Dipartimento INFOCOM
Università degli studi di
Roma "La Sapienza"

Departamento de Señales y
comunicaciones
ULPGC

Optical Communications

Telecommunication Engineering
School of Engineering
University of Rome La Sapienza
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Medium Access Control for Optical Communications Part I

WIRELESS ACCESS

- What is meant by “wireless access”?
  - The possibility for a wireless unit to **access** the fixed network infrastructure

But also

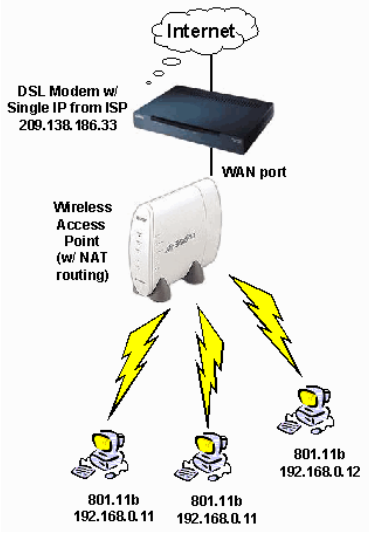
  - In general the **access** to the wireless medium, that is to the resource available in the system for transmitting information

CENTRALIZED VS. DECENTRALIZED ACCESS

- In the case of centralized access, the resource available to the system is managed and controlled by a central unit which functions as a coordinator

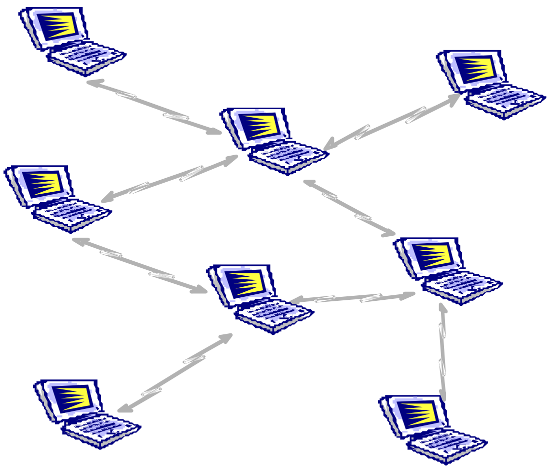
- In decentralized access systems, all nodes are hierarchically equivalent and a central unit is not necessary. The nodes may eventually collaborate for the purpose of resource sharing ▪ ▪ ▪

CENTRALIZED ACCESS: IEEE 802.11 NETWORKS



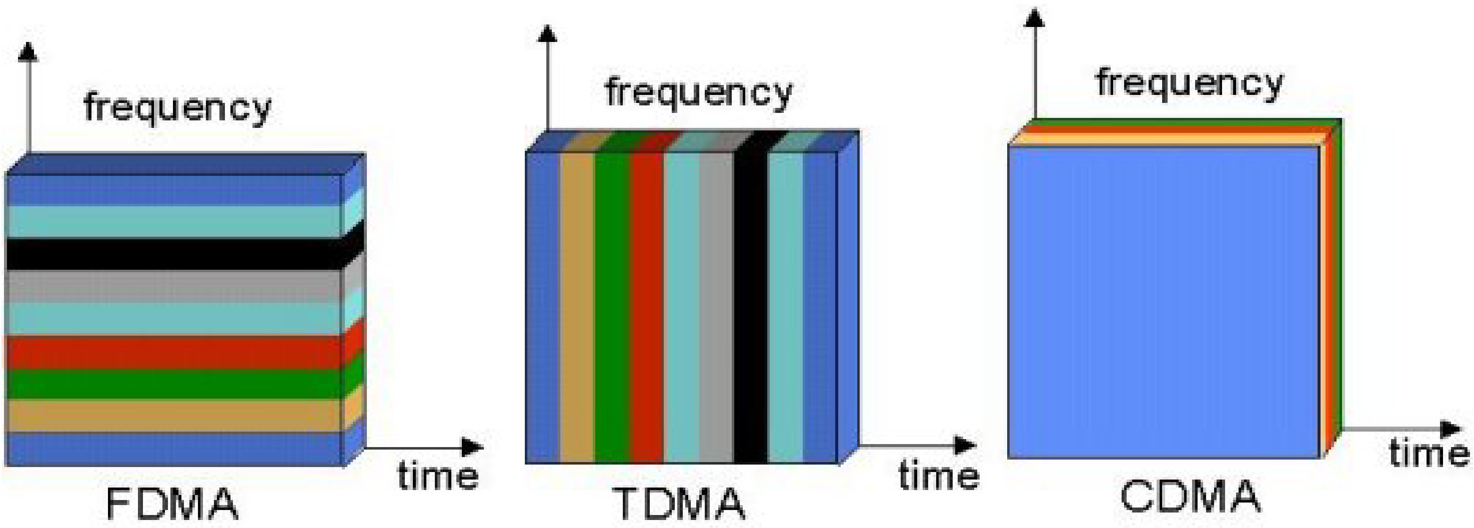
- Access Control in these networks is typically demanded to the element connected to the fixed network, which coordinates the access of wireless devices by managing the resource available in the system for transmissions

EXAMPLE OF DECENTRALIZED ACCESS: AD-HOC NETWORKS



Decentralized access among cooperative or non-cooperative nodes

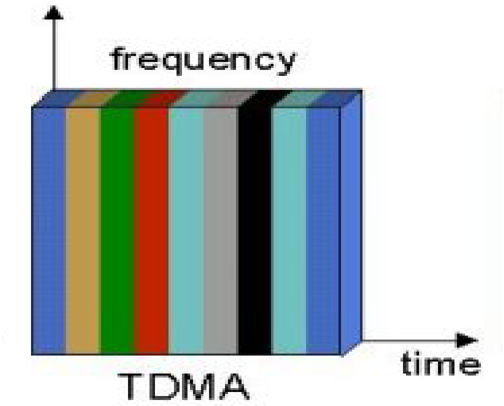
ACCESS TECHNIQUES



TIME DIVISION MULTIPLE ACCESS (TDMA)

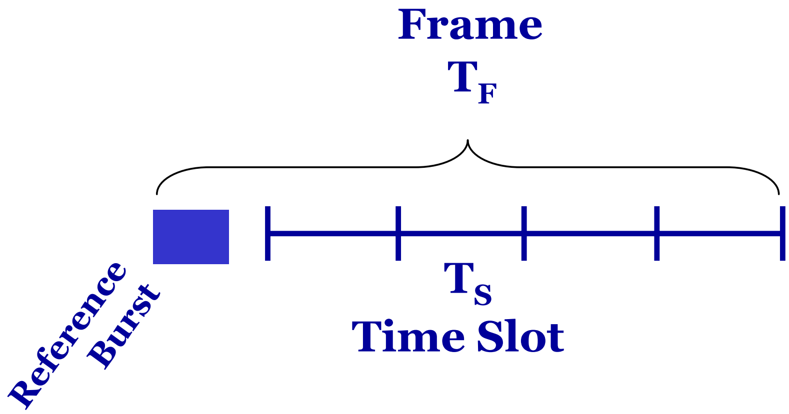
- Each user is allowed to transmit only within specified time intervals (Time Slots). Different users transmit in differents Time Slots.

- When users transmit, they occupy the whole frequency bandwidth (separation among users is performed in the time domain).

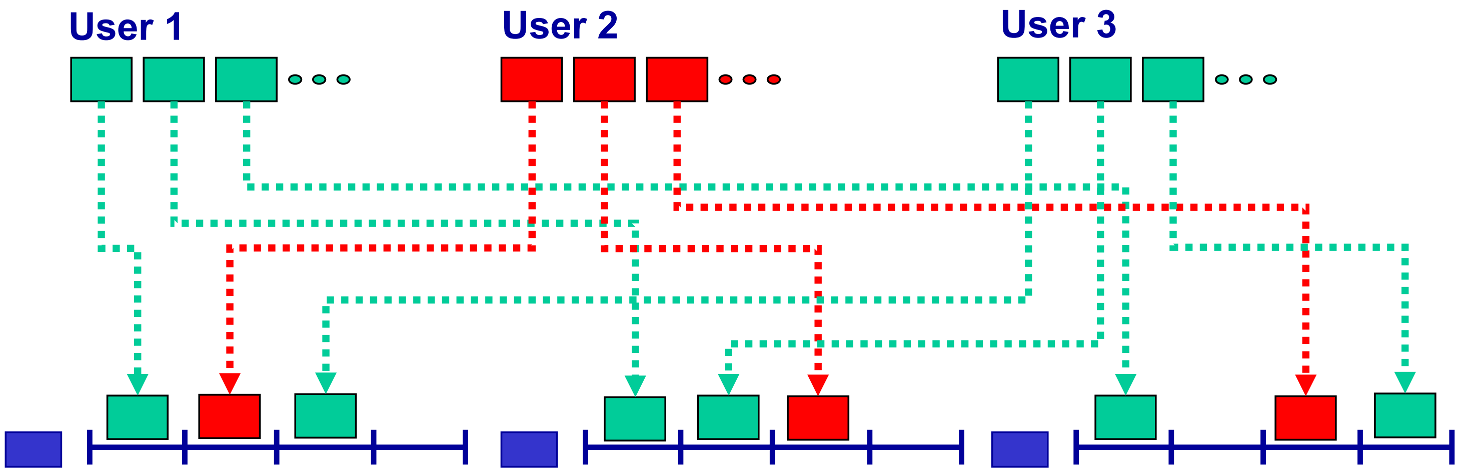


TDMA FRAME STRUCTURE

- TDMA requires a centralized control node, whose primary function is to transmit a periodic **reference burst** that defines a frame and forces a measure of synchronization of all the users.
- The frame so-defined is divided into time slots, and each user is assigned a Time Slot in which to transmit its information.



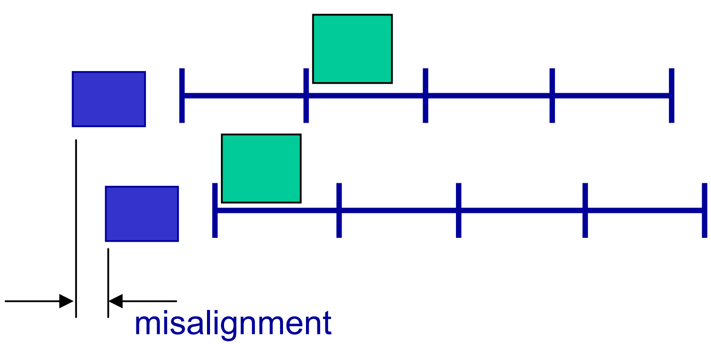
TDMA FRAME STRUCTURE



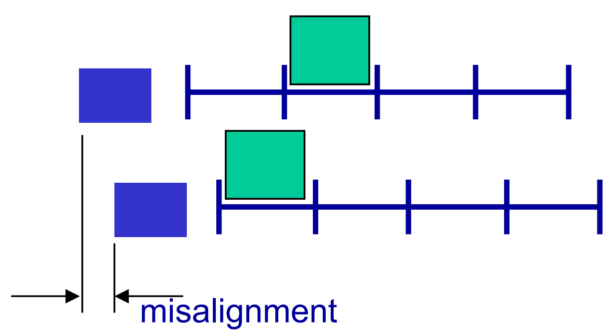
TDMA GUARD TIMES

- Since there are significant delays between users, each user receives the reference burst with a different phase, and its traffic burst is transmitted with a correspondingly different phase within the time slot.
- There is therefore a need for **guard times** to take account of this uncertainty.
- Each Time Slot is therefore longer than the period needed for the actual traffic burst, thereby avoiding the overlap of traffic burst even in the presence of these propagation delays.

with guard time

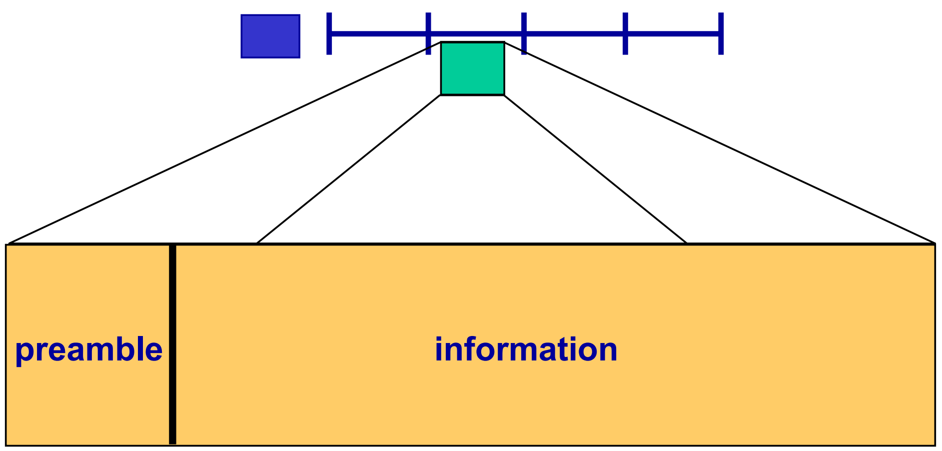


without guard time

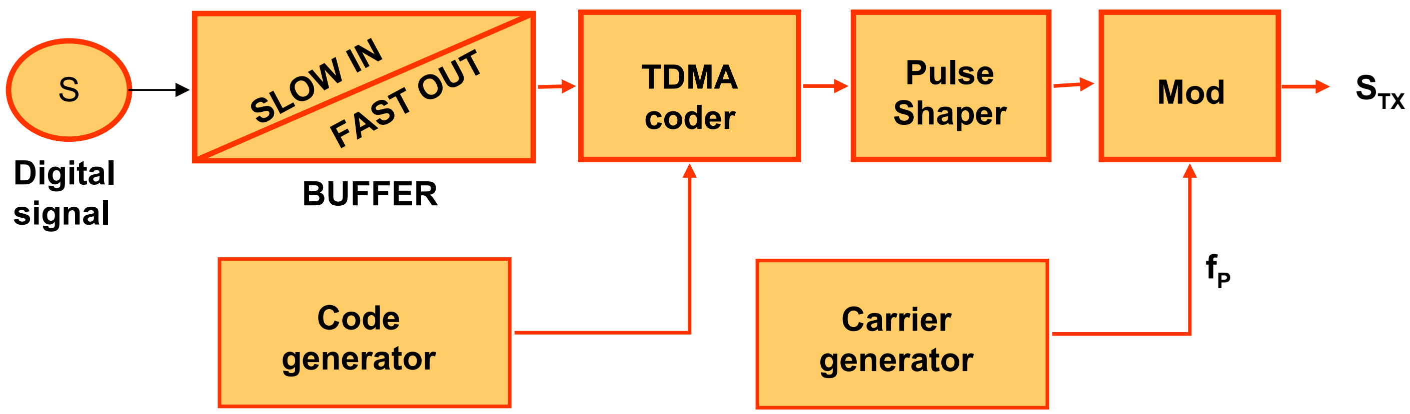


TDMA: PREAMBLE

- Since each traffic burst is transmitted independently with an uncertain phase relaive to the reference burst, there is the need for a **preamble** at the beginning of each traffic burst.
- The preamble allows the receiver to acquire on top of the coarse synchronization provided by the reference burst a fine estimate of timing and carrier phase.



TDMA: REFERENCE TRANSMITTER SCHEME



CDMA: BASIC PRINCIPLES

- In CDMA each user is assigned a unique code sequence (spreading code), which it uses to encode its data signal.
- The receiver, knowing the code sequence of the user, decodes the received signal and recovers the original data.
- The bandwidth of the coded data signal is chosen to be much larger than the bandwidth of the original data signal, that is, the encoding process enlarges (spreads) the spectrum of the data signal.
  - CDMA is based on spread-spectrum modulation.
- If multiple users transmit a spread-spectrum signal at the same time, the receiver will still be able to distinguish between users, provided that each user has a unique code that has a sufficiently low cross-correlation with the other codes.

CDMA SCHEMES

- **Direct Sequence CDMA (DS-CDMA)**
  - The original data signal is multiplied directly by the high chip rate spreading code.
- **Frequency Hopping CDMA (FH-CDMA)**
  - The carrier frequency at which the original data signal is transmitted is rapidly changed according to the spreading code.
- **Time Hopping CDMA (TH-CDMA)**
  - The original data signal is not transmitted continuously. Instead, the signal is transmitted in short bursts where the times of the bursts are decided by the spreading code.

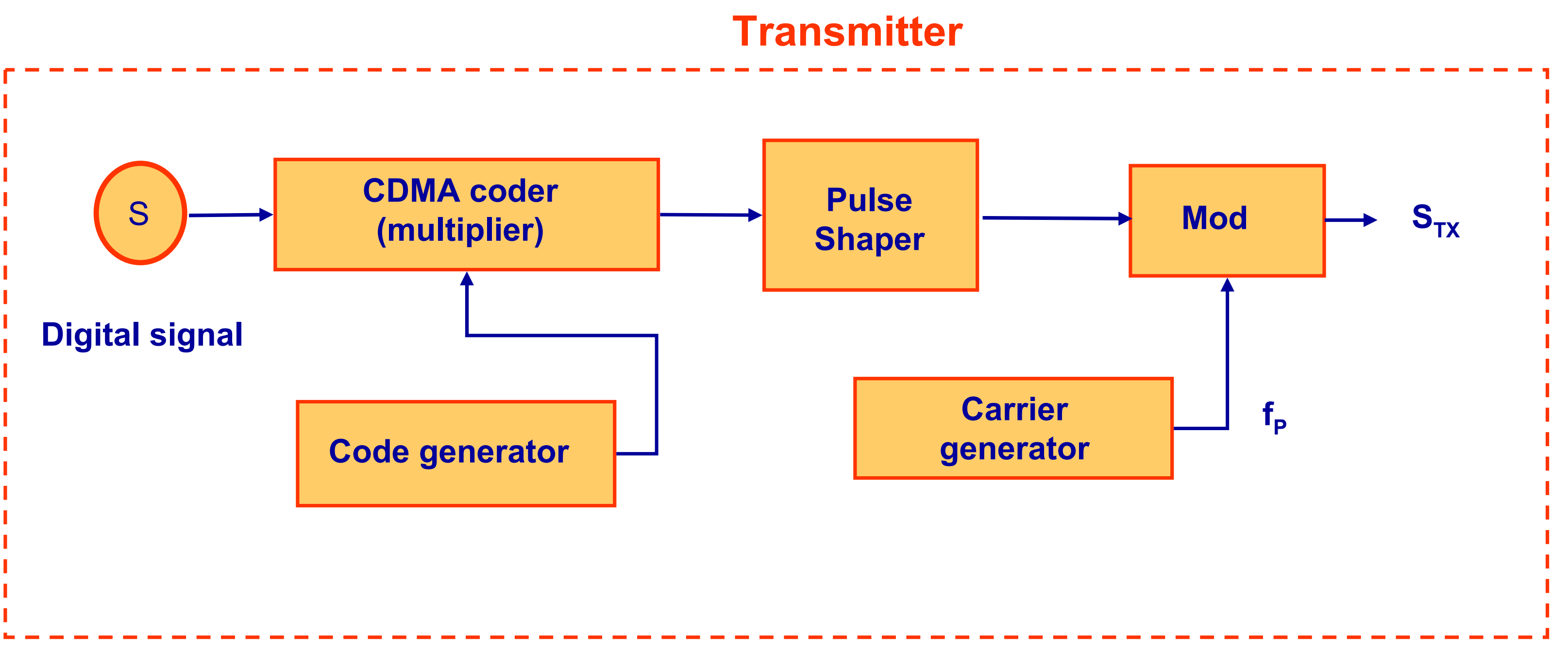
CDMA: THE PARTIAL CORRELATION PROBLEM

- **Partial correlations** among encoded signals arise when no attempt is made to synchronize the transmitters sharing the channel, or when propagation delays cause misalignment even when transmitters are synchronized.
- Partial correlations impede the receiver to totally cancel the contributions of other users even in the presence of spreading codes having low cross-correlation.
- In presence of partial correlations, the received signal is therefore affected by Multi User Interference.
- The partial correlations can be reduced by proper choice of the spreading codes, but cannot be totally eliminated.
- **CDMA system capacity is thus tipically limited by the interference from other users, rather than by thermal noise**.

CDMA: THE NEAR-FAR PROBLEM

- If all the users transmit at the same power level, then the received power is higher for transmitters closer to the receiving antenna.
- Thus, transmitters that are far from the receiving antenna are at a disadvantage with respect to interference from other users.
- This inequity can be compensated by using **power control**.
- Each transmitter can accept central control of its transmitted power, such that the power arriving at the common receiving antenna is the same for all transmitters.
- In other words, the nearby transmitters are assigned a lower transmit power level than the far away transmitters.
- Power control can be easily achieved in centralized access schemes (e.g. third generation cellular networks), but is a challenging issue in distributed systems.

CDMA: REFERENCE SCHEME



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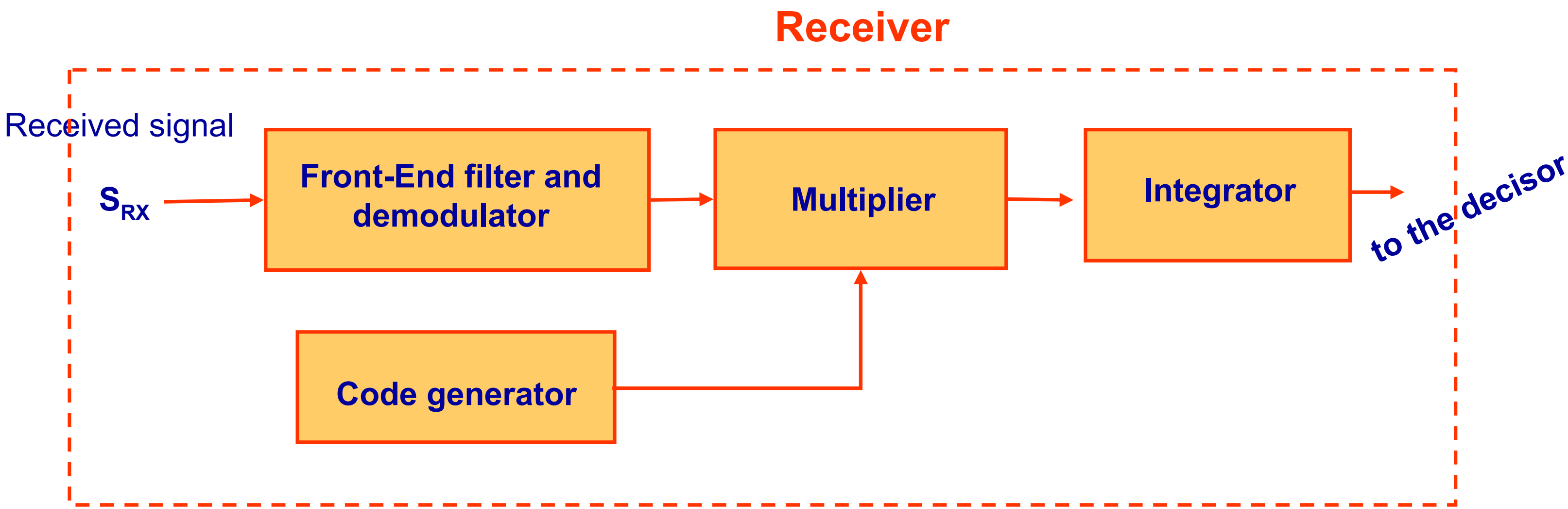
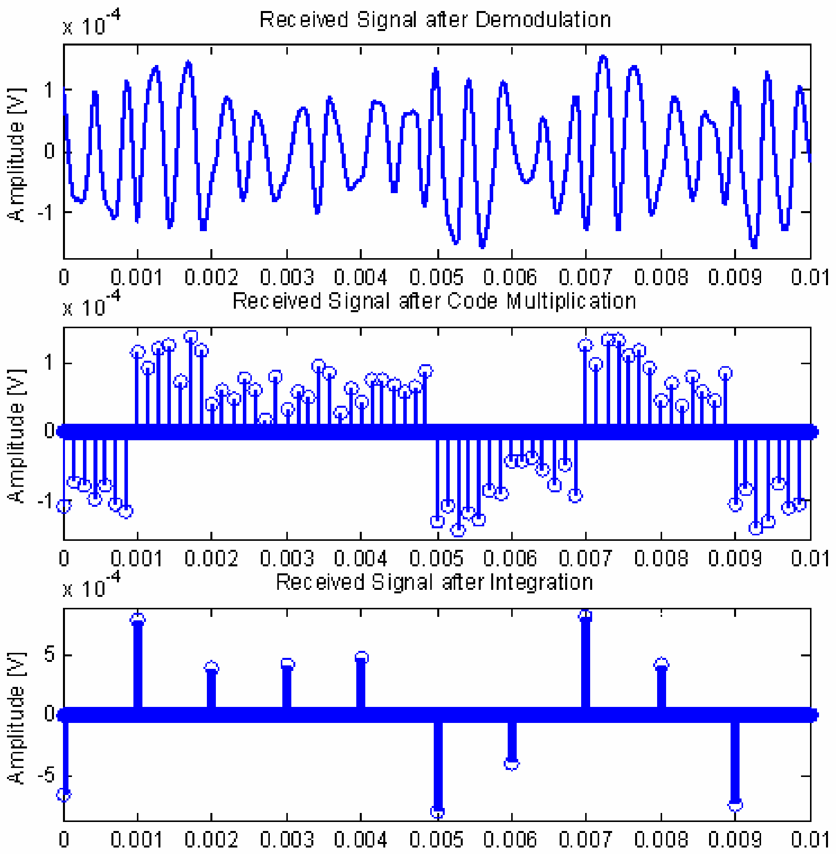
CDMA: REFERENCE SCHEME



DS-CDMA: EXAMPLE

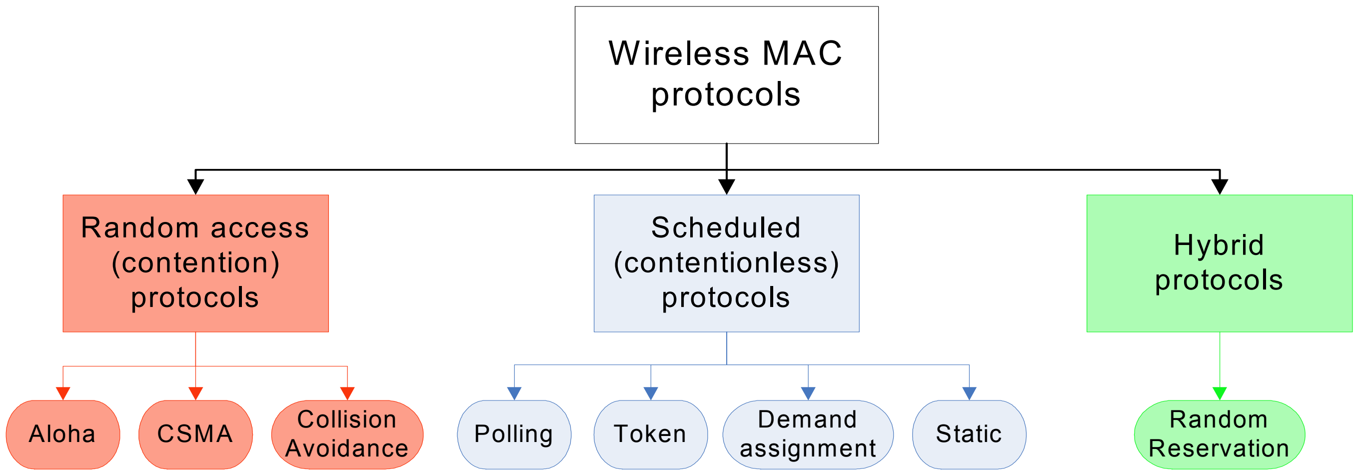


Received signal after Front-End filtering and demodulation

Signal obtained by direct multiplication of the base-band signal with the spreading signal

Received sequence after integration of the above samples

CLASSIFICATION OF MAC PROTOCOLS



- The above classification is based on how DATA traffic is transferred
- Most scheduled protocols, in fact, foresee a random access phase in which control packets are subject to collision

RANDOM ACCESS PROTOCOLS

- In random access protocols each packet is subject to collision, since no resource reservation is adopted
- The main advantage of this family of protocols is simplicity:
  - Each terminal can transmit with no (or limited) information regarding other terminals
  - Random access protocols provide low delays, since packets are transmitted (almost) immediately
- The main drawback is the low scalability with traffic load:
  - When the offered traffic increases, the probability of collision increases as well, and the number of lost packets increases
  - This reduces the throughput (roughly: the amount of data successfully transferred) and increases the delay, since lost packets must be eventually retransmitted
- In order to reduce the negative effect of collisions, Collision Avoidance mechanisms are often adopted

ALOHA

- The simplest random access protocol is **ALOHA**
- Developed in 1970 at University of Hawaii

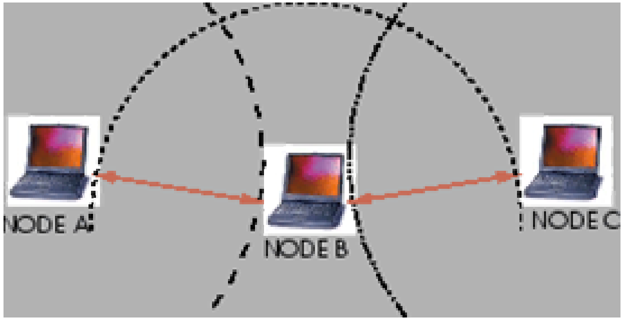
- ALOHA does not require any action by terminals before they transmit a packet
- A checksum is added at the end of each packet
- The receiving terminal uses the checksum to evaluate if the packet was received correctly or was corrupted by collision
- In case of collision the packet is discarded
- Retransmission of discarded packets is accomplished based on an Automatic Repeat on ReQuest (ARQ) protocol, that re-schedules packets after a random delay

CARRIER SENSING MULTIPLE ACCESS

- In networks with high traffic load ALOHA is not effective due to collisions
- Performance can be improved by introducing Carrier Sensing, leading to *Carrier Sensing Multiple Access* (*CSMA*)
- When a terminal A has packets to transmit, it **senses** the channel before starting transmission
- If another terminal B is already transmitting, terminal A will detect its transmission
- In this case A will postpone its own transmission
- When A senses the channel as **idle** for a predefined amount of time, it assumes the channel as available and starts transmission.

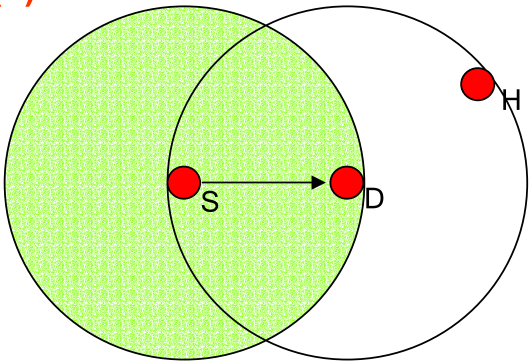
CSMA ISSUES (1/4)

- The performance of CSMA heavily depends on the network scenario
- Wireless networks are in fact characterized by:
  1. Varying network topology
  2. Partial connectivity
     - This can lead to errors in protocols that work perfectly fine in wired networks
- In the case of CSMA, the wireless medium causes two phenomena that significantly reduce the protocol performance:
  - Hidden terminal
  - Exposed terminal



CSMA ISSUES (2/4)

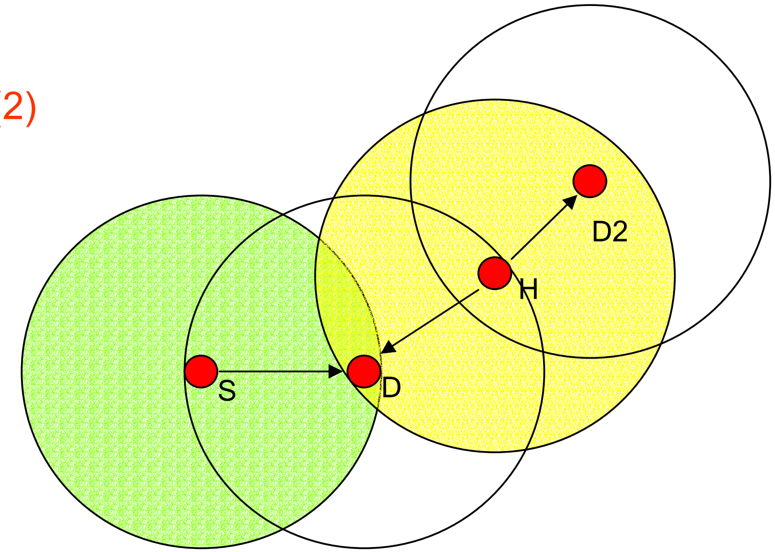
- **Hidden terminal (1)**



- Node S is sending a packet to D, which is acting only as receiver
- Node H, willing to transmit, starts the Carrier Sensing procedure, sensing the channel for the time period w defined in the protocol
- After a time w, H, which cannot detect the transmission by node S (due to limited radio coverage), assumes the medium is available

CSMA ISSUES (3/4)

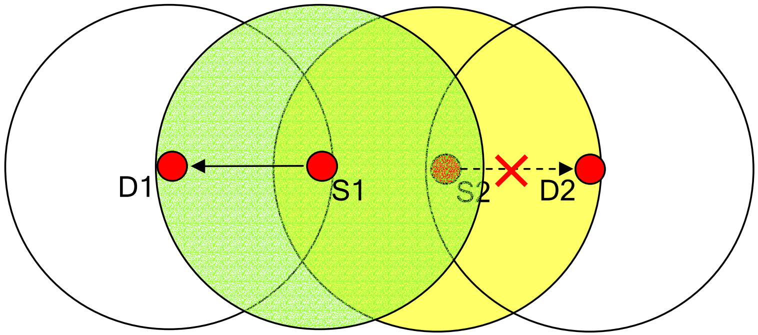
- Hidden terminal (2)



- H starts its transmission, causing a collision in D, and potentially the loss of both packets
- N.B.: Since wireless medium is inherently broadcast, this issue arises even if H is not willing to transmit to D, but to another terminal D2 in its range!

CSMA ISSUES (4/4)

- Exposed terminal



- In t = 0 terminal **S1** starts a packet transmission to **D1**
- In t = t_0, **S2** is willing to transmit a packet to **D2**
- **S2** starts the Carrier Sensing procedure
- **S2** detects a transmission already active, and assumes the channel is **busy**, postponing thus the transmission to **D2**
- **Since D2 is not reached by S1, however, the transmission S2 -> D2 could be activated without causing any collision**