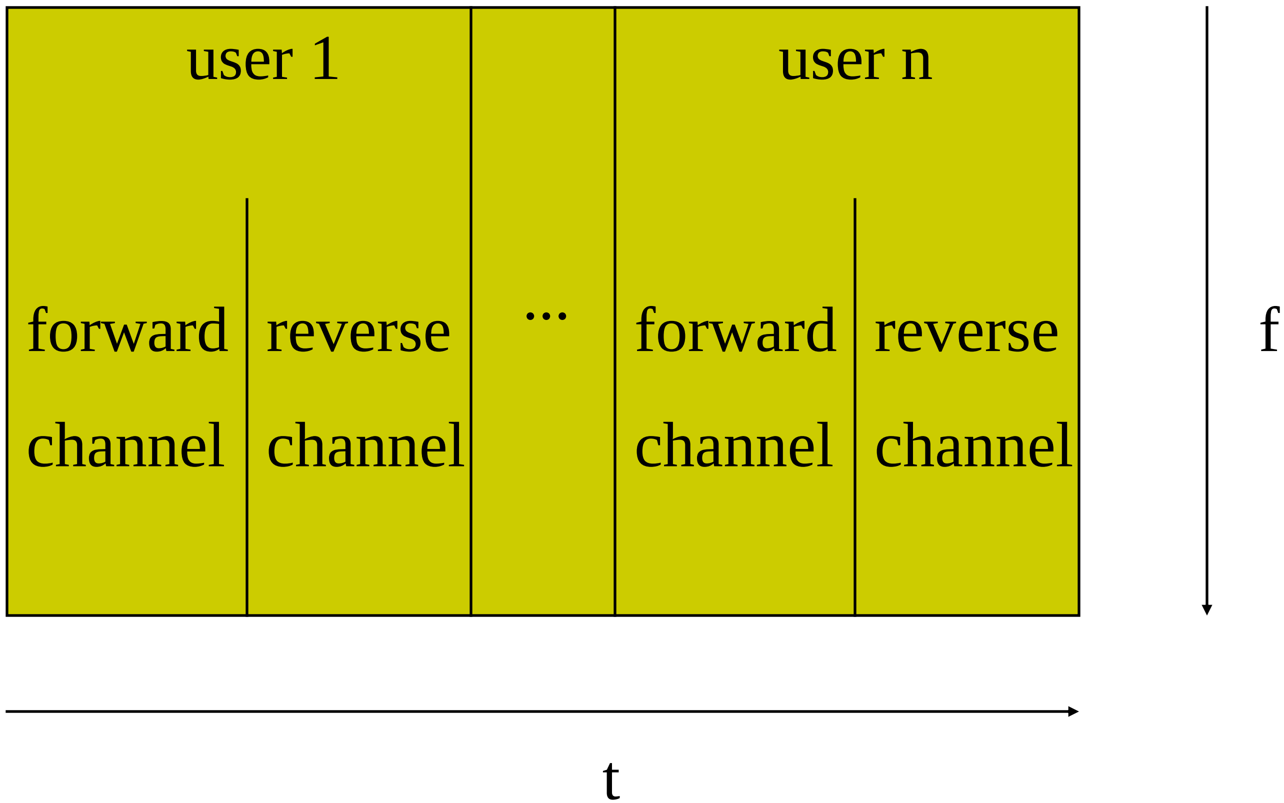
Logical separation FDMA/TDD



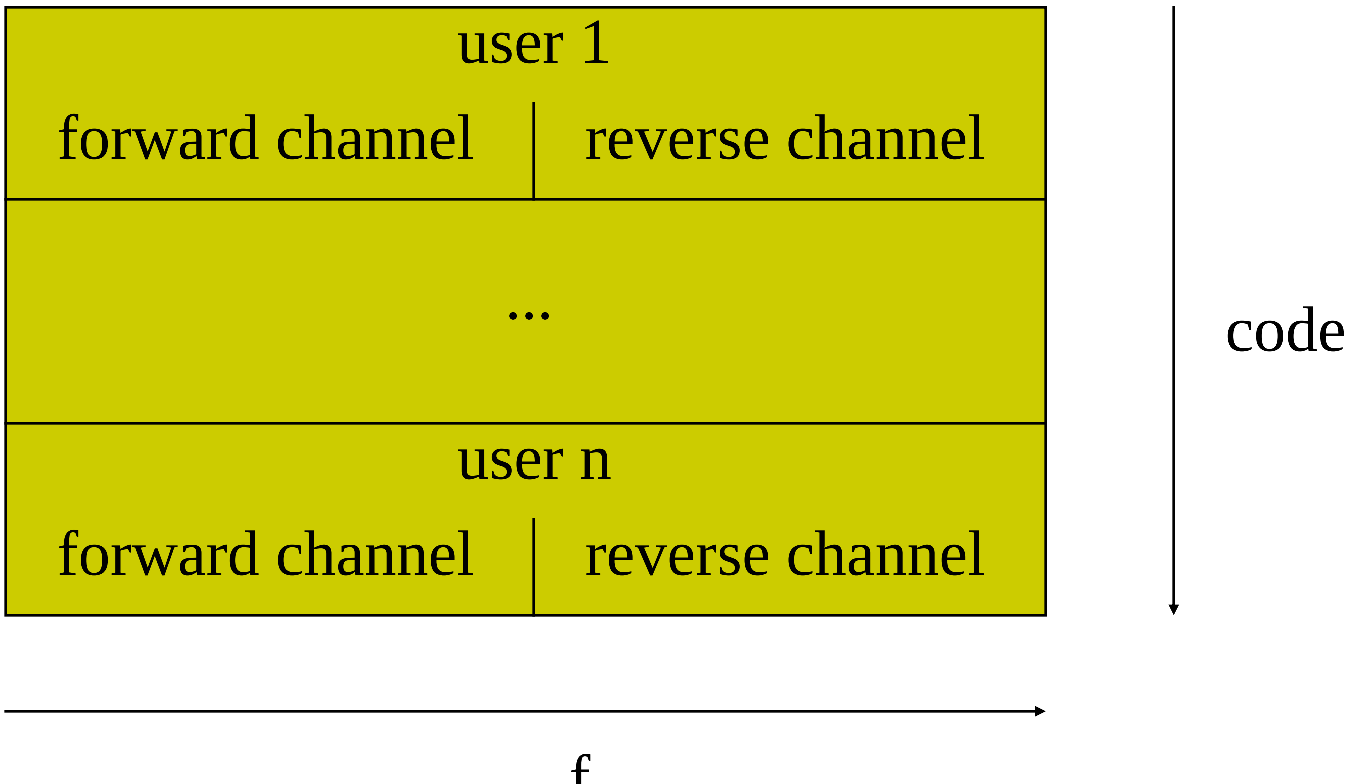
Logical separation TDMA/FDD



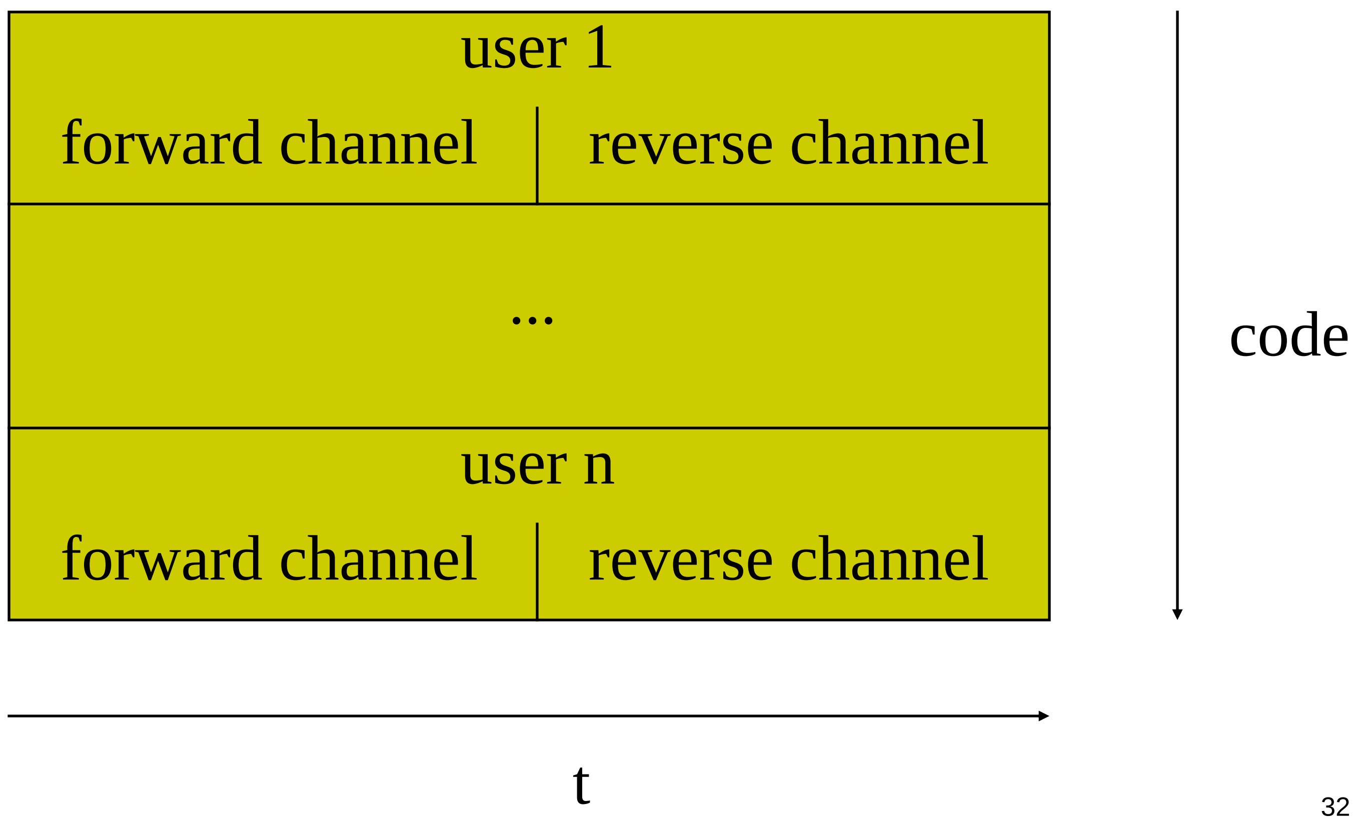
Logical separation TDMA/TDD



Logical separation CDMA/FDD



Logical separation CDMA/TDD



Switching in Telecommunication

- Basically there are two type of switching:
  - Circuit Switching
  - Packet Switching

Circuit Switching

- A dedicated communication link (source to sink), based on:
  - Frequency
  - Time
  - Code
- Management function is required to establish and terminate connection
- Most IEEE 802 systems use reservation-based transmission – short live duration of the channel reserved.

Packet Switching

- Communication is based on data segmented into packets for transmission
- Each packet has to compete on its own for medium access – cause considerable initial access delay
- May drop some packets due to congestion
- Flow control is required

Forward Error Correction

- The correction of transmission errors with the help of channel coding is called Forward Error Correction (FEC).
- Redundancy is added by the sender to the data packet to allow the receiver to correct errors
- The codes used for FEC
  - linear block codes
  - convolutional codes.

Automatic Repeat Request

- Systematic redundancy at the transmitter in order to detect errors at the receiver, not to directly correct them
- Based on error detection (CRC/FCS) and request repeated transmission
- Requires acknowledgment which imply to the flow control

ARQ Protocols

- Send-and-Wait
- Go-back-N
- Selective-Reject

Send-and-Wait

- The simplest but inefficient
- Also known as Stop-and-Wait ARQ
- Both stations have window size of 1
- Throughput is very low, which given by:

$$S_{SW} = \frac{n \cdot (1 - PER)}{n + t_{rd} \cdot v},$$

Go-back-N

- Leads to a continuous data flow on the channel
- Also known as Reject-ARQ, Cumulative ARQ or Continuous ARQ.
- Retransmits all packets starting from the packet number specified in the NACK message
- Requires a sufficiently large buffer size at the sender
- Throughput given by

$$S_{GBN} = \frac{n \cdot (1 - PER)}{n + PER \cdot t_{rd} \cdot v}.$$

Selective-Reject

- Similar to Go-back-N, permits continuous transmission
- Sends a reject message to the sender identifying error of selected packet.
- All packets with sequence numbers higher than the rejected one must wait in the receiver buffer
- Also known as Selective-Repeat ARQ
- Throughput given by:

$$S_{SR} = 1 - PER.$$

ARQ Protocols

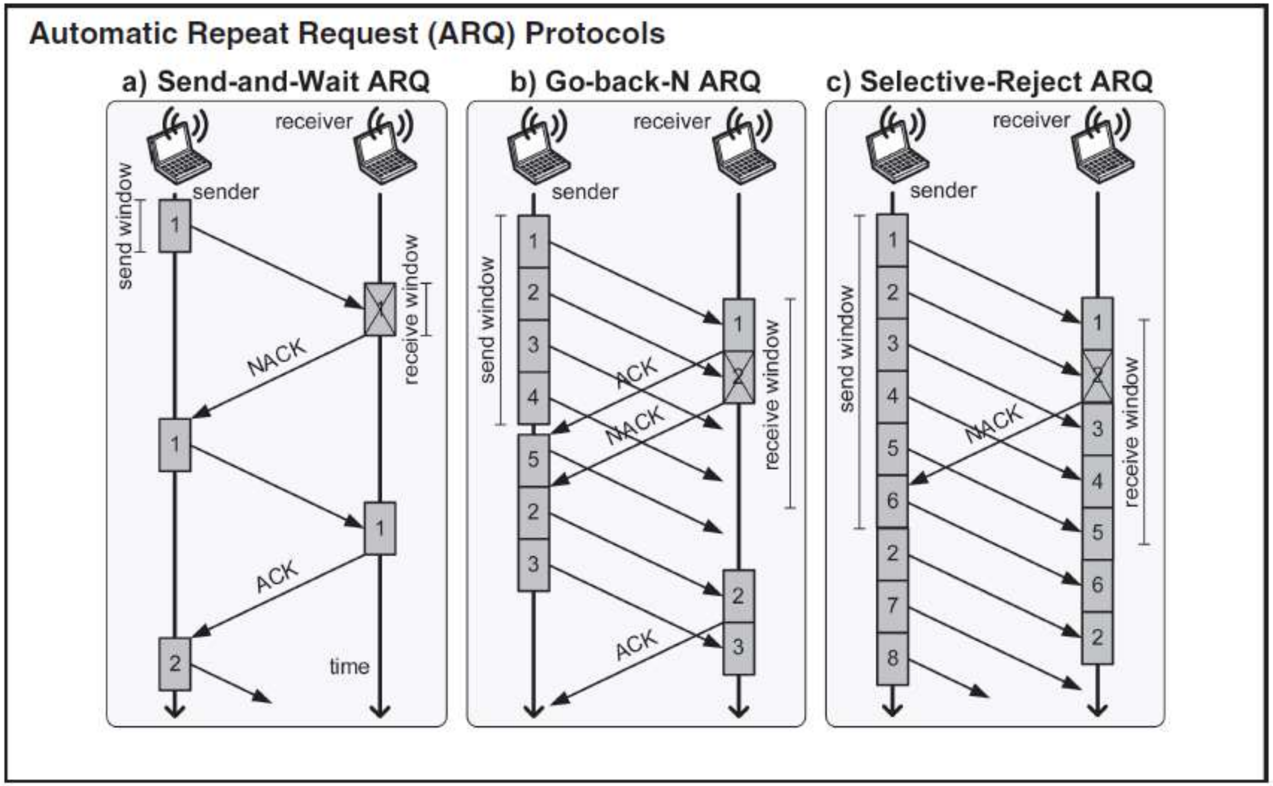
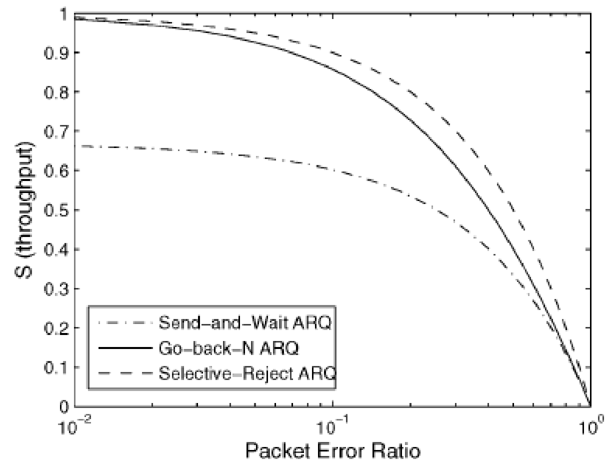


Figure 2.14 Different versions of Automatic Repeat Request (ARQ) protocols. (a) The Send-and-Wait ARQ. (b) Go-back-N ARQ. (c) Selective-Reject ARQ.

ARQ Protocols Throughput

Automatic Repeat Request Protocol – Normalized Throughput



- Packet size is 1514 byte; channel has capacity of 6 Mbit/s
- Send-and-Wait ARQ has lowest throughput
- Throughput of Go-back-N ARQ reflects retransmissions of complete packet sequences
- Selective-Reject ARQ has highest throughput - only selective retransmission

Figure 2.15 Normalized throughput of Send-and-Wait ARQ, Go-back-N ARQ and Selective-Reject ARQ is dependent on the packet error ratio.

CSMA

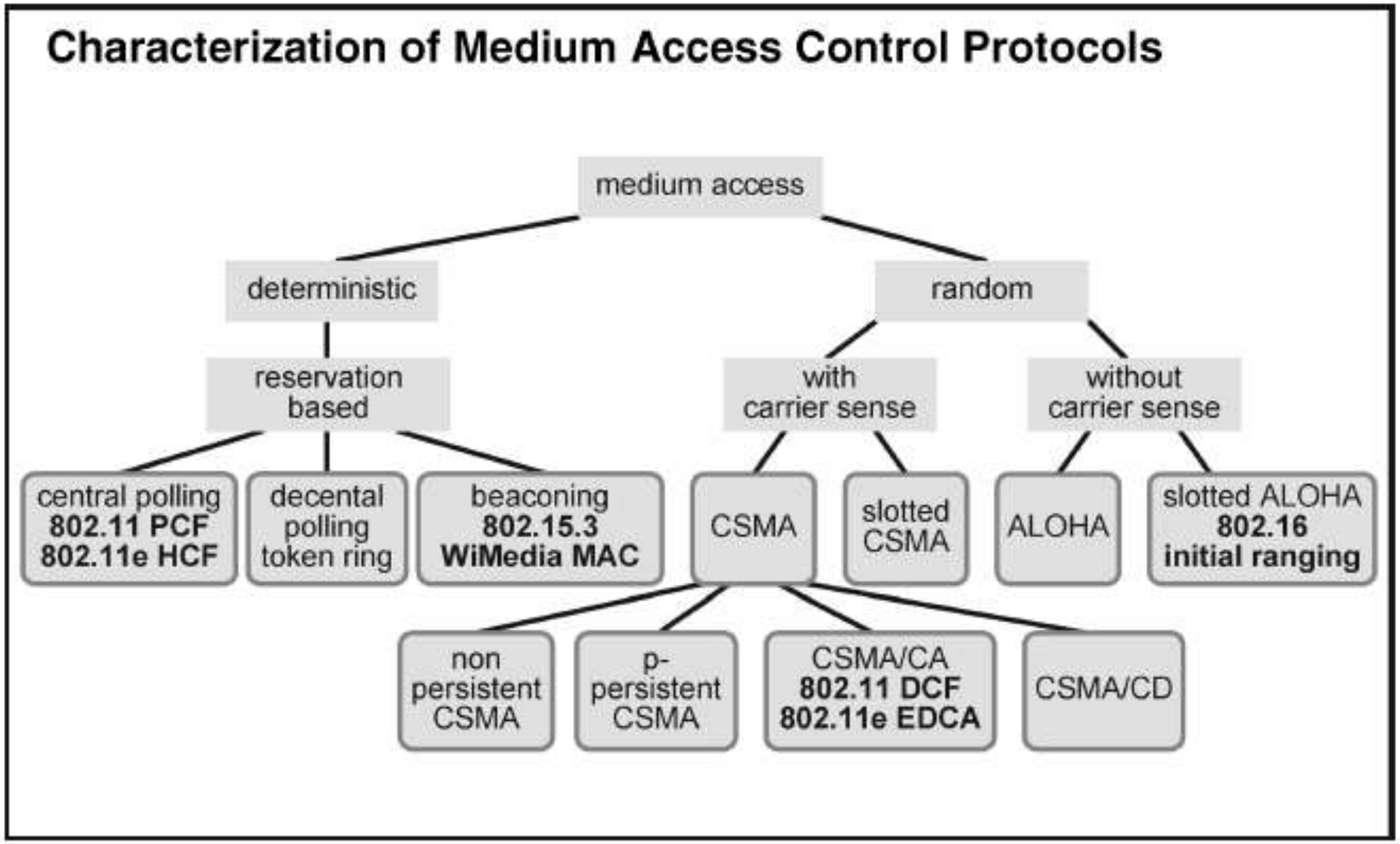


Figure 2.16 Overview of different medium access control protocols. Standards discussed in this book that use these protocols are in bold.

MAC Protocols

- Random contention-based
  - The main characteristic of random-based medium access is that no predictable or scheduled point in time for medium access of stations exists.
  - QoS is therefore difficult to support
- Deterministic contention-based
  - Realize through reservation
  - Coordination of reservations is required

ALOHA

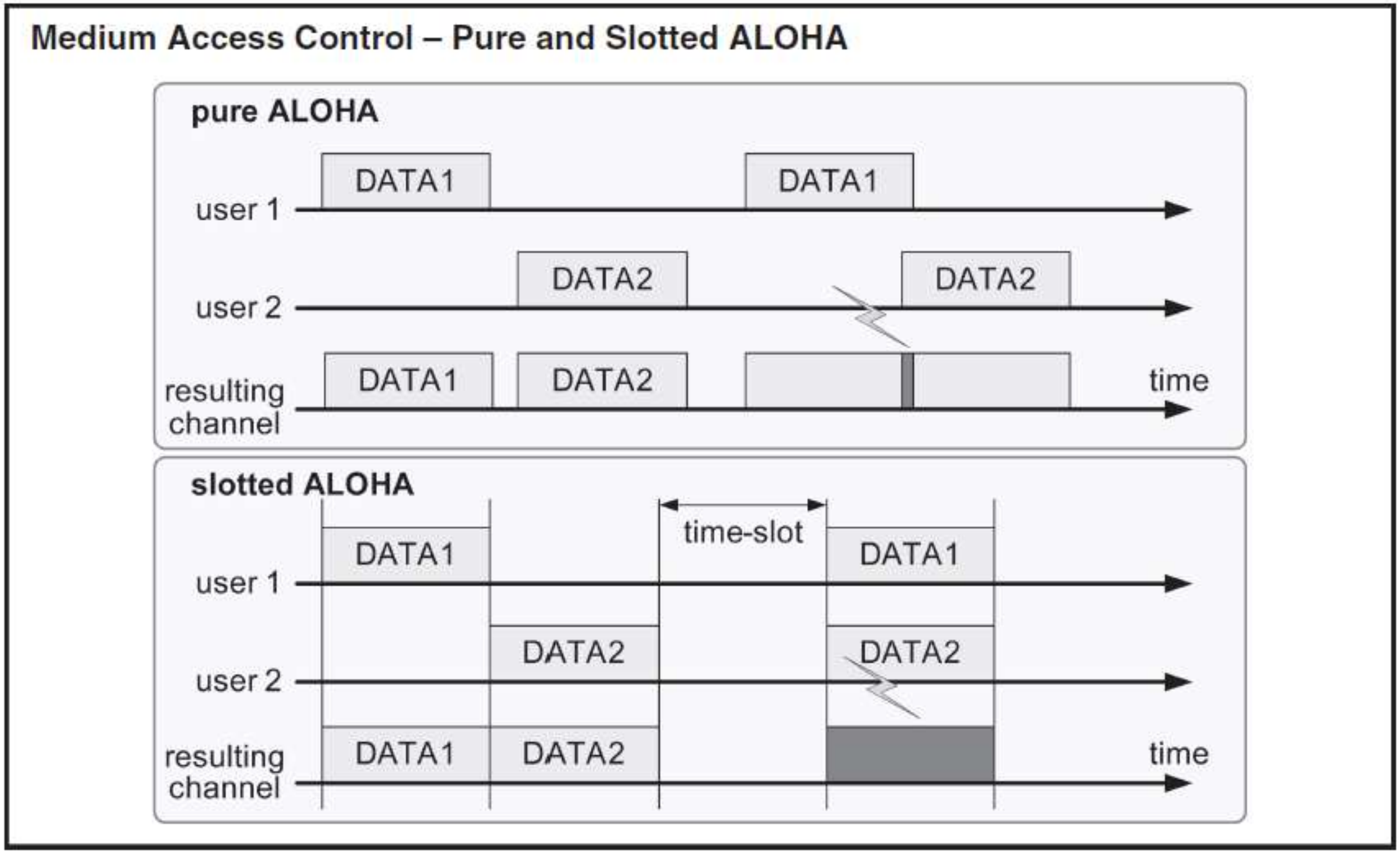
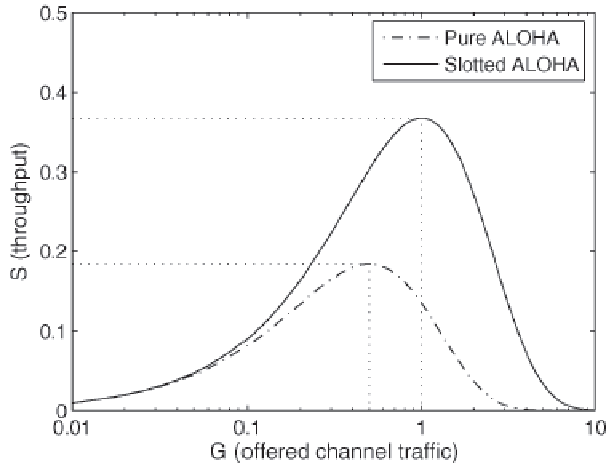


Figure 2.17 Random medium access according to pure and slotted ALOHA principles.

Pure and Slotted ALOHA – Normalized Throughput



- Maximum possible system throughput in slotted ALOHA twice that of pure ALOHA
- Pure ALOHA max. throughput is 18% of medium capacity (for G=0.5)
- Slotted ALOHA max. throughput is 37% of medium capacity (for G=1)

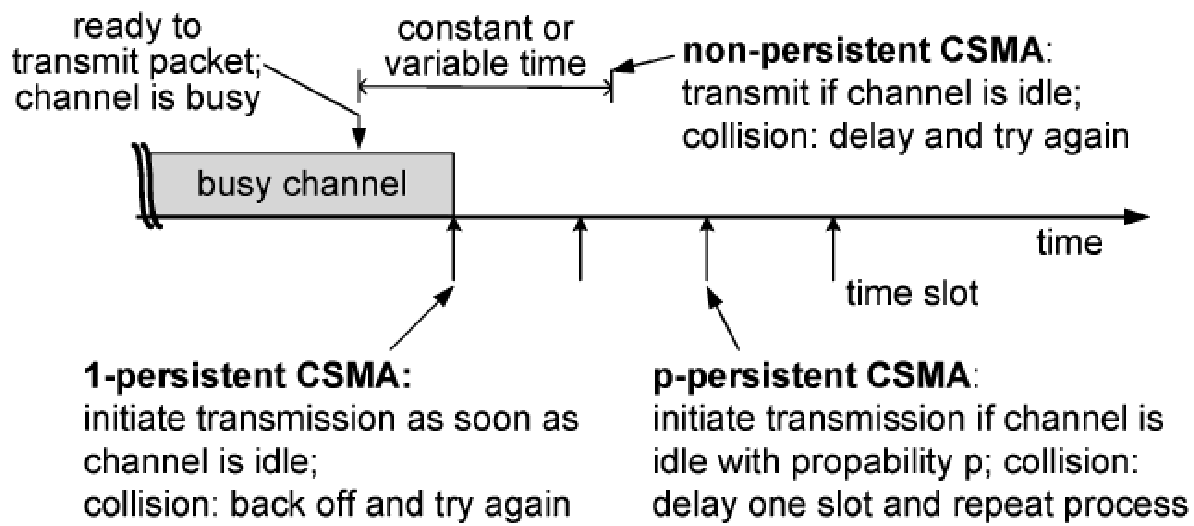
Figure 2.18 Normalized system throughput and delay for pure and slotted ALOHA.

CSMA

- Improve channel utilization of slotted ALOHA
- Listening to (sensing) the radio channel before deciding to transmit is useful to avoid collisions (Listen-before-Talk)
- More than one station may attempt to access the channel at the same time, collision will occur

CSMA Protocols

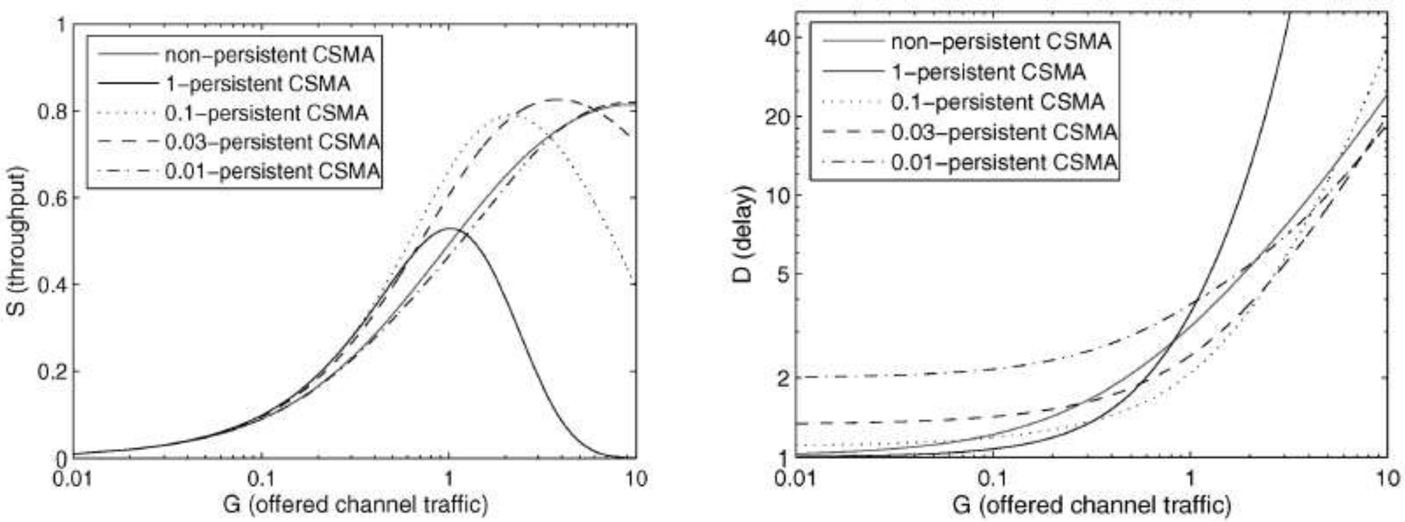
Medium Access Control – Carrier Sense Multiple Access (CSMA)



- Enhancements of CSMA:
- CSMA with Collision Detection (CSMA/CD): Jamming signal is sent when detecting a collision and transmission is terminated (IEEE 802.3)
- CSMA with Collision Avoidance (CSMA/CA): Channel is reserved and stations defer from medium access when being notified about transmissions (IEEE 802.11)

Figure 2.19 Medium access according to the Carrier Sense Multiple Access scheme.

Carrier Sense Multiple Access (CSMA)



- CSMA increases efficiency of channel utilisation up to 80 percent
- System throughput differs essentially at a given offered traffic load
- Delay depends on CSMA version and increases exponentially with increasing offered traffic
- Tradeoff between maximum achievable throughput and delay

Figure 2.20 Comparison of the normalized system throughput of multiple ALOHA and CSMA versions.

CSMA/CD

- The performance of CSMA can be improved when introducing means for Collision Detection (CD) resulting in CSMA/CD.
- On a wired medium, stations may observe the shared channel to detect if two transmissions have been started simultaneously, or at least overlap.
- If such a collision is detected, a jamming signal is transmitted by the respective station and its transmission is terminated immediately.
- CSMA/CD is used in the LAN Ethernet (IEEE 802.3).

CSMA/CA

- Collision Avoidance (CA) is an enhancement of CSMA-based radio channel access leading to CSMA/CA.
- Collision avoidance aims at reserving the channel in advance by broadcasting reservation-related information.
- Stations that sense the carrier may receive a channel reservation message containing a specific time duration that other stations are being asked to defer from channel access.
- After expiration of the time reserved all stations may compete again for medium access.
- In centrally controlled networks, the controlling device may invite (poll) associated stations one by one to transmit its data packets
  - The PCF/HCF functions of IEEE 802.11/802.11e are prominent examples for applying polling techniques in wireless networks with central control.