ΕΠΛ 427: ΚΙΝΗΤΑ ΔΙΚΤΥΑ ΥΠΟΛΟΓΙΣΤΩΝ (MOBILE NETWORKS)

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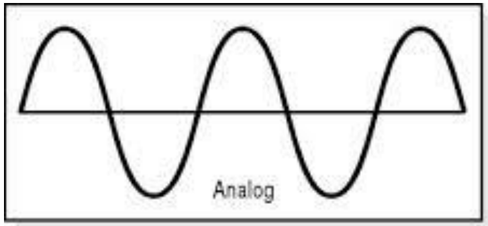
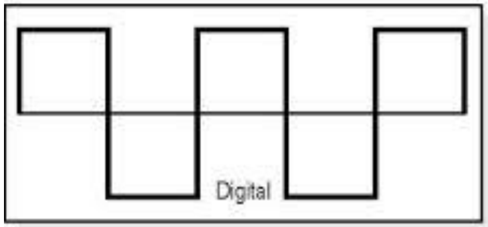
Επανάληψη για Ενδιάμεση

Definitions
Analog and Digital Signals

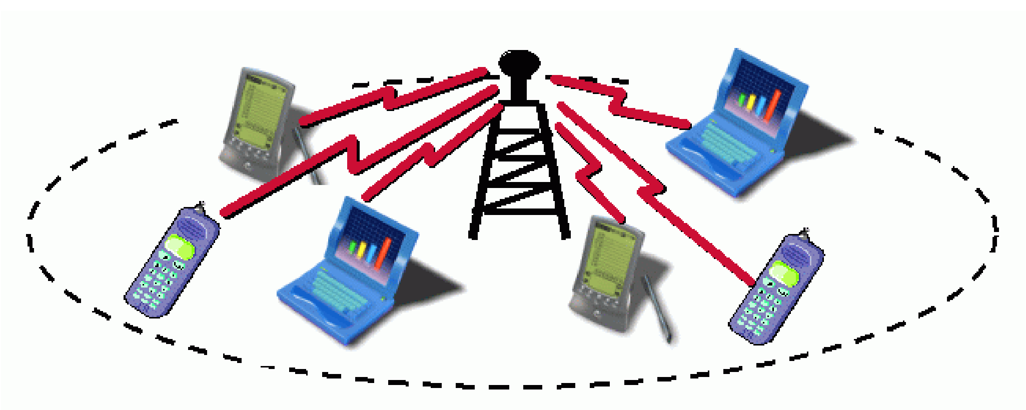
- Means by which data are propagated (διαδίδονται) over a Communication Channel.
  - **Analog Signal:** is a continuously varying electromagnetic wave that may be propagated **over a variety of media. E.g.,**:
    - Wire, coaxial, **space (wireless), etc.**
    - There are **no breaks or discontinuities in the signal** (Continuous Signal)
  - **Digital Signal:** is a sequence of discrete (διακριτές) voltage pulses that can be transmitted over a **wire medium (cannot be used to transfer data over the air)**.
    - For example, a constant **positive level of voltage is send** to represent binary 0 and a constant **negative level of voltage is send** to represent binary 1.

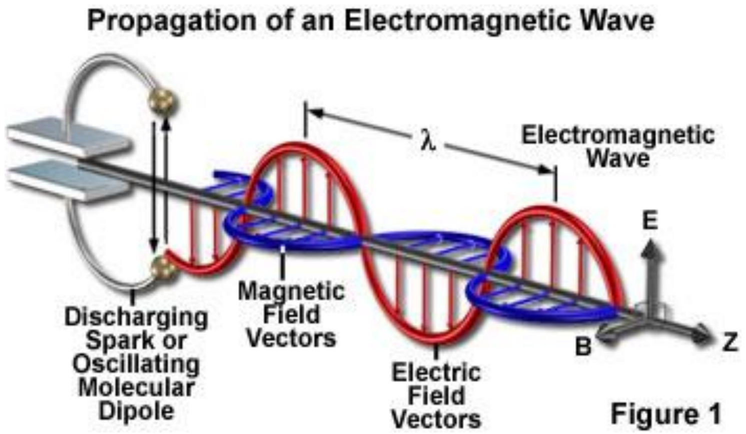




Definitions
Communication and Wireless Networks

- Wireless Networks **utilize Electromagnetic Waves** (radio waves) **of a certain frequency (Carrier Frequency)** to establish **Communication Channels and transmit data** between Wireless Communication Devices (e.g., Mobile Devices and the Base Station).





Challenges with Wireless/Mobile Networks

- **Two important challenges** with wireless/mobile networks (beyond those of traditional fixed networks):
  - **Wireless**: Communication over a **wireless link** - Transmitting voice and data using **electromagnetic (radio) waves in open space** (using a given frequency band).
    - The **Quality of a link connection** is **subjected to many (environmental) factors** and can vary substantially → Especially from the effects caused by the **Multipath propagation phenomenon**.
  - **Mobility**: Handling the mobile user who **changes point of attachment** (handover) to the network.

What is Mobility?

- **Two aspects of mobility**:
  - **Device Portability:** The device can **easily be carried** and can be connected (wireless) anytime and from anywhere to the network. **Changing point of attachment to the network offline** (connect from home, from work, from coffee shop, etc.)
  - **User Mobility (includes device portability):** Users communicates (wireless) with anyone, anytime and from anywhere. **Changing point of attachment (Handover) to the network online** (e.g., the user is driving from home to work and the call/connection is hand off from one cell to another during the call)

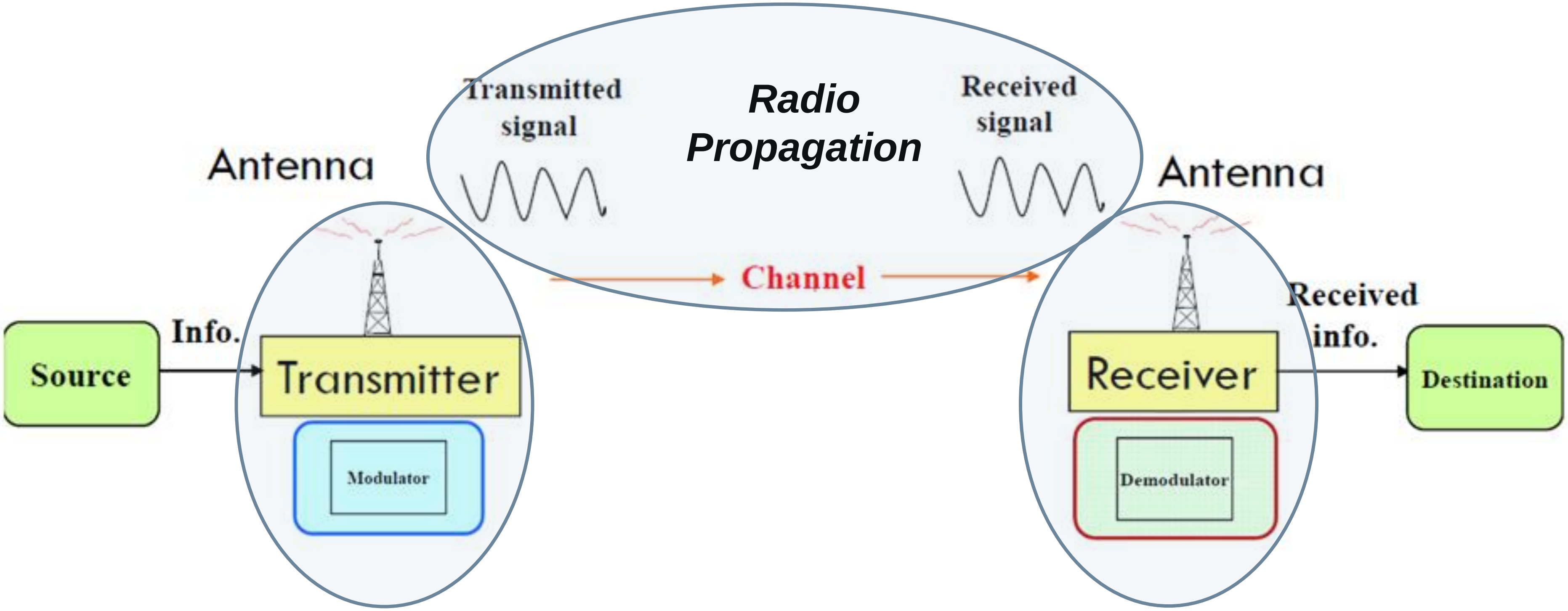
Benefits of Wireless Networking

- **Allows Mobility**
  - **Freedom to move** in the geographical area without being tethered by wires
  - Permits companies to shift toward an increasingly **mobile workforce**
- **Increased Reliability (no cables needed)**
  - **Network cable failures** is the most common source of network problems
- **Easier and Less Expensive Installation**
  - Installing network cabling can be a difficult, slow, and costly task!
  - Installation in Difficult-to-Wire Areas

Benefits of Wireless Networking

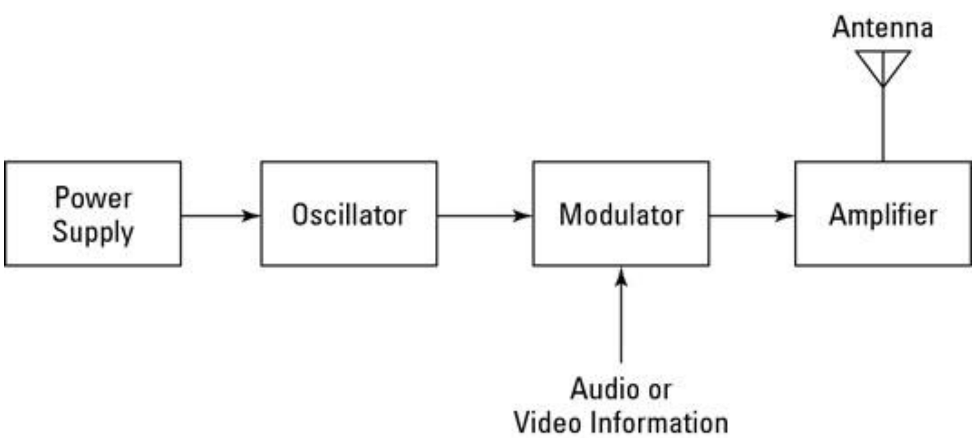
- **Expandability**
  - **Easy to add stations (Mobile/Portable Devices) on the network** since no cables or plugs are required to connect to the network
- **Long-Term Cost Savings**
  - **No need of Re-cabling** in case of re-organization of companies (i.e., new floor plans, office partitions, moving to a different building, renovations)

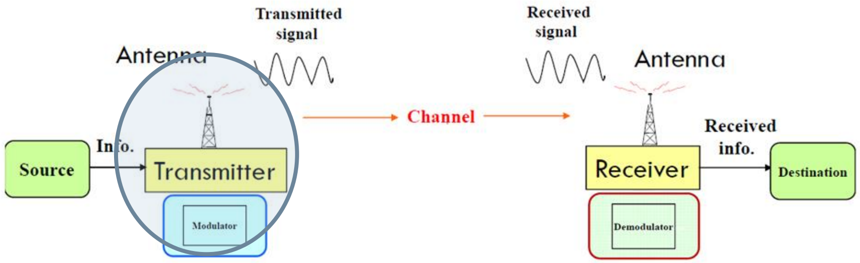
Process and Elements of Radio (Wireless) Transmission
Διαδικασία και Στοιχεία Ασύρματης Διάδοσης



Process and Elements of Radio (Wireless) Transmission
Διαδικασία και Στοιχεία Ασύρματης Διάδοσης

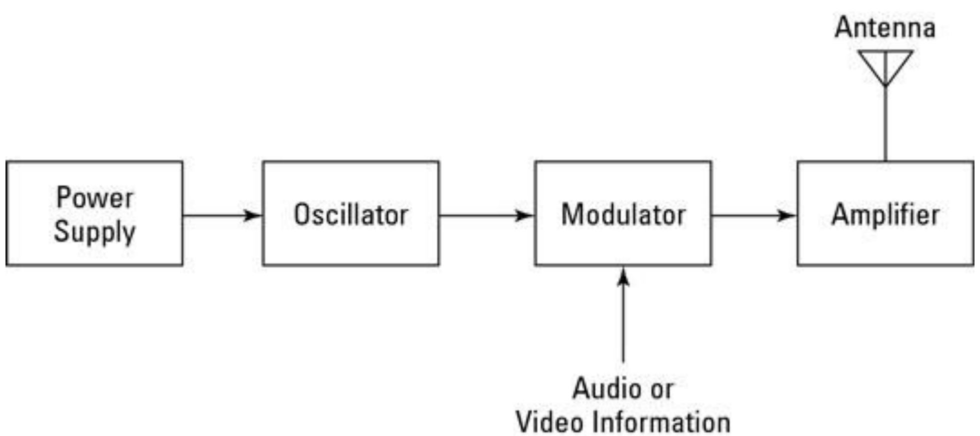
- **Radio Transmitter and Modulation (Πομπός και Διαμόρφωση)**
  - A **Transmitter (Πομπός)** or **Radio Transmitter** is an electronic device which, **with the aid of several components (Power Supply, Oscillator (Ταλαντωτής), Modulator (Διαμορφωτής), Amplifier, Antenna), produces radio waves that contain useful information** (10110111011111….) such as audio, video, or digital data.

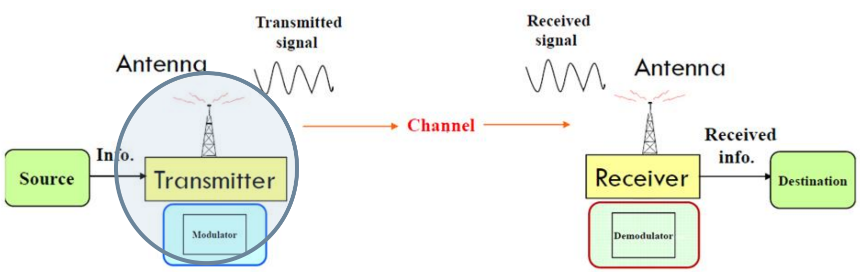




Process and Elements of Radio (Wireless) Transmission Διαδικασία και Στοιχεία Ασύρματης Διάδοσης

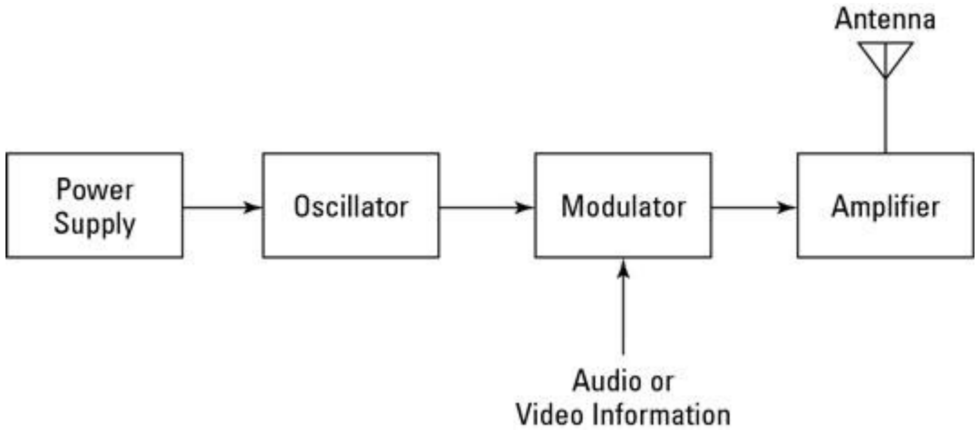
- **Radio Transmitter and Modulation (Πομπός και Διαμόρφωση)**
  - The **Power Supply** provides the necessary electrical power to operate the Transmitter.
  - The **Oscillator generates an alternating/oscillating (ταλαντευόμενο) electrical current** at the **specific frequency** on which the Transmitter will transmit (**carrier frequency**). The Oscillator usually generates a **sine wave**, which is referred to as a ***carrier wave (or carrier signal)***.

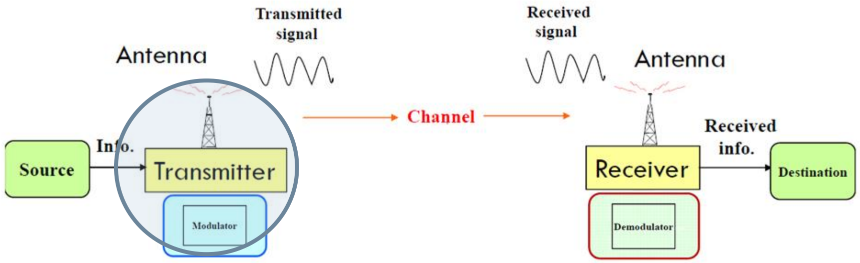




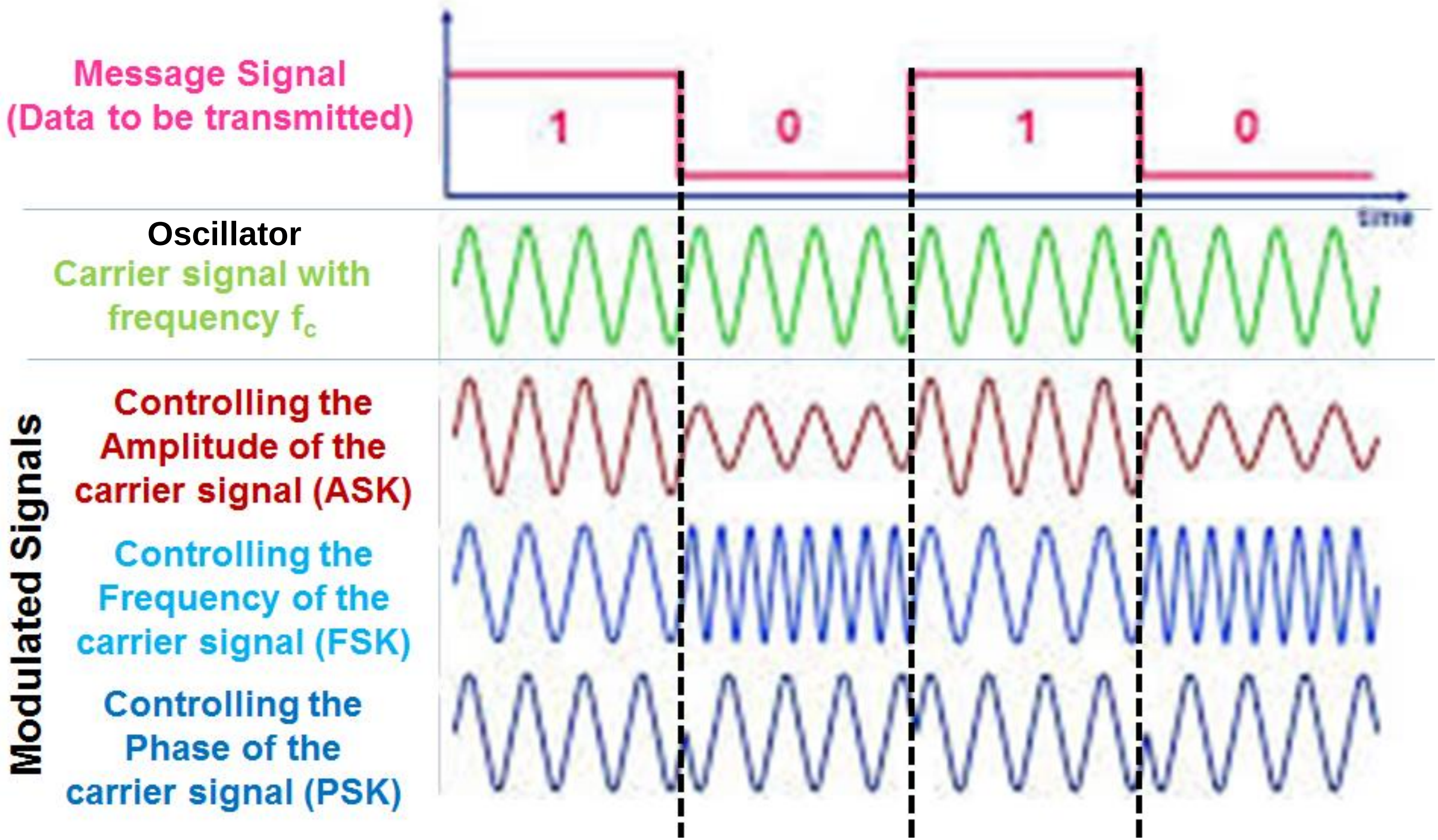
Process and Elements of Radio (Wireless) Transmission
Διαδικασία και Στοιχεία Ασύρματης Διάδοσης

- **Radio Transmitter and Modulation (Πομπός και Διαμόρφωση)**
  - The **Modulator (Διαμορφωτής)** adds the **useful information** to the carrier wave by **modulating (changing)** **some properties of the oscillating electrical current (i.e., the carrier wave), before applied to the antenna.**
    - Such as its **Amplitude**, **Frequency**, **Phase**, or combinations of these properties. → ***Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), Phase Shift Keying (PSK), etc.***



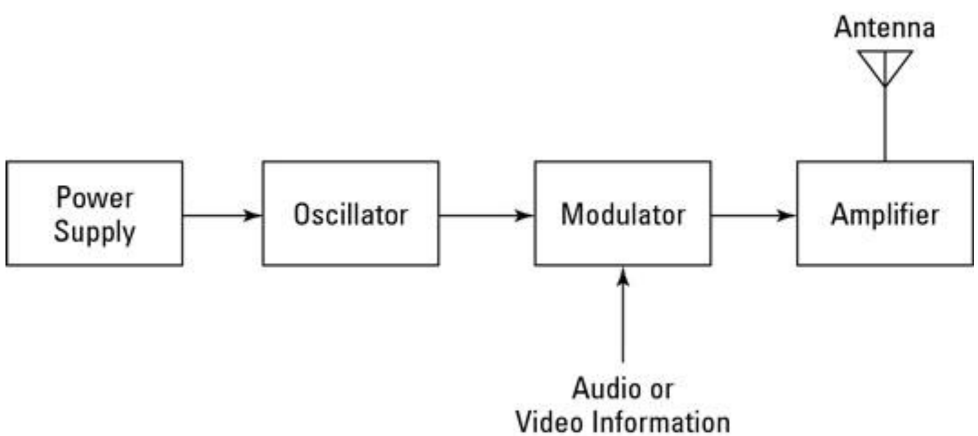


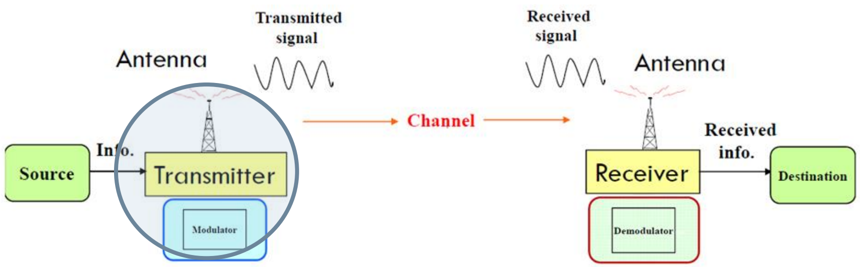
Process and Elements of Radio (Wireless) Transmission
Διαδικασία και Στοιχεία Ασύρματης Διάδοσης



Process and Elements of Radio (Wireless) Transmission
Διαδικασία και Στοιχεία Ασύρματης Διάδοσης

- **Radio Transmitter and Modulation**
  - The **Amplifier amplifies** the **modulated carrier wave** to **increase its power**. The more powerful the amplifier, the more powerful the broadcast.
  - The **amplifier** applies the **amplified modulated oscillating electrical current** to the **Antenna** which converts it into an **electromagnetic wave (or radio wave)** that can propagate through the air.





Process and Elements of Radio (Wireless) Transmission
Διαδικασία και Στοιχεία Ασύρματης Διάδοσης

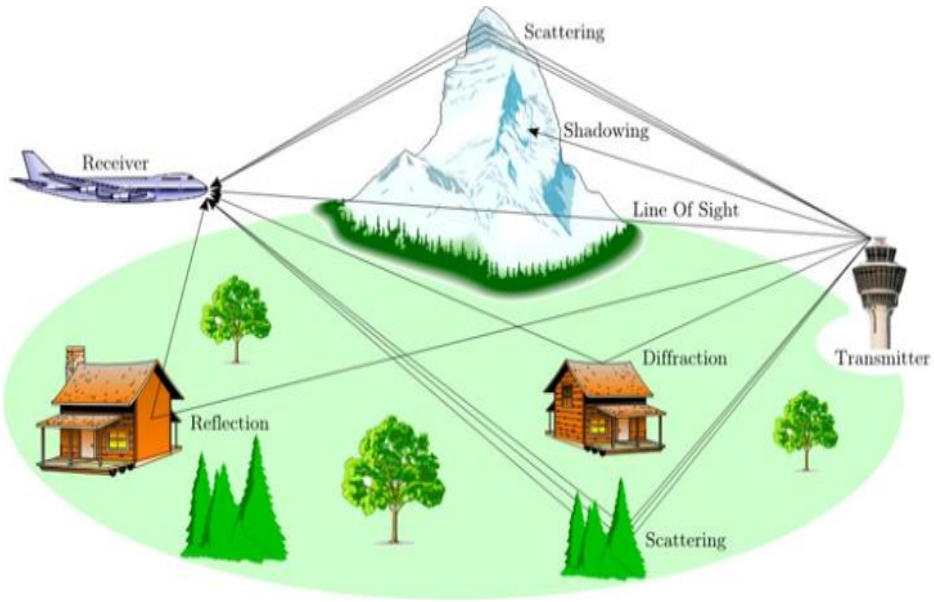
- **Radio Transmitter and Modulation**
  - In a **wireless environment**, a Base Station or an Access Point (i.e., the Antenna) needs a **radio connection between all the Mobile Stations in their transmission range**.
  - Thus, there is a need to address the issue of **simultaneous multiple access by numerous users** in the transmission range.
  - **Multiple Access techniques (Τεχνικές Πολύπλεξης)** are used to **allow a large number of mobile users to share the allocated spectrum** in the most efficient manner. E.g.:
    - Frequency Division Multiple Access (FDMA)
    - Time Division Multiple Access (TDMA)
    - Code Division Multiple Access (CDMA)
    - Orthogonal Frequency Division Multiple Access (OFDMA)

Process and Elements of Radio (Wireless) Transmission
Διαδικασία και Στοιχεία Ασύρματης Διάδοσης

- **Radio Propagation (Ασύρματη Διάδοση Σήματος)**
  - Once generated, **electromagnetic waves travel through space either directly (line of sight)**, or have their **path altered** by Reflection (Ανταγάκλαση), Diffraction (Περίθλαση) or Scattering (Διασκόρπιση) → **Multipath Propagation - Πολυδιαδρομική Διάδοση**.

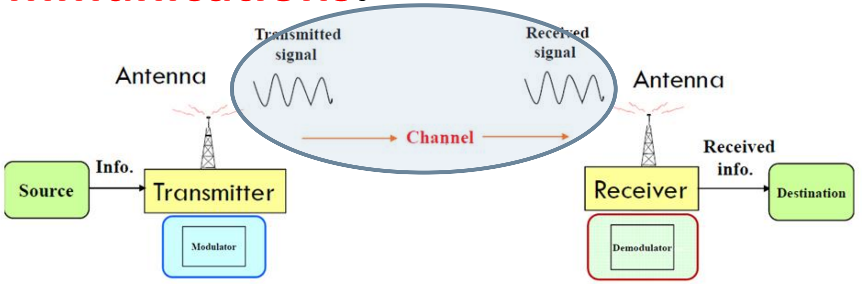
Multipath Propagation The phenomenon that results in **multiple copies of the same radio signal** reaching the receiving antenna by two or more paths.

Results in **Inter-symbol interference** and **fast fading**



Process and Elements of Radio (Wireless) Transmission
Διαδικασία και Στοιχεία Ασύρματης Διάδοσης

- **Radio Propagation (Ασύρματη Διάδοση Σήματος)**
  - The **intensity** of the radio waves **attenuates** during propagation (**Pathloss**); some energy may also be absorbed by the **intervening medium** in some cases.
  - **Also during propagation, Noise and Interference present in the air alter the desired signal.**
  - If the **magnitude** of the **Noise + Interference is large enough** compared to the **strength of the desired signal**, the desired/original signal **will be altered** is such a way that it will **no longer be discernible (διακριτό)**; **this is the fundamental limit to the range (εμβέλεια) of radio communications.**



Process and Elements of Radio (Wireless) Transmission
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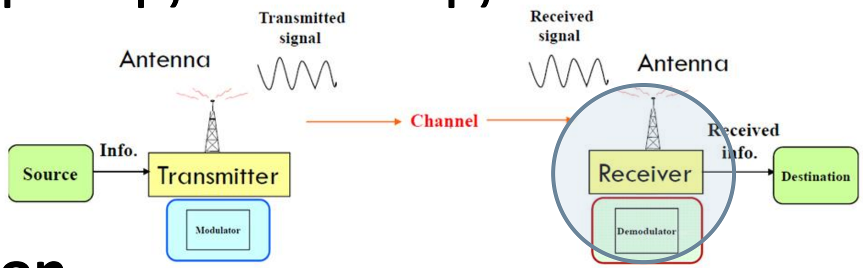
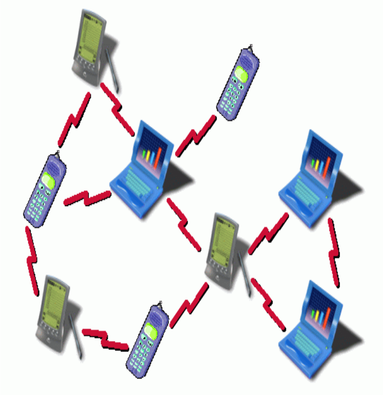


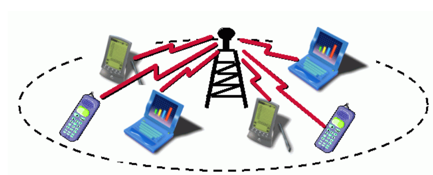
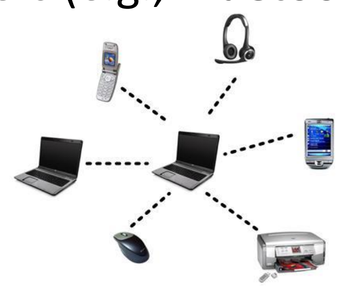
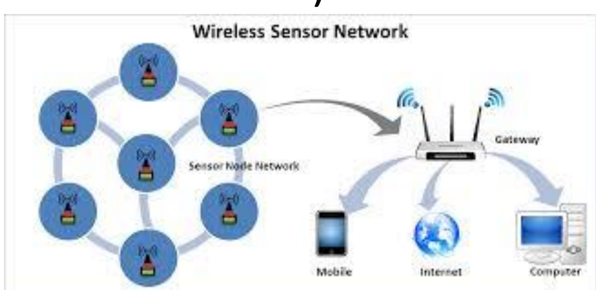
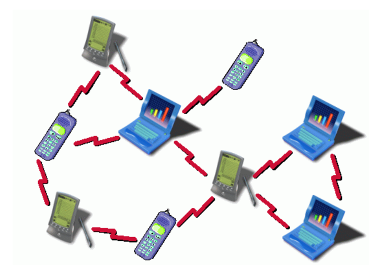
- **Radio Receiver and Demodulation**
  - The energy carried by the **modulated electromagnetic wave** is **captured** by the **receiving Antenna** and **returns it to the Radio Receiver** to the form of **oscillating/alternating electrical currents**.
  - The **Radio Receiver** uses **electronic filters (tuners)** to **separate the wanted radio signal** (transmitted in the **specific frequency** set for the **communication channel**) from all other signals picked up by its Antenna.
  - At the **Receiver**, these **oscillating electrical currents are amplified, demodulated** (recovers the useful information contained in the modulated radio wave) and converted into **to a usable signal form for interpreting the data.**

Infrastructure Vs Infrastructure-less (Ad Hoc) Based Networks

- **Infrastructure-based Networks**
  - **Wireless Hosts are associated with a Base Station** and **communication takes place only between the Wireless hosts and the Access Point** (Not directly between the Wireless Nodes) which is connected to the larger network infrastructure
  - **Traditional network services** (e.g., Resource Allocation, Routing, Transmissions Coordination, etc.) are **provided by the connected network infrastructure.**
- **Infrastructure-less (Ad hoc) based Networks**
  - Wireless hosts have **no infrastructure** to connect to (not associated with a Base Station or Access Point)
  - Hosts themselves **must provide network services** (hosts must organize themselves into a network)
  - Must **cooperate together** in a decentralized manner to **find a route** from one participant to another.

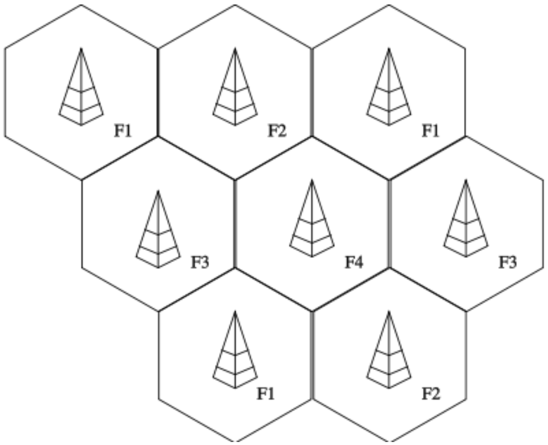


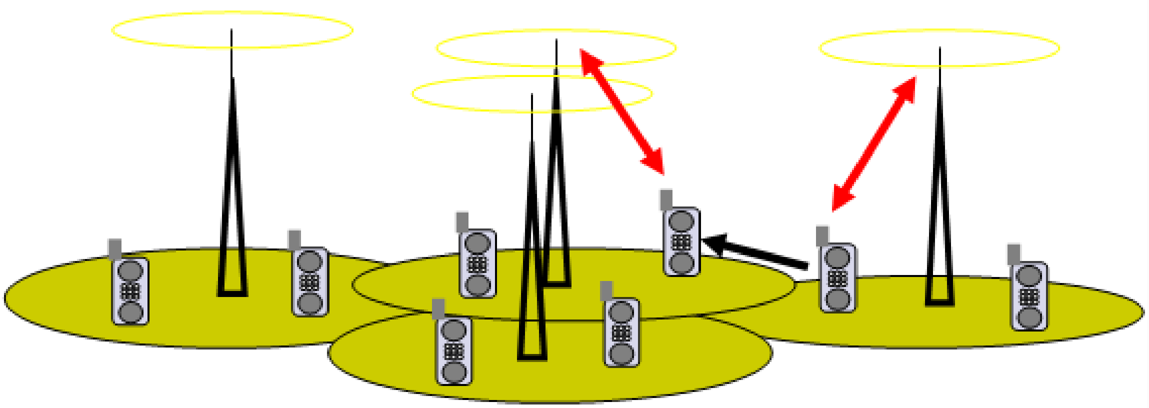
Different Types of Wireless Networks
Διαφορετικοί Τύποι Δικτύου

	Infrastructure based	Infrastructure-less based
Single hop	Base Station exists and nodes communicate directly with the Base Station (e.g., **Wireless LAN, Cellular Networks**) 	No Base Station Exists; One node coordinates the transmissions of the others (e.g., **Bluetooth**) 
Multi-hop	Base Station exists, but some nodes must relay data through other nodes (e.g., **Wireless Sensor Networks**) 	No Base Station exists, and some nodes must relay data through other nodes (e.g., **Mobile Ad Hoc Networks**) 

Mobile Cellular Networks

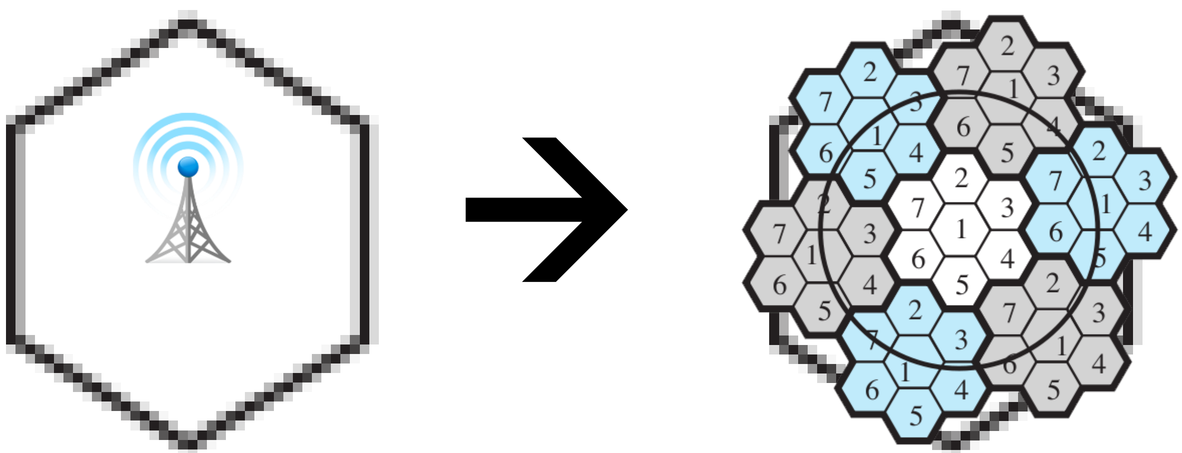
- **Mobile Cellular Networks concept:**
  - In a **Cellular** Network a geographical area is **split** into **several smaller land areas** called **Cells,** each served by a **fixed Base Station**.
  - **Service continuity** within this area is achieved by **handover**, which is the **seamless transfer of a call** from one Base Station to the other as the Mobile Station crosses Cell boundaries.





Cellular Network Advantages

Question: **Why** mobile network providers install several thousands of Base Stations throughout the country (**which is quite expensive**) and do not use powerful transmitters with huge cells?

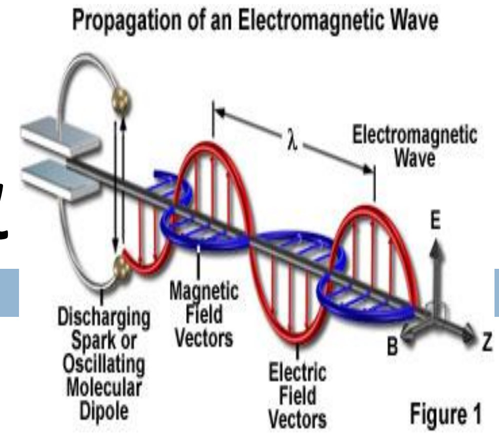


Cellular Network Advantages

Answer: Because Cellular Network provides:

- **Higher Capacity since smaller cells are used and the frequency reuse concept is applied**
- **Less Transmission Power is required by the MS to reach the BS, and vice versa, in shorter distances → Thus less the energy consumption (improves battery life for the MSs, lower power emissions thus positive health impacts, etc.)**
- **Interference is Reduced as less transmission power is required for the signal to cover shorter distances, thus less intra- and inter- cell interference.**
- **More Robustness to the network as if one BS fails, only one small part of the network will be affected.**

Electromagnetic Waves Ηλεκτρομαγνητικά Κύματα



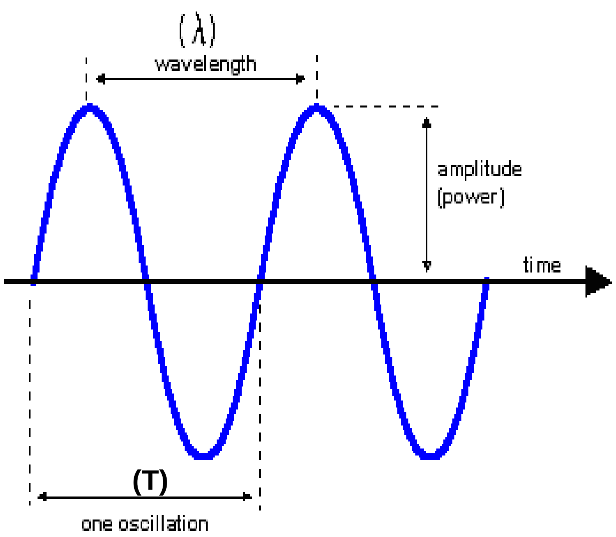
- The **electromagnetic waves** are **created** by the **vibration (ταλάντωση) of an electric charge**. This vibration creates a wave which has both an **electric** and a **magnetic field** and have the ability to **propagate through space**.
- The **speed of the electron vibration (η ταχύτητα ταλάντωσης των ηλεκτρονίων)** determines the **wave's frequency (measured in hertz).**
- Parameters that describe electromagnetic waves include **Frequency (f), Period (T), Amplitude (A) and Wavelength (λ)**.

Electromagnetic Waves
Ηλεκτρομαγνητικά Κύματα

- **Frequency (f) (Συχνότητα),** is the number of complete oscillations (or cycles) which take place in a second.
  - Measured in **hertz** .

$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$

- **Period (T) (Περίοδος)** is the **amount of time** required for **one oscillation** (cycle) and is measured in **seconds**.
- **Amplitude (A) (Πλάτος)** is the value or **strength (power)** of the signal over time. It is measured from the middle point until the peak point of the oscillation. The higher the amplitude the more the energy the radio ware is carrying. It is typically measured in **watts** or **volts**.
- **Wavelength (λ) (Μήκος Κύματος)** is the **distance occupied** by a **single oscillation** of the signal, and is usually **measured in meters**
  - Or, the distance between two points of **corresponding phase** of two **consecutive cycles (δύο αντίστοιχων φάσεων δυο διαδοχικών ταλαντώσεων).**



Electromagnetic Waves
Ηλεκτρομαγνητικά Κύματα

- **All electromagnetic (radio) waves travel** at the **speed of light**
  - C : Speed of Light (m/s) = ($3x10^8$ m/s or 300,000,000 m/s)
- In vacuum (e.g., the air), **all electromagnetic waves travel at this speed** .
- In copper or fiber the speed slows down to about 2/3 of this value.

- **Relationship** between the **Speed**, the **Frequency** and the **Wavelength** of the radio wave:
  - **Speed (C)= Frequency (f) x Wavelength (λ)**
    - **Speed** (**meters/sec**)
    - **Frequency** (oscillations per second; in Hz/second)
    - **Wavelength** (in meters)

Electromagnetic Waves
Ηλεκτρομαγνητικά Κύματα

- **Speed (C)= Frequency (f) x Wavelength (λ)**

  → Wavelength (λ) = Speed (C) / Frequency (f)

  → Frequency (f) = Speed (C) / Wavelength (λ)

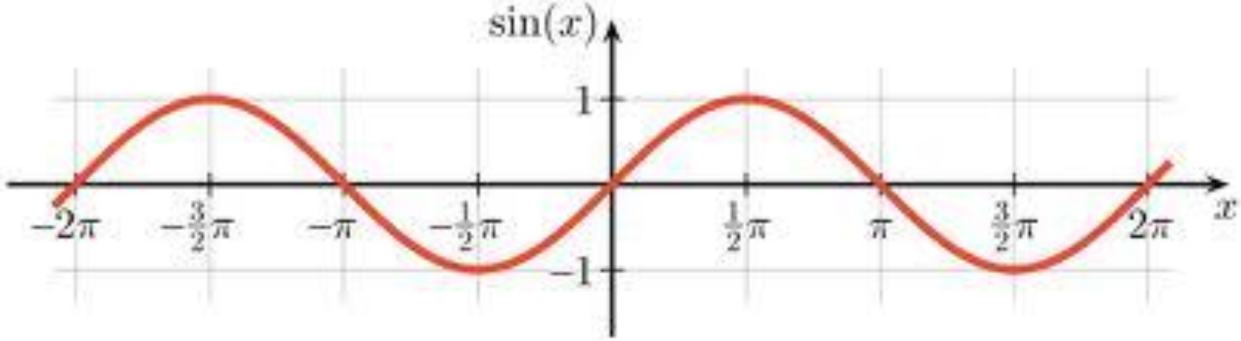
Frequency	Wavelength
60 Hz	5,000 km
100 MHz	3 m
800 MHz	37.5 cm
20 GHz	15 mm

Electromagnetic Waves
Ηλεκτρομαγνητικά Κύματα

- **Relationship** between the **Frequency (f)** and the **Period (T)** of the wave:
  - **Frequency** (total number of oscillations performed in one second)
  - **Period** (time required for one complete oscillation)
  - **Period (T)= 1/Frequency (f)**
  - **Examples:**
    - **Frequency** = 60 Hz → **Period** = 0.0166 seconds
    - **Frequency** = 100 MHz → **Period** = 1×10^{-8} seconds
    - **Frequency** = 800 MHz → **Period** = 1.25×10^{-9} seconds
    - **Frequency** = 20 GHz → **Period** = 5×10^{-11} seconds

Electromagnetic Waves – Sine Wave

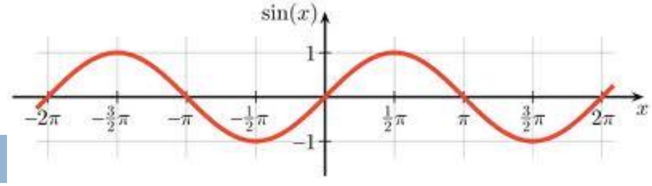
- **General Sine Wave:**
  - **s(t) = A sin(2πft + ϕ)** → **A:** Amplitude**, f:** Frequency**, ϕ:** Phase
  - Note: 2π radians = 360° = 1 Period

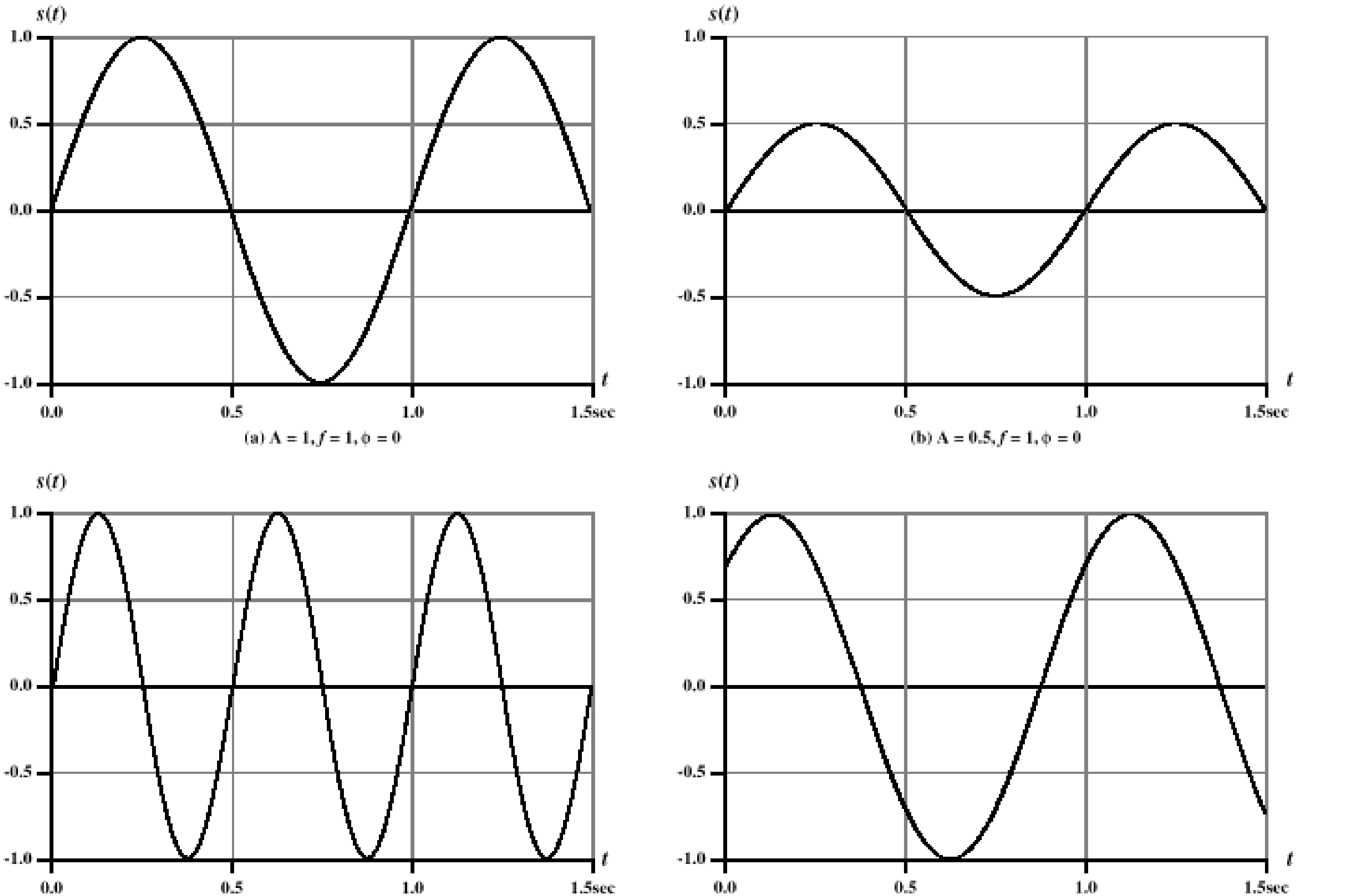


- The picture in the next slide shows the **effect of varying each of the three parameters** (**A**, **f** and **ϕ**)
  - (a) A = 1, f = 1 Hz, ϕ = 0; thus T = 1s
  - (b) Reduced peak amplitude; A=0.5, f = 1 Hz, ϕ = 0
  - (c) Increased frequency; A = 1, f = 2 Hz, ϕ = 0; thus T = 0.5s
  - (d) Phase shift; A = 1, f = 1 Hz, ϕ = π/4 radians (45 degrees)

Electromagnetic Waves – Sine Wave

$s(t) = A \sin(2\pi f t + \phi)$





(a) $A = 1, f = 1, \phi = 0$

(b) $A = 0.5, f = 1, \phi = 0$

(c) $A = 1, f = 2, \phi = 0$

(d) $A = 1, f = 1, \phi = \pi/4$

Low Frequencies Vs High Frequencies
Χαμηλές Συχνότητες Vs Ψηλές Συχνότητες

Low frequency = long wavelengths
High frequency = short wavelengths

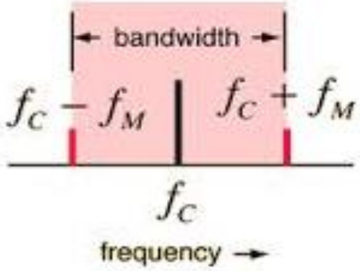
- **Lower frequency waves** have **better penetration (Καλύτερη Διαπέραση)**, meaning they pass through objects such as walls with **less attenuation (λιγότερη εξασθένιση)**, and also can **propagate longer distances (διαδίδονται σε μεγαλύτερες αποστάσεις)**.
- However, **higher frequency waves** are **easier to radiate (ευκολότερο να τα εκπέμψουμε)** **as** they **require** **smaller antennas** **(the antenna size is proportional to the ¼ of the signal wavelength)** to transmit and receive, and can **support higher bandwidths (and thus higher data rates)** than lower frequency waves.

Low Frequencies Vs High Frequencies
Χαμηλές Συχνότητες Vs Ψηλές Συχνότητες

- **Frequency Vs Coverage (Συχνότητα Vs Ραδιοκάλυψη)**
  - Καθώς η **συχνότητα αυξάνεται**, οι **απώλειες που προκαλούνται λόγω απορρόφησης της ενέργεια του σήματος από την ατμόσφαιρα ή από άλλα μέσα τα οποία διαπερνά το σήμα αυξάνονται**, οι οποίες με τη σειρά τους **μειώνουν γρηγορότερα την ενέργεια που μεταφέρεται**.
  - Το τελικό **αποτέλεσμα** είναι **πιο μικρή ραδιοκάλυψη**.
  - Αυτός είναι ο κύριος λόγος που ένα σήμα WLAN **5 GHz**, που χρησιμοποιεί την **ίδια ισχύ εκπομπής** και κέρδος κεραίας με ένα WLAN σήμα των 2.4 GHz, έχει **μικρότερο εύρος**.

Carrier Signal, Modulation, Carrier Frequency and Bandwidth

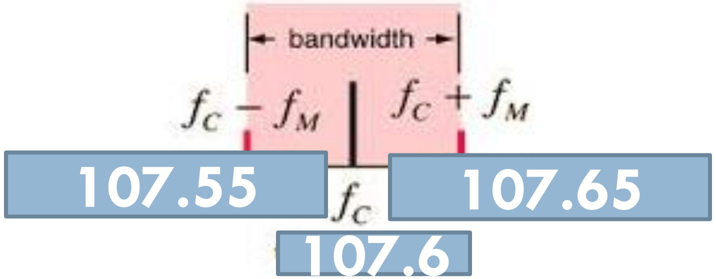
- The **Bandwidth (i.e., the frequency band) that needs to be allocated to send the data** it **strongly relates to the data rate that needs to be achieved** (**measured in bits per second (bit/s)**)
- Usually if the **Data Rate = R bps**, then the **Bandwidth** that should be allocated for the transmission should be **equal to 2 x R** (two times greater) so as to be able to carry the data with the specific data rate.
  - **However this also strongly depends on the Modulation Technique that will be used.**
- The **frequency band (Bandwidth)** that will be allocated will be in the range from **(f_C – f_M) to (f_C + f_M) having t**he carrier frequency (**f_C**) in the middle.



$$Bandwidth = f_{MAX} - f_{MIN}$$

Carrier Signal, Modulation, Carrier Frequency and Bandwidth

- For example, if a radio station that radiates at 107.6 MHz (Carrier Frequency), if it transmits a 50 Kbps audio, it will require **100 KHz bandwidth**!
  - Thus it will use the **frequency band** from **107.55 MHz** to **107.65 MHz** to transmit the audio.
- **The larger the bandwidth**, **the more data** that can be **conveyed** (να μεταφερθούν) **through the channel**.



Carrier Signal, Modulation, Carrier Frequency and Bandwidth

- Metaphorically speaking, imagine a **Train** that carries mail **letters**:
  - The **Carrier Signal (or Carrier Wave)** can be described as a **“Train”.**
  - **The Carrier frequency** can be described as “**The rail that the Train will follow”** to reach its destination.
  - **Modulation** can be described as the **Person Responsible for putting the** “letters” in the **“Train Wagon”.**
  - The **Bandwidth** can be described as the **“number of Wagons allowed to be carried by the Train”.**
    - The greater the “number of wagons allowed” to be carried by the train, the more the letters that can be carried at a given point in time.

Decibel (dB)

- **Decibel (dB)** is a logarithmic unit that is used to **describe a ratio (περιγραφή μιας αναλογίας)**.
  - Let say we have two values P1 and P2. The ratio between them **can be expressed in dB** and is computed as follows:
    - $10 \times \log_{10} (P1/P2)$ dB
  - **Example**: Transmit power **P1 = 100W**, Received power **P2 = 1 W**
    - The ratio is $\mathbf{10 \times \log_{10}(100/1)}$ = **20dB**. → P1 is **20 dB** stronger than P2
- **dB** unit can describe **very big ratios** with **numbers of modest size**.
  - Example: Transmit power = 100W, Received power = 1mW
    - Transmit power is **100,000 times** of received power
    - The **ratio** here is $10 \times \log_{10}(100/0.001)$ = **50dB** → Transmit power is **50 dB** stronger than Received power

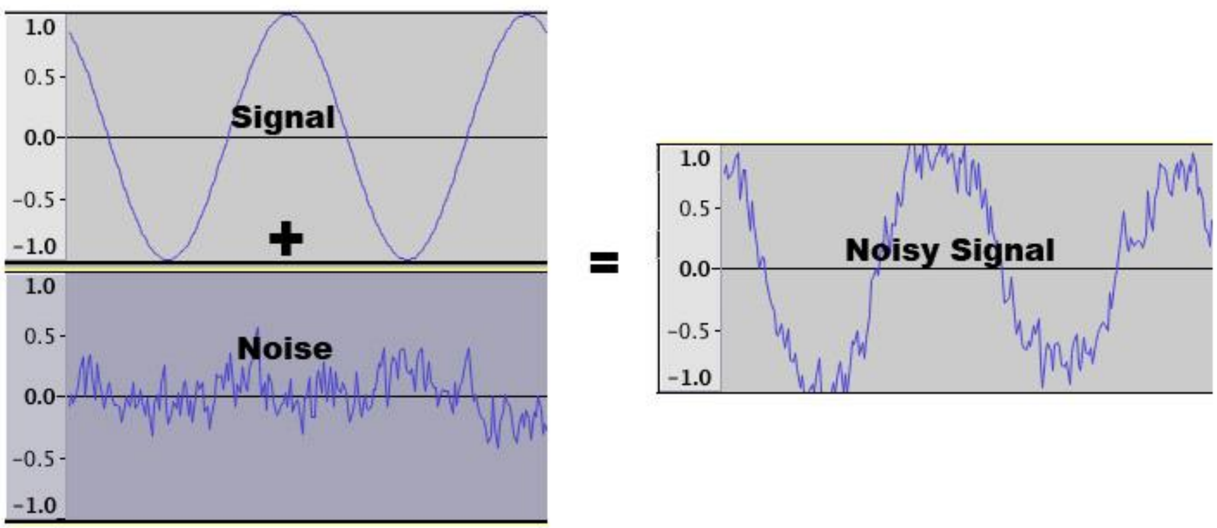
dBm and dBW

- **dBm** is used to denote a **power level (ένταση ισχύς) with respect to 1mW** (**milliwatt**) as the **reference power level**.
  - **Question:** Let say transmit power of a system is 100W. What is the transmit power in unit of dBm?
  - **Answer**: Transmit_Power(dBm) = $10\log_{10}(100W/1mW)$ = $10\log_{10}(100W/0.001W)$ = $10\log_{10}(100{,}000)$ = **50dBm**

- **dBW** is used to denote a **power level** with **respect to 1W** as the reference power level.
  - **Question:** Let say that the transmit power of a system is 100W. What is the transmit power in unit of dBW?
  - **Answer**: Transmit_Power(dBW) = $10\log_{10}(100W/1W)$ = $10\log_{10}(100)$ = **20dBW.**

Noise

- **Noise** is an error or **undesired random disturbance (ανεπιθύμητη τυχαία αναταραχή)** of a useful **information signal** in a communication channel.
- Is a **summation of unwanted or disturbing energy** from natural (i.e., thermal noise; generated by random motion of free electrons in the atmosphere, light, pressure, sounds, etc.) and sometimes man-made sources (i.e., microwave ovens).



Signal to Noise Ratio (SNR)

- **Compares the power** of a **desired signal** to the **power** of **background noise**. It is defined as the ratio of signal power to the noise power, often expressed **in decibels**.
- A **ratio higher than 1:1** (greater than 0 dB) indicates **more signal than noise**.
- This value is typically **measured at the Receiver**

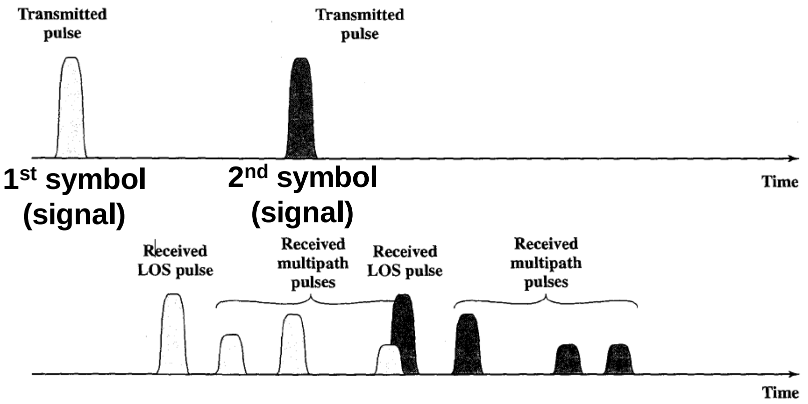
$$SNR_{dB} = 10\log_{10}\left(\frac{P_{Signal}}{P_{Noise}}\right)$$

- A **high SNR** means **a high-quality signal**.
- If the **SNR is low the Receiver** may not be able to decode the signal correctly (resulting in data losses).

Signal to Interference Plus Noise Ratio (SINR)

$$SINR_{dB} = 10\log_{10}\left(\frac{P_{Signal}}{P_{Noise} + P_{Interference}}\right)$$

- **SINR** is defined as **the power of a certain signal of interest** divided by **the sum of the interference power** (**from all the other interfering signals**) and **the power of the background Noise**.
- **Interference** typically refers to the **addition of unwanted signals to a useful signal** that **modifies**, or **disrupts** a signal as it travels along a channel between a source and a receiver.
  - **Co-Channel Interference** (i.e., interference caused from other channels that uses the same frequency band)
  - **Adjacent Channel Interference** (i.e., interference caused from other channels that uses the adjacent frequencies)
  - **Self-Interference: Inter-symbol Interference** and **Multipath (Fast) Fading** (i.e., interference caused by Multipath Propagation – due to **Delay Spread**)

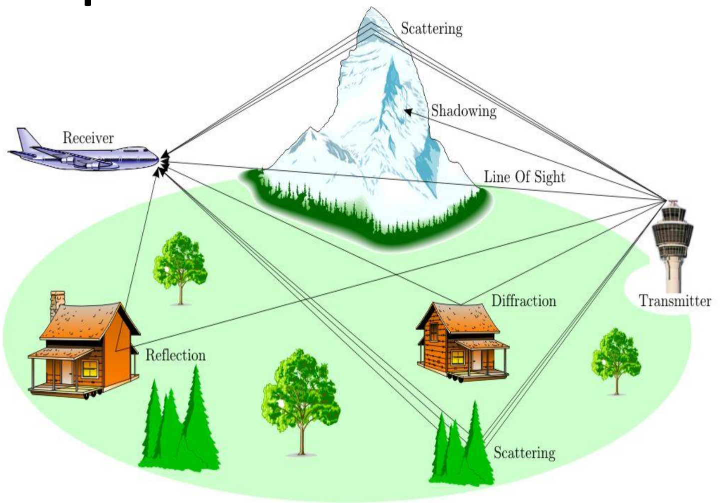


Radio Propagation
Ασύρματη Διάδοση Σήματος

- **Radio propagation** is the **behavior of radio waves** when they are transmitted, or **propagated from one point on the Earth to another**, into the atmosphere **(Ασύρματη Διάδοση** είναι η συμπεριφορά των σημάτων (ραδιοκυμάτων) καθώς διαδίδονται **ασύρματα** στην ατμόσφαιρα από ένα σημείο της γης σε ένα άλλο).
  - We will focus on how radio signals travel (propagate) from one **transmitting antenna** to **another receiving** antenna.

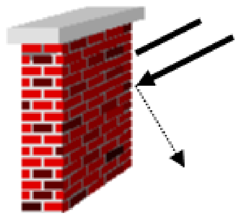
Radio Propagation
Ασύρματη Διάδοση Σήματος

- **Radio Propagation includes:**
  - **Line of Sight (LOS) Transmissions (**Υπάρχει γραμμή ορατότητας μεταξύ Transmitter και Receiver**):** There is a **direct path (**Υπάρχει απευθείας μονοπάτι**) between Transmitter** and **Receiver** (no obstacles in the way).
  - **Non-Line of Sight (NLOS) Transmissions (Δεν υπάρχει γραμμή ορατότητας μεταξύ Transmitter και Receiver)**: **Not a direct path (Δεν υπάρχει απευθείας μονοπάτι) between Transmitter** and **Receiver** (obstacles in the way). When the radio waves reach close to an obstacle (όταν τα ραδιοκύματα βρουν ένα εμπόδιο), the following **propagation phenomena** do occur to the waves:
    - **Shadowing (or blocking, Επισκίαση)**
    - **Refraction (Διάθλαση)**
    - **Reflection (Αντανάκλαση),**
    - **Diffraction (Περίθλαση),**
    - **Scattering (Διασκόρπιση)**

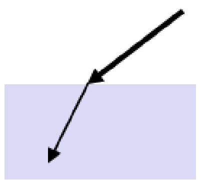


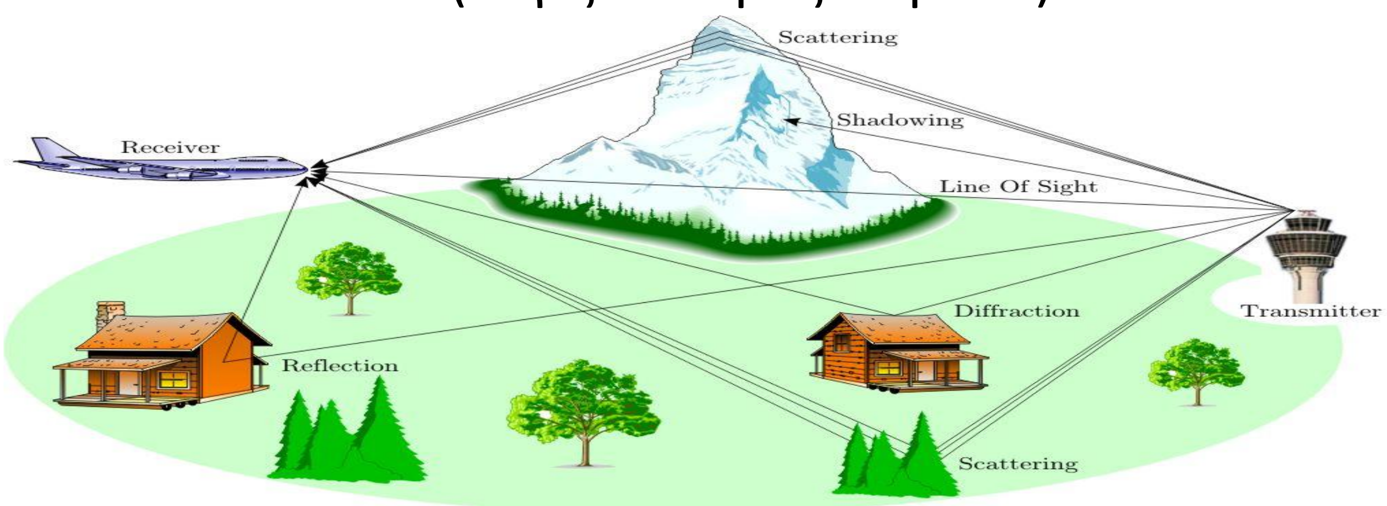
Radio Propagation Phenomena
Φαινόμενα Ασύρματης Διάδοσης

- **Radio Propagation Phenomena (I):**
  - **Shadowing (or blocking, επισκίαση):** The signal can be **blocked due to large obstacles**. The signal may not reach the Receiver.



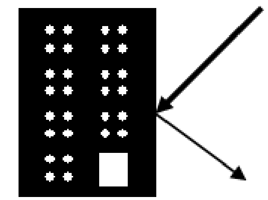
  - **Refraction (Διάθλαση):** Signals that travel **into a denser medium** (σε πιο πυκνό μέσο) not only become weaker (εξασθενούν) but also bents towards the medium (λυγίζουν προς το μέσο)

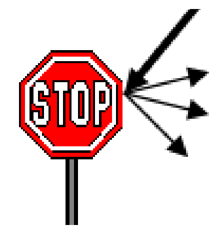




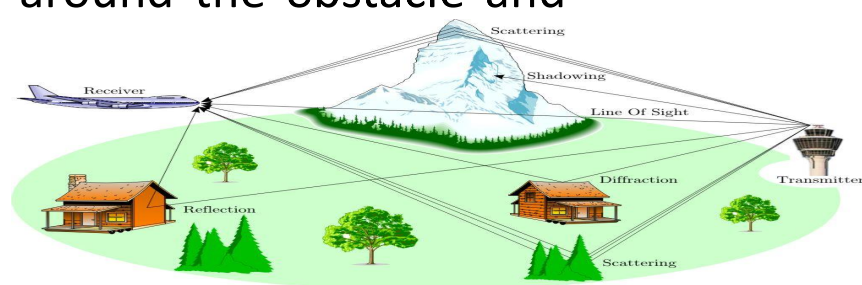
Radio Propagation Phenomena
Φαινόμενα Ασύρματης Διάδοσης

- **Radio Propagation Phenomena (II):**
  - **Reflection (Αντανάκλαση):** The signal can be reflected on buildings. The **reflected signal** is **not as strong as the original** as **objects can absorb some of the signal's energy** (Το ανακλώμενο σήμα δεν θα είναι τόσο δυνατό όσο το αρχικό επειδή κατά την ανάκλαση απορροφάται μερική από την ενέργεια του σήματος).
  - **Scattering (Διασκόρπιση)**: The incoming signal is **scattered into several weaker** outgoing signals**.**
  - **Diffraction (Περίθλαση):** Signals can be deflected (αποστρακίζονται) at the edge of a mountain (or other **surfaces with sharp irregular edges**) and **propagate in different directions** (Waves bend around the obstacle and move in different directions).





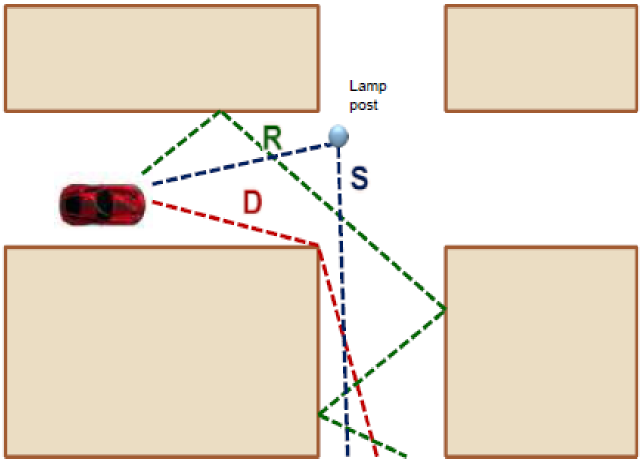
Reflection, Scattering and Diffraction helps transmitting a signal to the receiver if NLOS exists!



Radio Propagation Phenomena
Φαινόμενα Ασύρματης Διάδοσης

- **Reflection (Ανάκλαση)**: Occurs when a propagating electromagnetic wave meets **an object** that is **much larger than its wavelength** (συμβαίνει όταν το εμπόδιο έχει μέγεθος μεγαλύτερο από το μήκος του κύματος). - e.g., the surface of the Earth, buildings, walls, etc.

- **Scattering (Διασκόρπιση)**: Occurs when a propagating electromagnetic wave meets **an object that is smaller than its wavelength** (συμβαίνει όταν το εμπόδιο έχει μέγεθος μικρότερο από το μήκος του κύματος) - e.g., foliage, street signs, lamp posts.



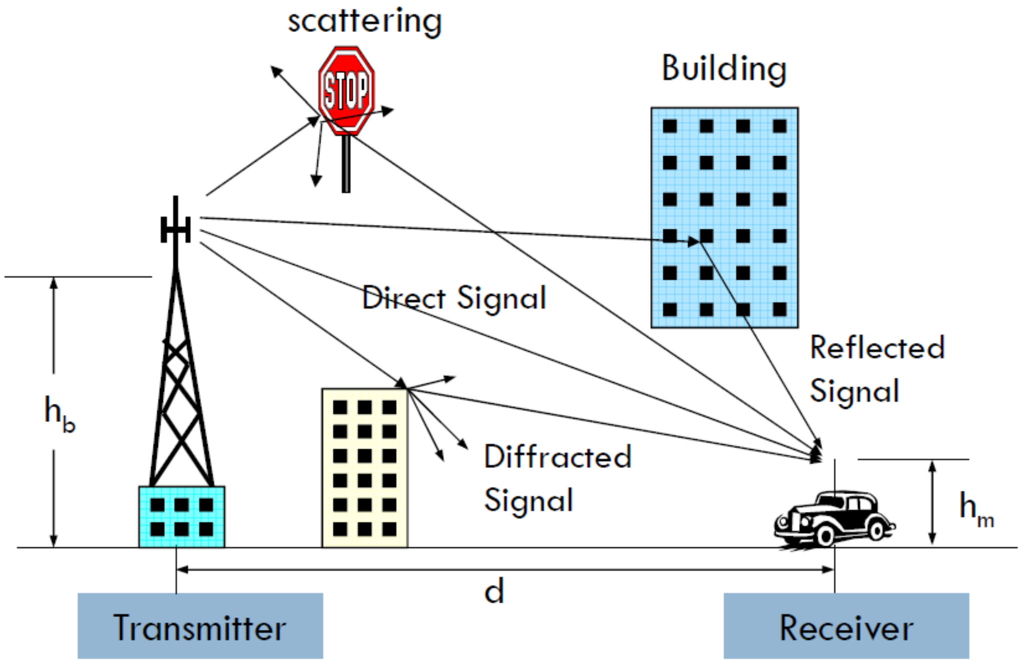
Reflection, Scattering and Diffraction leads to Multipath Propagation!!!

Οδηγούν στην Πολυδιαδρομική Μετάδοση!

Many copies of the same signal will reach the Receiver from many paths of different lengths!

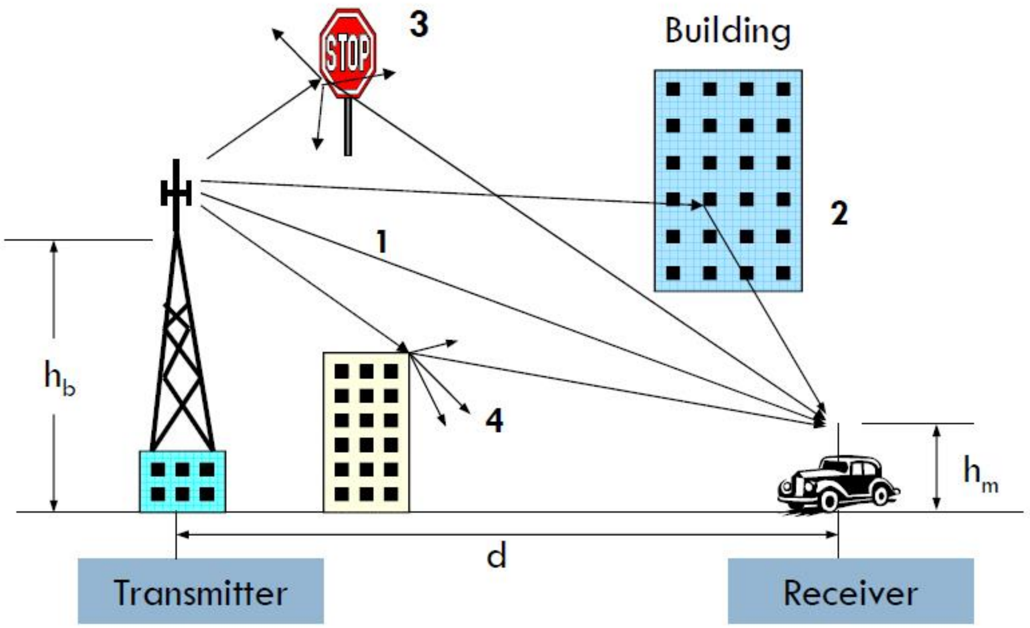
Multipath Propagation Effects
Επιπτώσεις Πολύδιαδρομικής Διάδοσης

- **Transmission paths** between **Sender** and **Receiver** could be:
  - **Direct Paths (Απευθείας Μονοπάτια)** → **LOS** between Transmitter and Receiver.
  - **Indirect Paths (Έμμεσα Μονοπάτια)** → Resulted by Scattering, Diffraction and Reflection by buildings, mountains, street signs, foliage, etc.



Multipath Propagation Effects
Επιπτώσεις Πολύδιαδρομικής Διάδοσης

- **Thus, the Received signal** is **made up of several paths** which can be classified as:
  1. **Direct Path**
  2. **Reflected Path**
  3. **Scattered Path**
  4. **Diffracted Path**



- In this case, **the Receiver** will receive **four different copies** of the **same signal (due to Multipath Propagation).**

Multipath Propagation Effects
Επιπτώσεις Πολύδιαδρομικής Διάδοσης

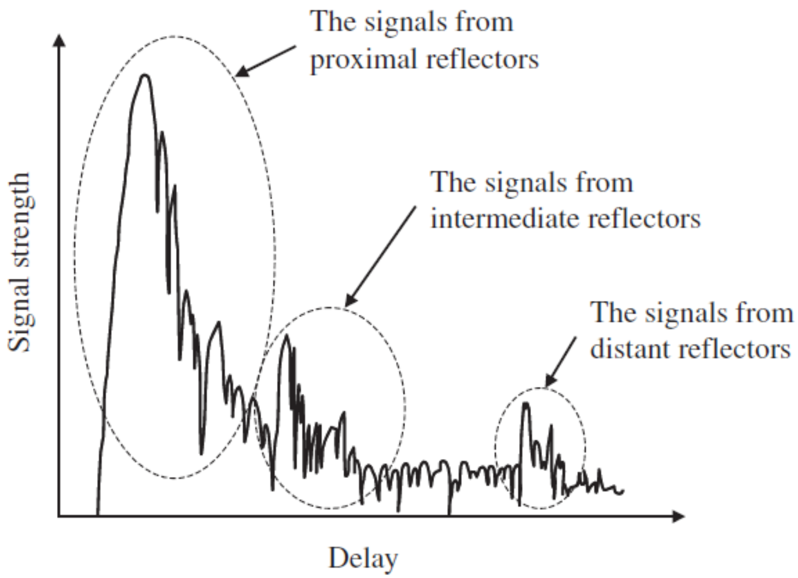
- **Multipath Propagation** results in:
  - **Delay Spread (**Διασκόρπιση σήματος λόγω καθυστερημένων μονοπατιών**)**
  - **Multipath Fading** (referred also as **Fast Fading**) (Ξεθώριασμα σήματος λόγω **constructive (εποικοδομητική)** or **distractive (καταστροφική) interference που προκαλείται από** τα πολλαπλά (καθυστερημένα) μονοπάτια που ακολουθεί το σήμα από τον Transmitter για να φτάσει στον Receiver)
  - **Inter-Symbol Interference (ISI) (**Παρεμβολές μεταξύ δύο διαφορετικών σημάτων/συμβόλων τα οποία στέλνονται στο ίδιο κανάλι (από τον Transmitter στον Receiver), με μια μικρή διαφορά χρόνου.

Although the effects caused, Multipath Propagation is what makes reception of the signal in Non Light Of Sight Conditions possible!!!

Παρά τις επιπτώσεις της, είναι η Πολυδιαδρομική Διάδοση που κάνει δυνατή τη διάδοση του σήματος σε περιπτώσεις που δεν υπάρχει γραμμή ορατότητας μεταξύ του Transmitter και του Receiver!!!

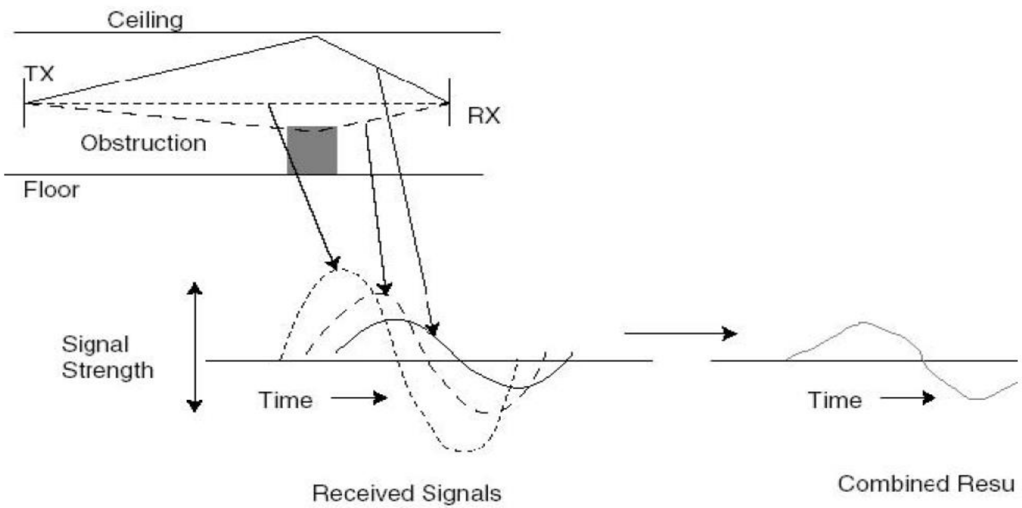
Multipath Propagation Effects
Επιπτώσεις Πολύδιαδρομικής Διάδοσης

- **Delay Spread**
  - When a signal propagates from a transmitter to a receiver, **the signal suffers one or more reflections (το σήμα αντανακλάται αρκετές φορές)**.
    - This forces radio signals to **follow different paths** (Multipath Propagation).
  - Since each path has a **different path length**, **the time of arrival** for **each path** is **different**.
  - The spreading out effect of the signal (Το αποτέλεσμα αυτό της διασποράς του σήματος) is called "**Delay Spread**."
  - The **Delay Spread** is what it **causes the Multipath Fading** and **InterSymbol Interference**.



Multipath Propagation Effects
Επιπτώσεις Πολύδιαδρομικής Διάδοσης

- **Multipath Fading (Known also as Fast Fading)**
  - Each signal copy will experience **differences in attenuation (εξασθένιση)**, **delay**, and **phase shift** while traveling from the source to the receiver.
  - At **the receiver**, these signals **will be combined** (θα προστεθούν), resulting in either **constructive (εποικοδομητική)** or **distractive (καταστροφική) interference**, **amplifying** or **attenuating** (ενισχύοντας είτε εξασθενώντας) the signal power **seen at the receiver**.



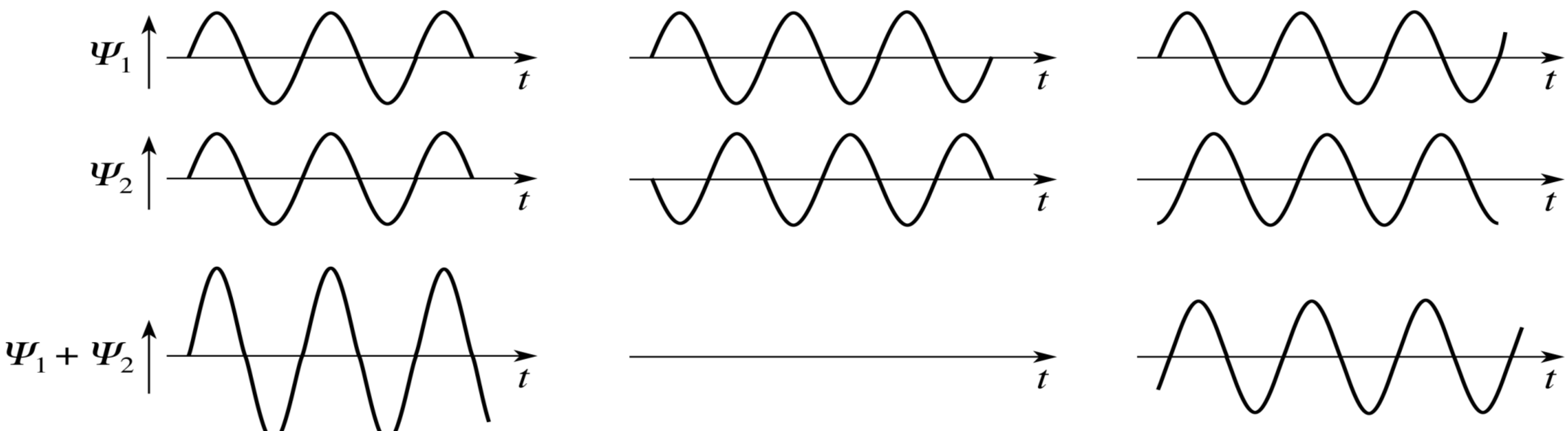
Multipath Propagation Effects
Επιπτώσεις Πολύδιαδρομικής Διάδοσης

- ***Multipath Fading - Signal Properties, the phenomenon of interference***
  - When two or more waves propagates at the same space using the same frequency band, the **net amplitude at each point** is **the sum of the amplitudes** of the **individual waves (i.e., these two waves are combined)**.

Constructive Interference
Signals are in phase

Destructive Interference
Signals are completely out of phase

Signals are slightly out of phase



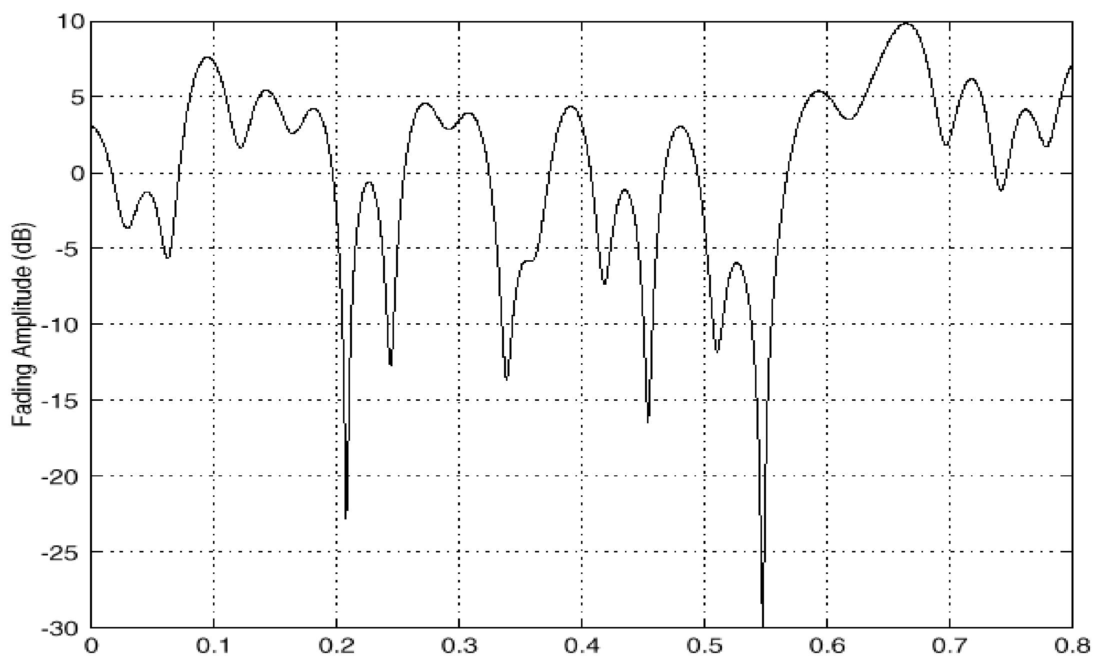
(a) (b) (c)

Multipath Propagation Effects
Επιπτώσεις Πολύδιαδρομικής Διάδοσης

Multipath Fading (Known also as Fast Fading)

- **Strong destructive interference** (Δραστικά καταστροφικές παρεμβολές) is frequently referred to as a **deep fade** (προκαλούν μεγάλη εξασθένιση στο σήμα) and may result in **temporary failure of communication** (προσωρινή αποτυχία της επικοινωνίας) due to a **severe drop** in the channel **Signal to Interference plus Noise (SNIR) ratio**.

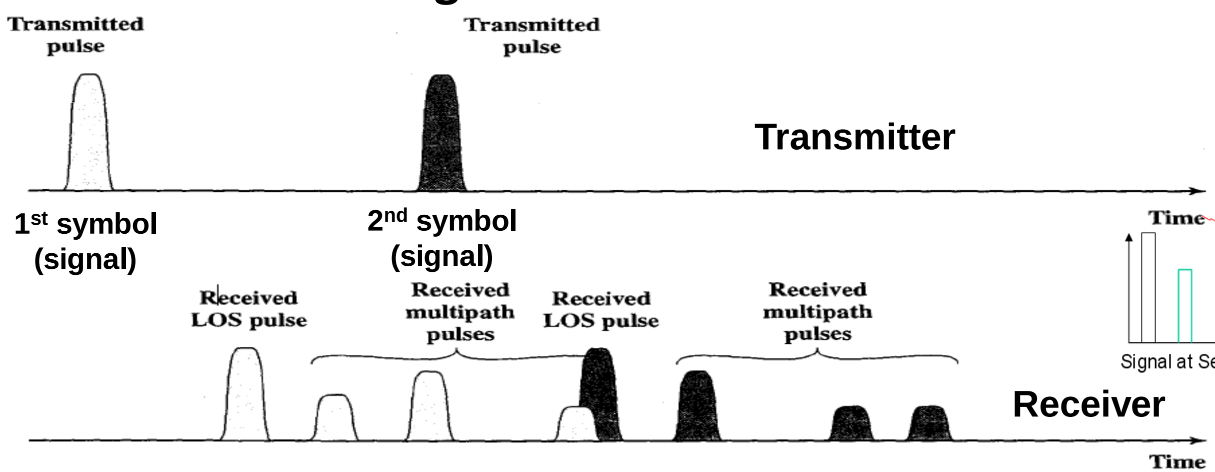
SINR

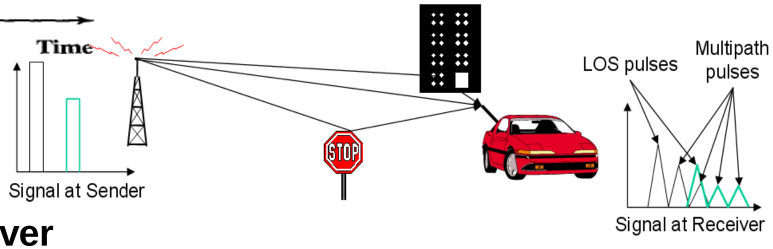


Multipath Propagation Effects
Επιπτώσεις Πολύδιαδρομικής Διάδοσης

Inter-Symbol Interference (ISI)

- Due to **Delay spread**, the **energy indented for one symbol splits over to an adjacent symbol** (**Η ενέργεια που προοριζόταν για ένα σήμα, διασκορπίζεται και ένα μέρος της συμπίπτει με την ενέργεια ενός άλλου σήματος**) (appeared as Noise).
- Due to this interference, the **signals of different symbols can cancel each other out** (σήματα διαφορετικών συμβόλων μπορούν να εξουδετερωθούν μεταξύ τους), leading to **misinterpretation (παρερμήνευση)** at the **receivers** and **causing errors during decoding.**

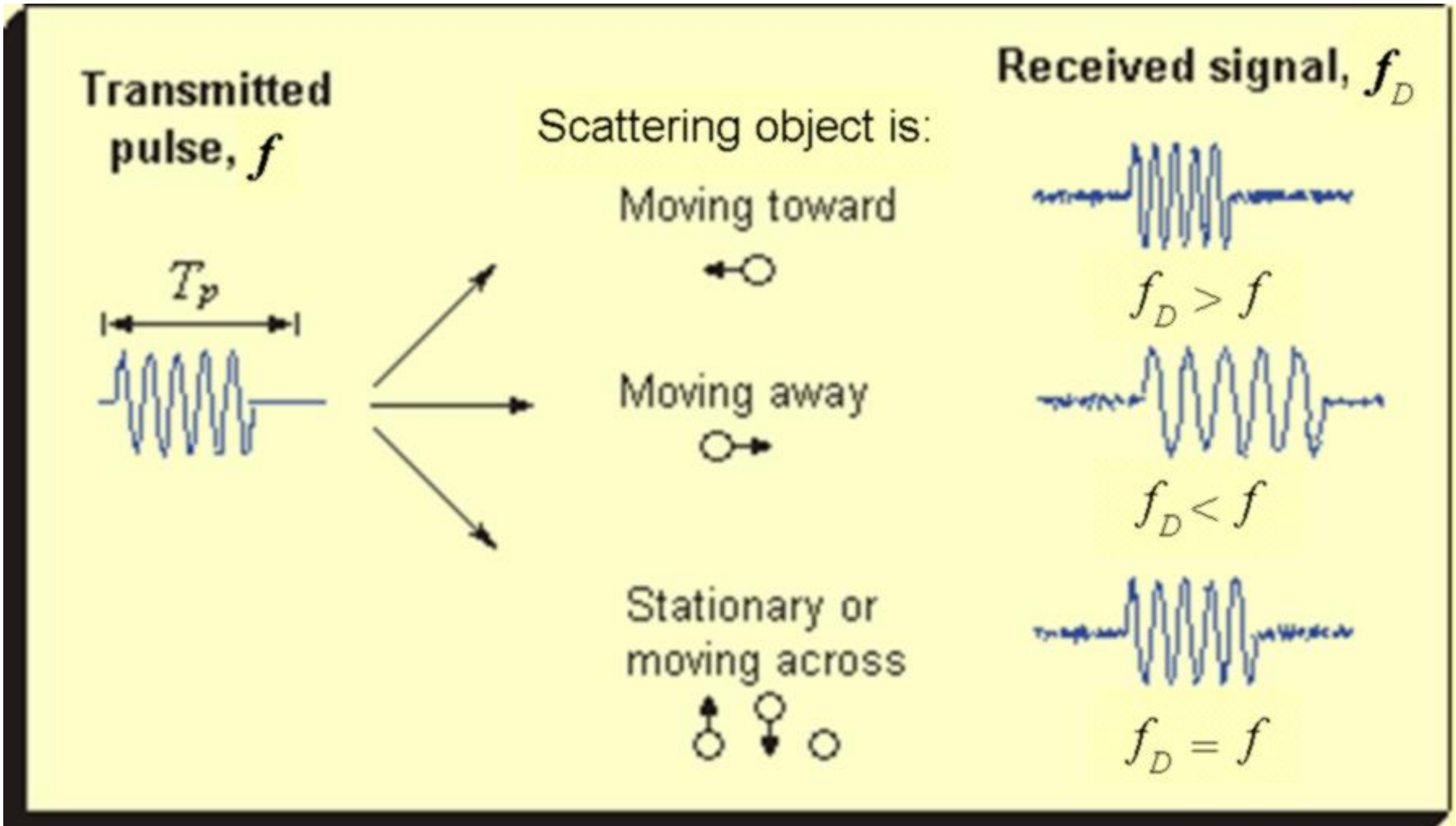




Doppler Effect

- The **Doppler effect** (or **Doppler shift**) is the **change in the frequency** (and thus the wavelength) of a wave for an observer (i.e., Mobile Station (MS)) moving relative to its source (i.e., Base Station (BS)) **(**Είναι η **αλλαγή στη συχνότητα του σήματος** που διακρίνει ένας **κινούμενος παρατηρητής κινούμενος** σε **σχέση με την πηγή** του σήματος)**.**
- In a wireless and mobile system, the location of the **BS is fixed** while the **MSs are mobile**.
  - Therefore, **as the receiver (i.e., the MS) is moving** with respect to the wave source (i.e., the BS), **the frequency of the received signal** will **not be the same as the one transmitted by the source** (ο receiver θα αντιλαμβάνεται διαφορετική συχνότητα από εκείνη που εκπέμπεται από τον Transmitter).
  - Compared to the **emitted frequency** (Συγκριτικά με την εκπεμπόμενη συχνότητα), the **received frequency** is **higher during the approach (προσέγγιση)** and **lower during the recession** (απομάκρυνση) from the source.
  - Also, the **speed (v)** of the receiver and its **direction (θ)** relative to the source, matters.

Doppler Effect



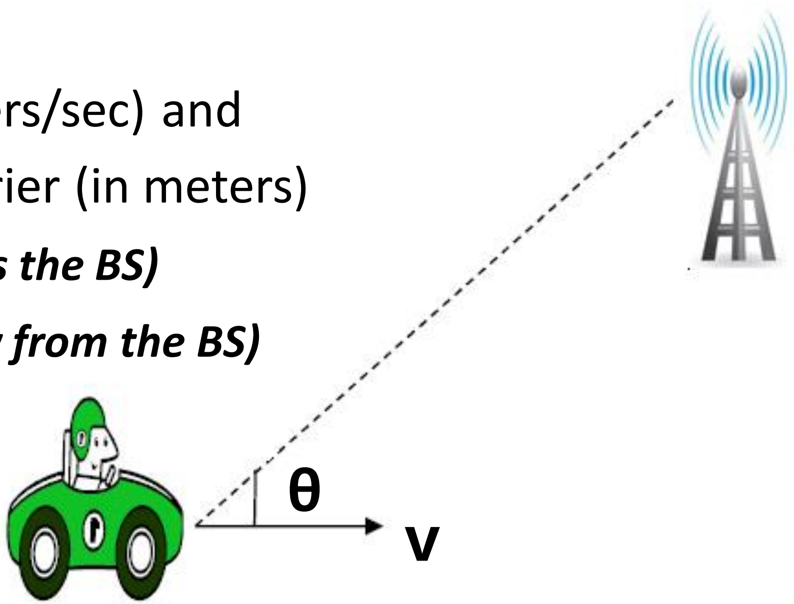
Doppler Effect

- The **frequency (f_r) that the moving user (the Receiver) will** experience is $f_r = f_c + f_d$

Where: f_c is the **emitted (from the source) radio wave carrier frequency** and
f_d is the Doppler frequency or **Doppler shift**

- **Doppler frequency** or **Doppler shift** is $f_d = \frac{v}{\lambda} \cos\theta$

Where: f_d *is measured in Hertz*
v is the moving speed (in meters/sec) and
λ is the wavelength of the carrier (in meters)
When θ = 0º (MS moving towards the BS)
When θ = 180º (MS moving away from the BS)



Doppler Effect

$$f_d = \frac{v}{\lambda} \cos \theta$$

An example:

Radio wave Carrier Frequency (f_c) = *100 MHz (100,000,000 Hz)*

→ ***Wavelength (λ)*** *= C / f = 300,000,000 / 100,000,000*

→ ***λ = 3 meters***

Speed of the User (v) 60 Km/h → v = *16.6666666 meters/second*

We assume that ***the MS is moving towards the source*** *(θ = 0º)*

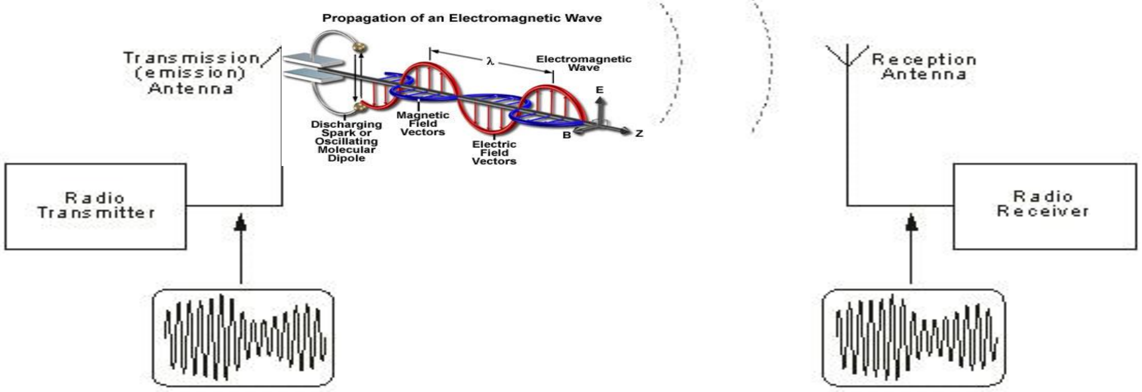
f_d = (16.66666666/3) cos 0º → f_d = 5.5544Hz

$f_r = f_c + f_d$ =100,000,000 Hz + (5.5544Hz) → f_r = 100,000,005.55 Hz

Antennas

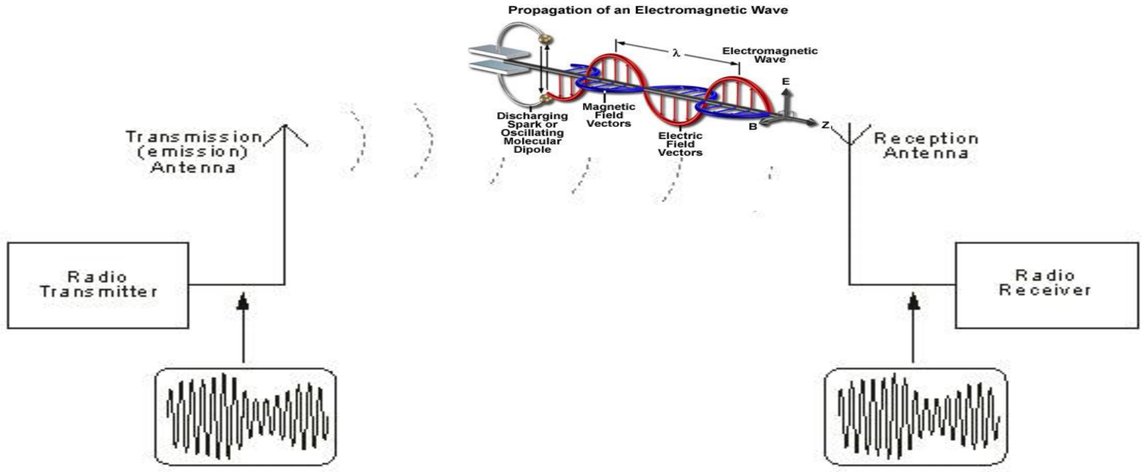
- The **first antennas** were built in 1888 by German physicist **Heinrich Hertz** in his pioneering experiments to **prove the existence of electromagnetic waves**.
- An antenna is an electrical device which converts **oscillating electric currents** into **radio waves** (μετατρέπει ταλαντευόμενα ηλεκτρικά φορτία σε ραδιοκύματα), and vice versa.
  - **Transmission**: Radiates (εκπέμπει) electromagnetic energy into space.
  - **Reception**: Collects electromagnetic energy from space.
- In two-way communication, the same antenna can be used both for Transmission and Reception.

Antennas



- Typically an antenna consists of an arrangement of **metallic conductors** (“**antenna elements**”) (**μια διάταξη μεταλλικών αγωγών**), **electrically connected (using a cable)** to the Receiver or the Transmitter.
- In **Transmission:**
  - The **Radio Transmitter** **applies** a **modulated** **oscillating electric current** to the antenna.
  - This **oscillating electric current** will create an **oscillating** **magnetic field** around the **antenna elements**, while **the** **charge of the electrons** **(το φορτίο των ηλεκτρονίων)** also creates an oscillating **electric field** along the elements.
  - These time-varying fields (μεταβαλλόμενα στο χρόνο πεδία) **radiate away from the antenna** into space **as a moving electromagnetic wave** (radio waves).

Antennas



- In **Reception:**
  - **During Reception**, the **oscillating electric** and **magnetic fields** of an incoming radio wave **exert force on the electrons (ασκούν μια δύναμη στα ηλεκτρόνια) in the antenna elements**, causing them to **move back and forth**, creating **oscillating electric currents in the antenna**
  - The produced **oscillating electric current** is **applied to the Radio Receiver to be amplified and demodulated** so as to **extract the information included**.

Antennas

- According to their **applications** and **technology available**, antennas generally fall in one of **two categories (Omni-Directional and Directional)**:
  - **Omni-directional (Όμοιο-κατευθυντικές)** which **receive or transmit (radiate) radio waves equally more or less in all directions (Two types are the Isotropic** (Ισοτροπικές κεραίες) and **Dipoles** (Κεραίες Διπόλων)**)**.

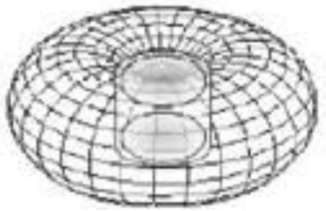
    - Employed when **the relative position of the other station is unknown or arbitrary (αυθαίρετη, τυχαία)**.
    - Omni-directional antennas have **shorter range (μικρότερη εμβέλεια) than Directional antennas**, but the **orientation (προσανατολισμός) of the antenna** is relatively **inconsequential (ασήμαντος)**.

Antennas

- **Isotropic** Antenna **(Ισοτροπική κεραία)**
  - Εκπέμπει το σήμα με την ίδια δύναμη σε όλες τις κατευθύνσεις (σφαιρικά)
- **Dipole Antenna (Κεραίες Διπόλων)**
  - Οι κεραίες διπόλων έχουν ένα διαφορετικό διάγραμμα ακτινοβολίας συγκρινόμενες με μια ισοτροπική κεραία.
  - Το **διάγραμμα ακτινοβολίας διπόλων** είναι **360º στο οριζόντιο επίπεδο** και συνήθως περίπου **75º στο κάθετο επίπεδο** (υποθέτοντας φυσικά ότι το δίπολο στέκεται κατακόρυφα)

Radiation Pattern
Διάγραμμα Ακτινοβολίας

Isotropic

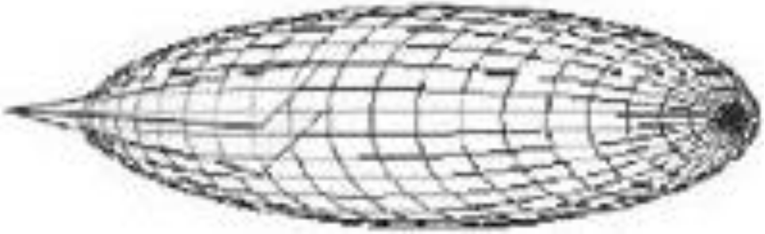


Dipole

Antennas

- **Directional** antennas (Κατευθυντικές Κεραίες) **transmit (εκπέμπουν) radio waves in a particular direction covering a specific sector** and **receive radio waves from that direction/sector only**.
  - Directional antennas have the advantage of **longer range (μεγαλύτερη ραδιοκάλυψη)** and **better signal quality (καλύτερο σήμα)**, but **must be aimed carefully in a particular direction**

Radiation Pattern
Διάγραμμα Ακτινοβολίας



Directional Antenna

Antennas

- For example:

  - **Directional antenna**: A dish antenna (receiving a TV signal) must be pointed to the satellite to be effective.

  - **Omnidirectional antenna (isotropic or dipole)**: A typical Wi-Fi antenna in a smartphone (isotropic) or in an Access Point (isotropic or dipole). As long as the Base Station is within range, the antenna can be in any orientation in space.

Digital Modulation

- The **modulation** that will be applied on the (analog) **carrier signal to include the data that will be carried (e.g., 1 or 0, etc.)** are **chosen** from a **finite number** of **M alternative symbols (or signal units** or **signal elements) based on the Digital Modulation Technique** and the ***Modulation Alphabet*** **that will be used**. (Η διαμόρφωση που θα γίνει στον (αναλογικό) μεταφορέα σήματος για να συμπεριλάβουν την πληροφορία που θα μεταφερθεί (π.χ., 1 ή 0) επιλέγονται από ένα πεπερασμένο αριθμό από εναλλακτικά σύμβολα (σήματα) ανάλογα με την **Τεχνική διαμόρφωσης και** το ***Αλφάβητο Διαμόρφωσης*** που θα χρησιμοποιηθεί.
  - Symbol Pattern 1 → 0
  - Symbol Pattern 2 → 1
- This **same Modulation Alphabet** have to be **used both** from the **Transmitter** (for modulating the signal) **and the Receiver** (for demodulating the signal)

Modulation for Wireless
Digital Modulation

- The general form (pattern) of the modulated signal is (Η γενική μορφή ενός διαμορφωμένου σήματος):

$$s(t) = A(t)\,\sin(2\pi \times (f_c + f_m(t))\,t + \phi(t)$$

Modulation for Wireless
Digital Modulation

- **The three essential parameters that can be modulated (**Οι τρείς βασικές παράμετροι που μπορούμε να διαμορφώσουμε**)**

$$s(t) = A \sin(2\pi f t + \phi)$$

- Amplitude value (**A**) — **ASK** (Amplitude Shift Keying)
- Frequency value (**f**) — **FSK** (Frequency Shift Keying)
- Phase value (**ϕ**) — **PSK** (Phase Shift Keying)

- **Digital modulation**: Amplitude (***A***), frequency (***f***) and Phase (ϕ) are used to represent a **digital state**. (Στην Ψηφιακή διαμόρφωση το **πλάτος**, η **συχνότητα**, και η **φάση** του σήματος χρησιμοποιούνται για να αναπαραστήσουν μία **ψηφιακή κατάσταση ή τιμή**)

Basic Digital Modulation Techniques

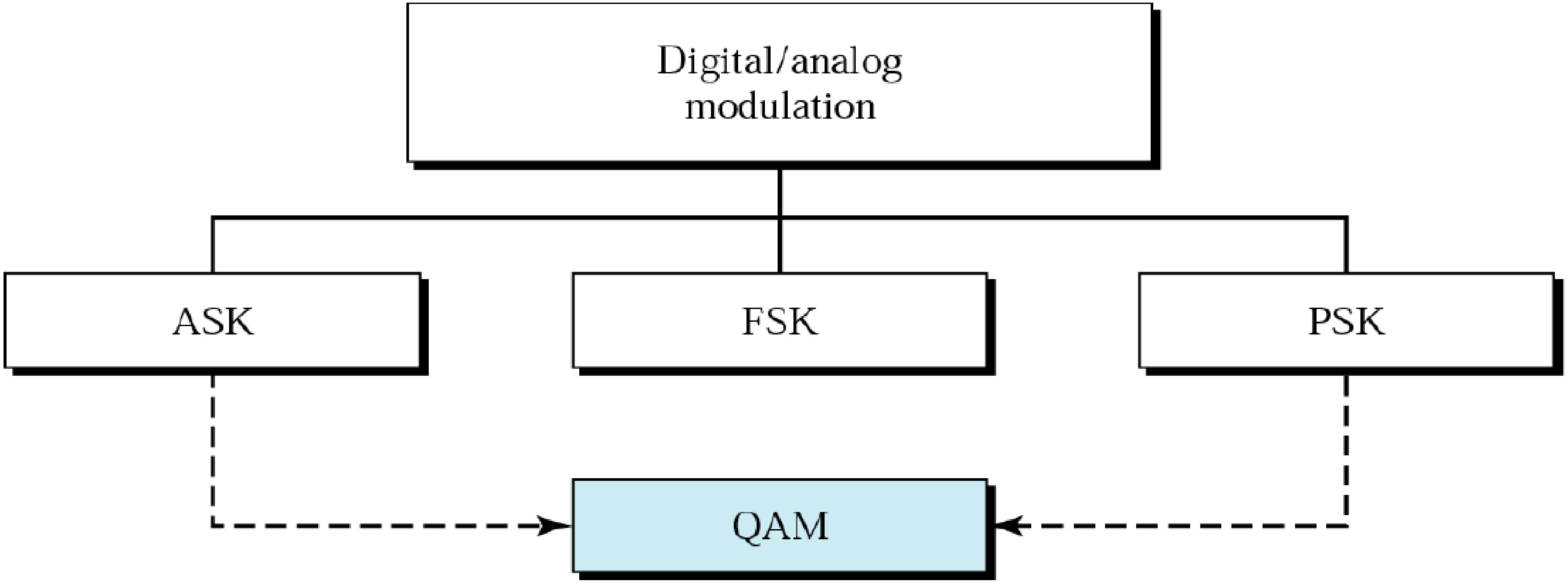
- **Basic Digital Modulation Techniques** work by **varying** the **Amplitude**, **Frequency** or **Phase** (**or a combination of them**) of **a sinusoidal carrier wave** depending on the **information (data)** that will be transmitted and the **Modulation Alphabet** that will be used.

  - **ASK**: Amplitude Shift Keying $s(t) = A\sin(2\pi f t + \phi)$
  - **FSK:** Frequency Shift Keying $s(t) = A\sin(2\pi f t + \phi)$
  - **PSK:** Phase Shift Keying $s(t) = A\sin(2\pi f t + \phi)$
  - **Quadrature Amplitude Modulation (QAM)** or **Amplitude Phase Shift Keying (APSK)**

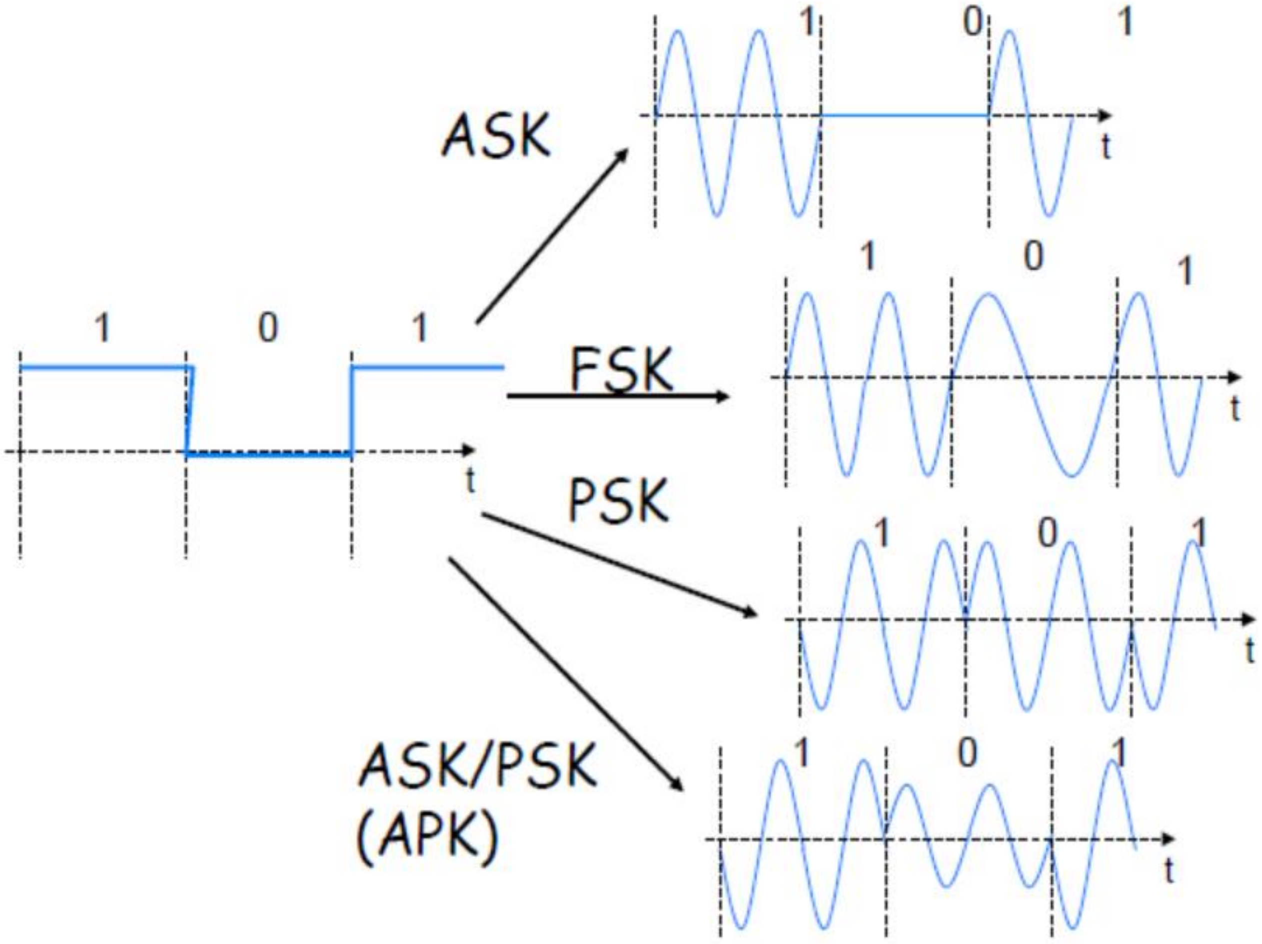
    $$s(t) = A\sin(2\pi f t + \phi)$$

Basic Digital Modulation Techniques

- Types of Digital to Analog Modulation



Basic Digital Modulation Techniques Illustration



$A(t).\sin[2.\pi.f_c.t]$

$\sin[2.\pi.(f_c+f_m(t)).t]$

$\sin[2.\pi.f_c.t + \theta(t)]$

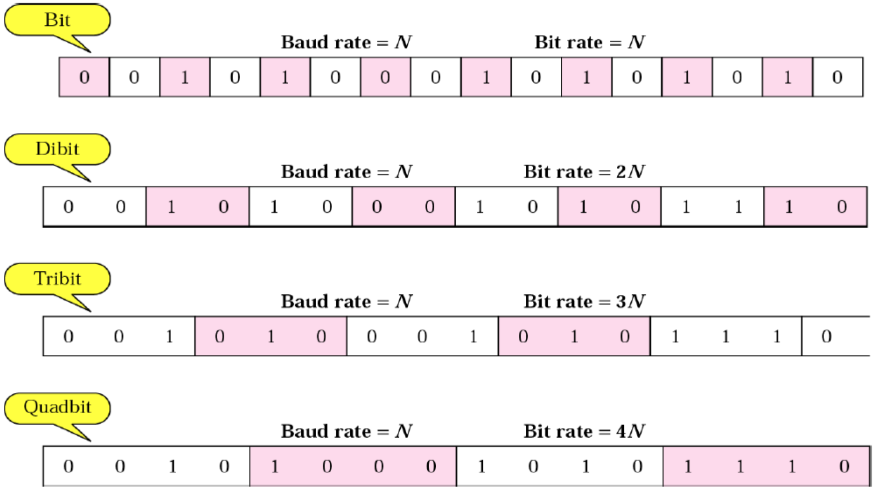
$A(t).\sin[2.\pi.f_c.t + \theta(t)]$

Bit Rate and Baud Rate

- **Bit Rate** is the **number of bits (data) that can be carried per second**.
- **Baud Rate** is the **number** of **signal units (or symbols) per second used for carrying the bits (and achieve the Bit Rate).**
  - **Baud Rate** can be **less than** or **equal** to the **bit rate** → Note that **each symbol can carry one or more bits!**
  - **Baud Rate** is important in **Bandwidth efficiency**.
    - Baud rate **determines the bandwidth required** to send the **message signal (**Καθορίζει το εύρος ζώνης που απαιτείται για να σταλεί μήνυμα**)**
    - **Baud Rate = Bit Rate / Number of Bits per Symbol**
    - Thus, the **lower the Baud Rate (symbols/second)** the **less the bandwidth required**
  - **The number of bits that can be carried by one Symbol**, depends on the **Modulation Technique used**.
    - The **Baud Rate** depends on the **type of Modulation** used.

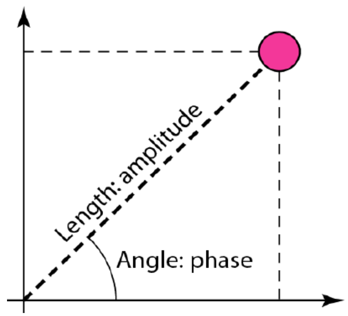
Bit Rate and Baud Rate Examples

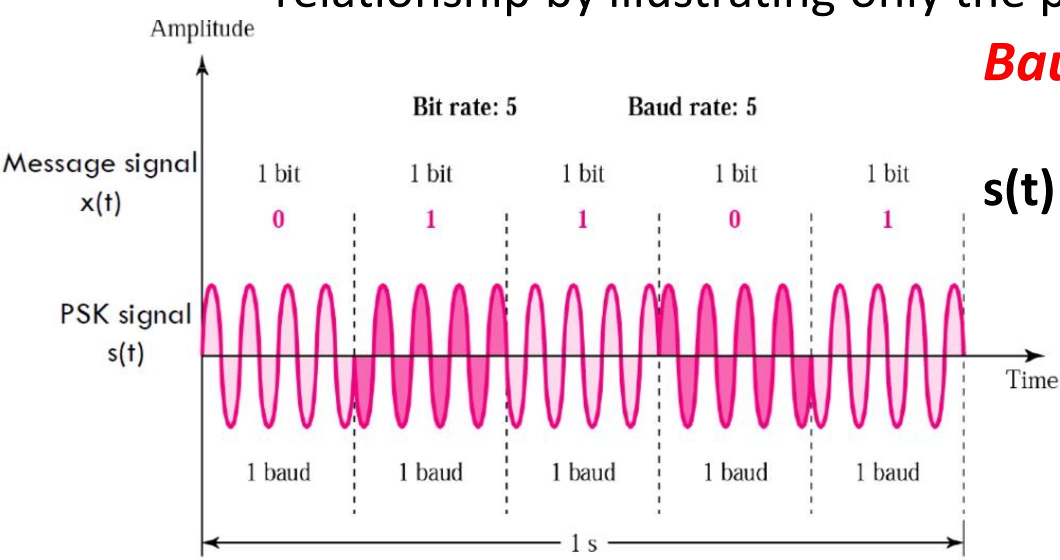
- **Example 1**: A modulated signal **carries 4 bits** in **each signal unit (i.e., symbol)**. If **1000 signal units (symbols)** are sent per second, find the Baud Rate and the Bit Rate
  - **Baud Rate = 1000 baud/s**
  - **Bit Rate** = 1000 x 4 = **4000 bps**
- **Example 2:** The **bit rate** of a modulated signal is **3000 bps**. If each **signal unit** carries **6 bits**, what is the baud rate?
  - **Baud Rate =** 3000/6 = **500 (baud/s)**
- **Example 3**: A modulated signal has a **bit rate of 8000 bps** and a baud rate of **1000 baud**. How many bits are carried by each signal element?
  - **Bits/Baud** = **8000/1000 = 8**



Phase Shift Keying (PSK)

- The **phase of the carrier signal** is varied to represent digital data (binary 0 or 1), i.e., **Binary PSK (BPSK)**
- Both **peak amplitude** and **frequency remain constant** as the phase changes.
- **Phases are separated by 180 degrees.**
  - If we start with a **phase of 0°** to represent **bit 0**, then we can change the **phase to 180°** to send **bit 1** (or inversely).
  - The **Constellation** or **phase-state Diagram** shows the relationship by illustrating only the phases.



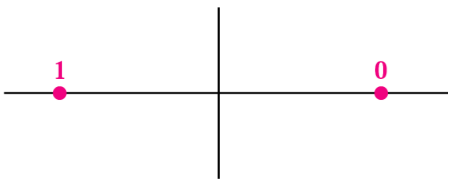


Baud Rate = Bit Rate

$$s(t) = \begin{cases} A \sin(2\pi f t + 0^\circ) & 0 \\ A \sin(2\pi f t + 180^\circ) & 1 \end{cases}$$

Bit	Phase
0	0
1	180

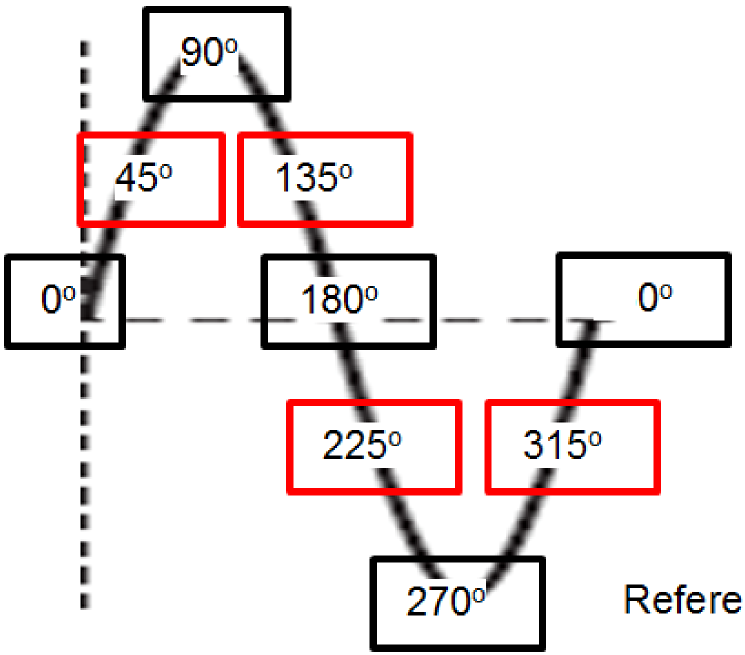
Bits

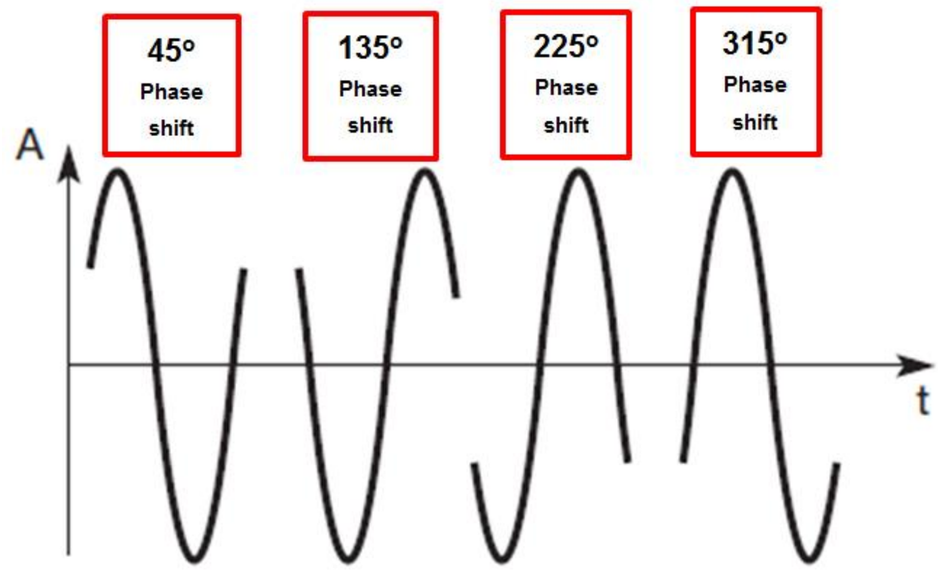


Constellation diagram

Phase Shift Keying (PSK)
Phase Shifts Examples

- **Phase Shifts Example**

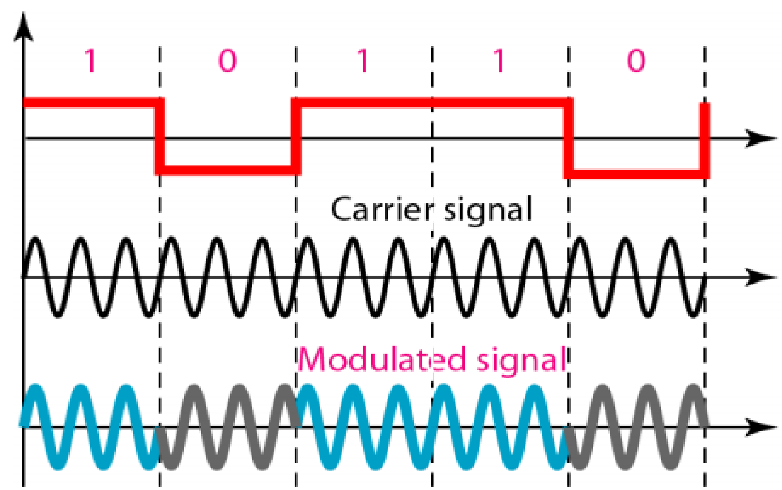




Phase Shift Keying (PSK)

73

- PSK is **not susceptible to noise degradation** that affects **ASK, neither has the limitation of FSK that needs to repeatedly tune at different frequencies (i.e., no need for filtering the signal of different frequencies → simpler demodulator needed).**
- **Simple to implement**, and is used extensively in wireless communication.



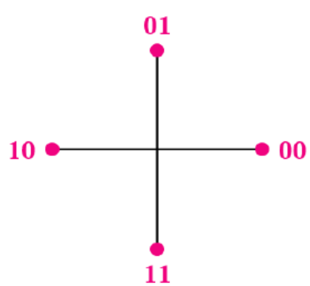
Quadrature Phase Shift Keying (QPSK)

- **QPSK** refers to **PSK with 4 states**.
- The "Q - *Quadrature*" in QPSK refers to **four phases** in which **a carrier is modulated and send in QPSK**. Also, called **4-PSK**.
- Because QPSK has **4 possible states**, QPSK can encode **two bits per symbol**.
  - Because **2 bits are allocated to each symbol**, QPSK can achieve **twice the Data Rate** of a **comparable BPSK** scheme **for a given bandwidth.**

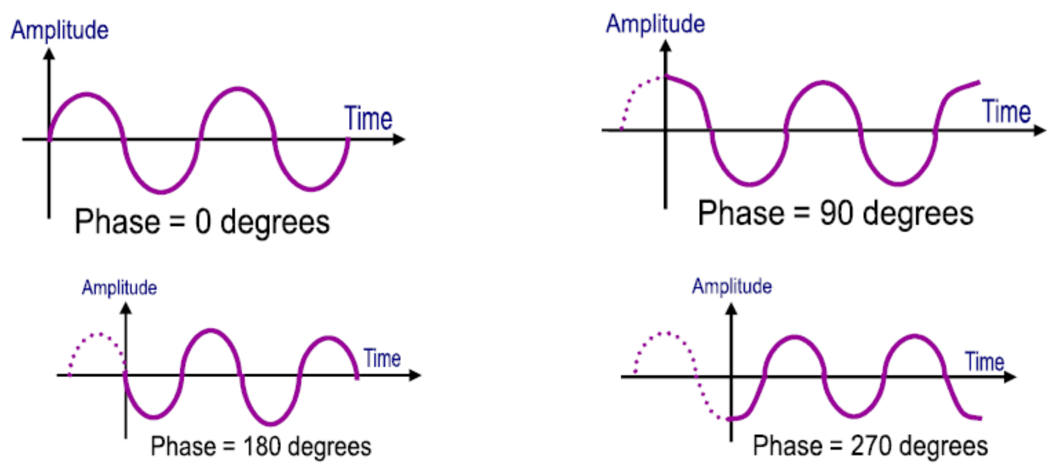
Example: Relationship between different phases:

Dibit	Phase
00	0
01	90
10	180
11	270

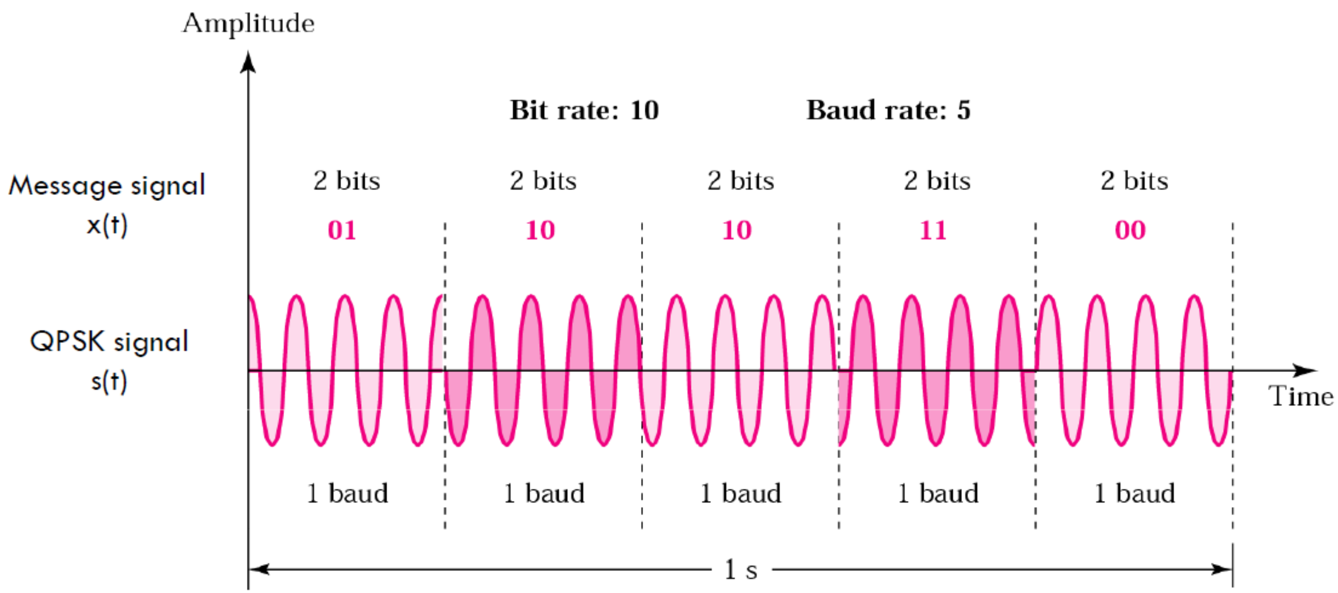
Dibit
(2 bits)



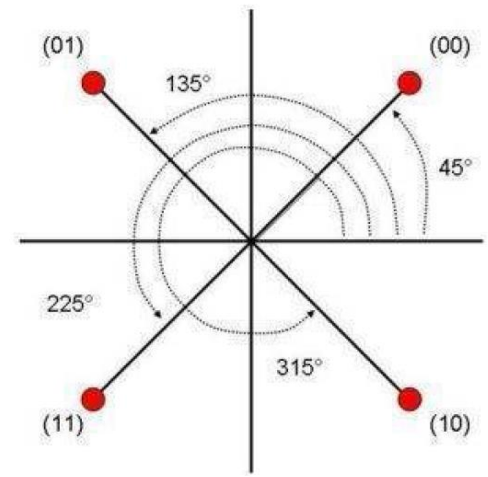
Constellation diagram



Quadrature Phase Shift Keying (QPSK)



Phase	Data
45	00
135	01
225	11
315	10

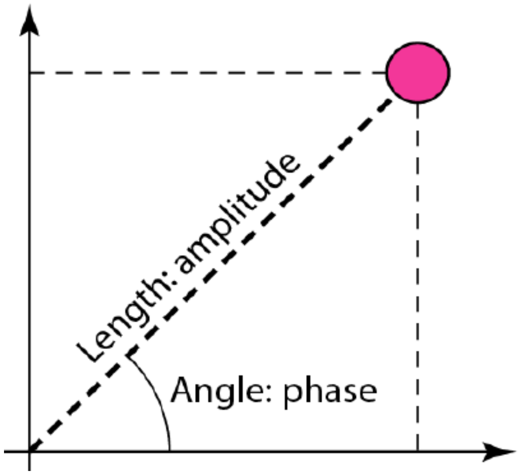


Two Modulation Alphabets

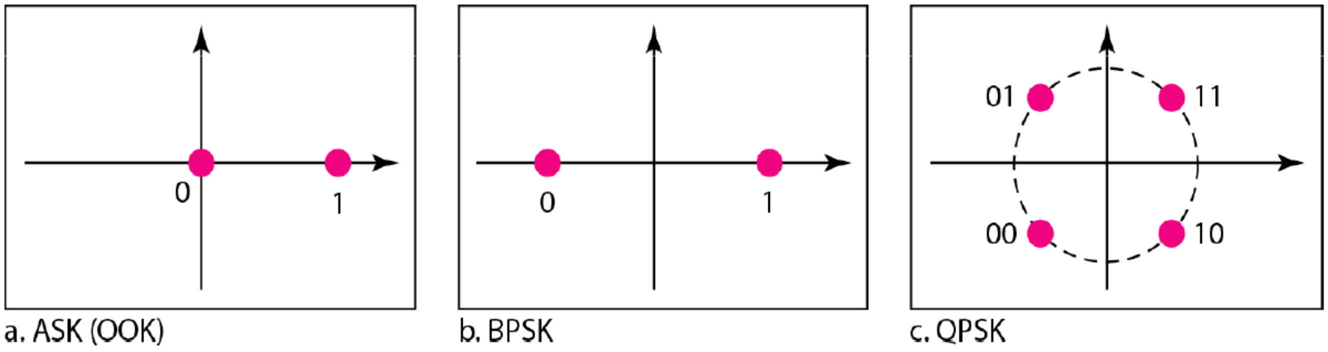
$$s(t) = \begin{cases} A\sin(2\pi f t + \phi_1) \\ A\sin(2\pi f t + \phi_2) \\ A\sin(2\pi f t + \phi_3) \\ A\sin(2\pi f t + \phi_4) \end{cases} \quad \begin{cases} \phi_1 = 0^o \\ \phi_2 = 90^o \\ \phi_3 = 180^o \\ \phi_4 = 270^o \end{cases} \quad \text{OR} \quad \begin{cases} \phi_1 = 45^o & 00 \\ \phi_2 = 135^o & 01 \\ \phi_3 = 225^o & 10 \\ \phi_4 = 315^o & 11 \end{cases}$$

Constellation Diagrams
Διαγράμματα Αστερισμού

- It is a **convenient way** to **represent the symbols (define the amplitude and phase)** of the **Modulation Alphabet** that will be used for **modulating signal carrier** and **transmitting the signal**. (Είναι ένας εύκολος τρόπος για να αναπαραστήσουμε **τα σύμβολα του Αλφαβήτου Διαμόρφωσης** που θα χρησιμοποιηθούν για τη διαμόρφωση του μεταφορέα σήματος για την αποστολή του σήματος)

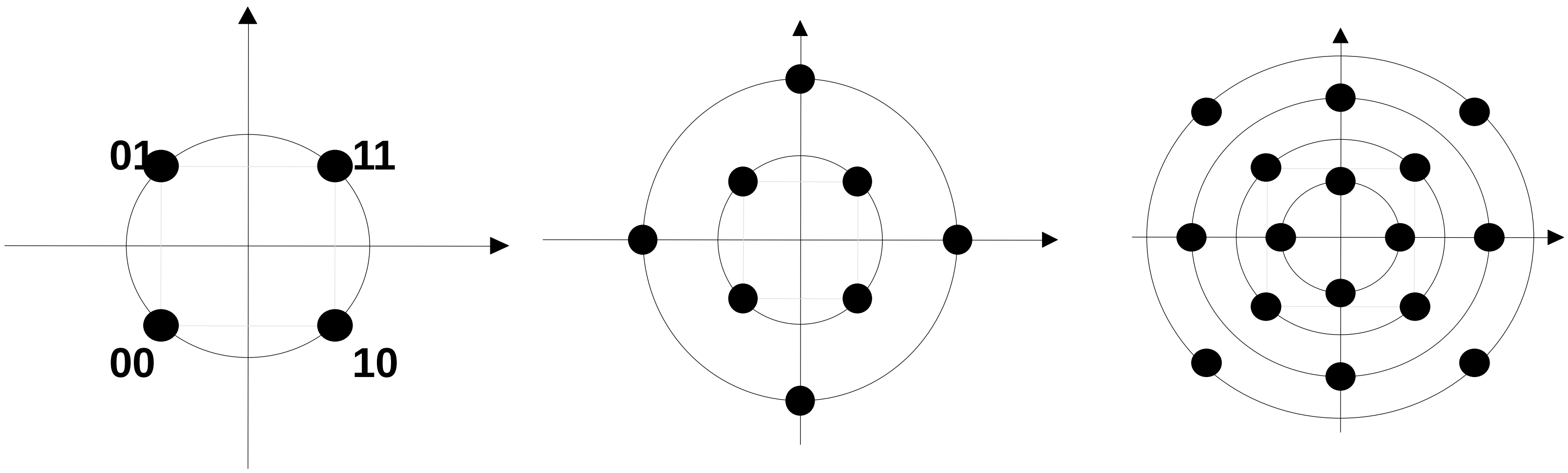


Examples:



Constellation Diagrams
Circular Constellation Diagrams

Examples:



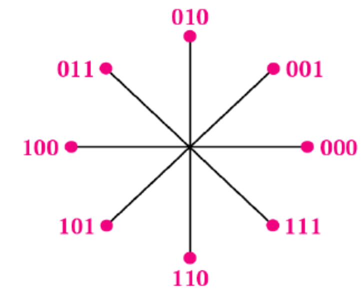
(a) Circular 4-QAM

(b) Circular 8-QAM

(c) Circular 16-QAM

Higher Order Modulation: 8-PSK

- We **can extend the Modulation Alphabet**, by varying the **signal by shifts of 45º** (instead of 90º in QPSK). (Μπορούμε να επεκτείνουμε το Αλφάβητο Διαμόρφωσης με το μεταβάλλουμε το σήμα με μετατοπίσεις 45º παρά 90º όπως το QPSK)
- With 8 (2^3) different phases, each phase (i.e., signal unit or symbol) can represent **3 bits.**



Constellation diagram

Baud Rate = Bit Rate/3 → Reduces the Required Bandwidth to one third

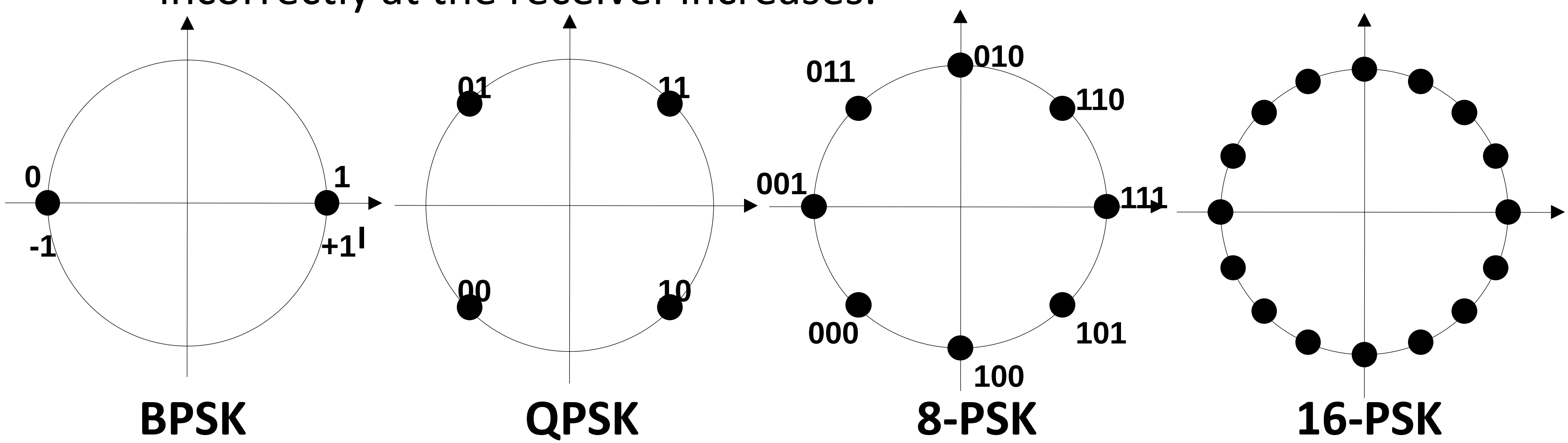
$$s(t) = \begin{cases} A\sin(2\pi f t + \phi_1) & 000 \\ A\sin(2\pi f t + \phi_2) & 001 \\ A\sin(2\pi f t + \phi_3) & 010 \\ A\sin(2\pi f t + \phi_4) & 011 \\ A\sin(2\pi f t + \phi_5) & 100 \\ A\sin(2\pi f t + \phi_6) & 101 \\ A\sin(2\pi f t + \phi_7) & 110 \\ A\sin(2\pi f t + \phi_8) & 111 \end{cases} \qquad \begin{cases} \phi_1 = 0^\circ \\ \phi_2 = 45^\circ \\ \phi_3 = 90^\circ \\ \phi_4 = 135^\circ \\ \phi_5 = 180^\circ \\ \phi_6 = 225^\circ \\ \phi_7 = 270^\circ \\ \phi_8 = 315^\circ \end{cases}$$

Using the Constellation Diagram we can easily produce the Modulation Alphabet

Tribit	Phase
000	0
001	45
010	90
011	135
100	180
101	225
110	270
111	315

Higher Order Modulation: M-PSK

- Obviously **the** **bandwidth efficiency** of a M-ary PSK scheme increases as **M (the number of possible states) increases** because **more bits per symbol can be sent**
- ...however **the distance between 2 points** in the **constellation** **is reduced** and therefore the possibility for decoding the symbol incorrectly at the receiver increases.



- As M increases, **the** **bandwidth efficiency** **increases** but the **waveform energy (i.e., the transmission power used to send the symbol)** must **be increased to keep the BER at a certain level**.

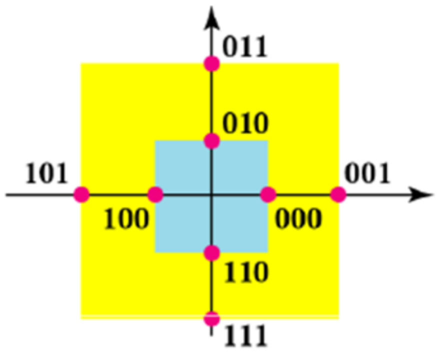
Quadrature Amplitude Modulation (QAM) – Phase and Amplitude Modulation

- **PSK is limited** by the ability of the equipment to **distinguish between small differences in phases**.
  - Limits the potential data rate. (Περιορίζει το πιθανό data rate)
- The principle of **Quadrature Amplitude Modulation** (QAM) or **Amplitude Phase Shift Keying** (APSK) is to have **X possible variations** in **Phase** (Χ πιθανές διαφορετικές φάσεις) and **Y possible variations** of **Amplitude** (Y πιθανά διαφορετικά πλάτη) .
  - Up to **X • Y** possible variations → **More different states** that the **carrier signal can be modulated**, therefore **more bits can be carried per symbol** → Therefore greater Data Rates and Throughput.
  - **QAM (or APSK) is an application of ASK to PSK (**Εφαρμογή του ASK πάνω στο PSK**)**

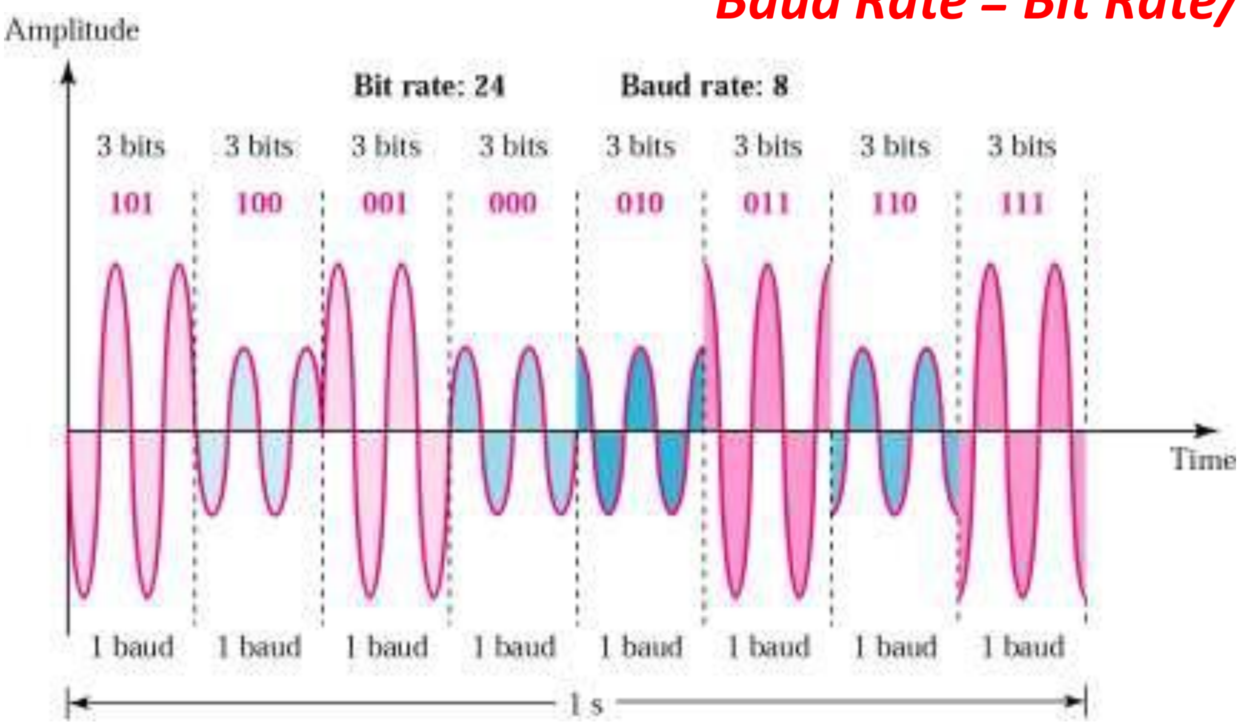
Quadrature Amplitude Modulation (QAM) – Phase and Amplitude Modulation

Example: **8-QAM example**

- ***Two (2) possible*** *different* ***Amplitudes*** *(A1 = 1; A2 = 2)*
- ***Four (4) possible*** *different* ***Phases*** *(0º, 90º, 180º, 270º)*
- ***Total*** *of* ***8*** **QAM symbols** → ***3 bits per symbol***



Baud Rate = Bit Rate/3

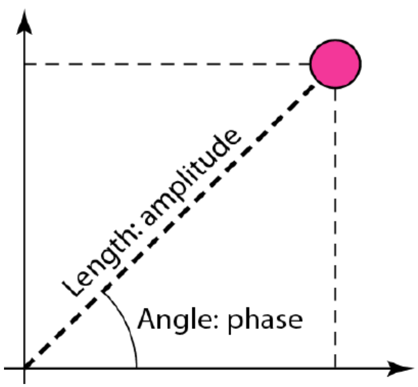


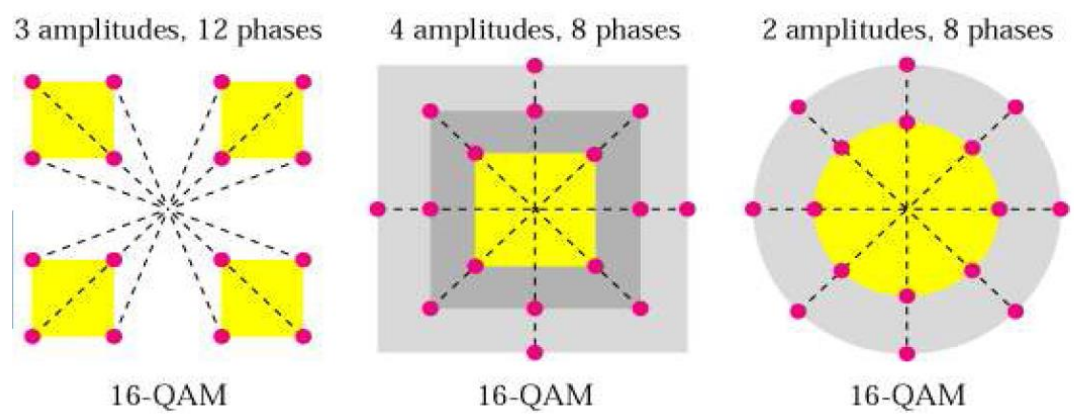
Modulation Alphabet

A = 1, Phase = 0º:	**000**
A = 2, Phase = 0º:	**001**
A = 1, Phase = 90º:	**010**
A = 2, Phase = 90º:	**011**
A = 1, Phase = 180º:	**100**
A = 2, Phase = 180º:	**101**
A = 1, Phase = 270º:	**110**
A = 2, Phase = 270º:	**111**

Quadrature Amplitude Modulation (QAM) or APSK

- We can have **numerous possible variations** (Διάφορες πιθανές παραλλαγές) of **Phase Shifts** and **Amplitude shifts**
  - However the **Number of Phase Shifts** should selected to be **GREATER** than **Number of Amplitude shifts**. (Why??)





16-QAM for example:

- There are **sixteen QAM symbols** → ***4 bits per symbol***.
- **A variety of constellations diagrams can be used**

Spread Spectrum Techniques
Τεχνικές Διασποράς Φάσματος

- Spread Spectrum techniques **use a transmission bandwidth** that is **several orders of magnitude greater** than **the required bandwidth to spread the data (**Χρησιμοποιούν ένα εύρος ζώνης πολύ μεγαλύτερο από αυτό που πραγματικά χρειάζεται για διασπείρουν τα δεδομένα**).**

Spread Spectrum Techniques
Τεχνικές Διασποράς Φάσματος

- **Each bit** of the data that we want to transmit is **encoded** using **a sequence of digits (chips)** known as a **Spreading Code** → Κάθε bit των δεδομένων που θα διαδοθούν κωδικοποιείται χρησιμοποιώντας μια ακολουθία ψηφίων (τα ψηφία αυτά ονομάζονται **chips**) η οποία είναι γνωστή ως ο **Κώδικας Διασποράς**.
  - **Each bit (0 or 1)** that will be transmitted by the transmitter in the specific channel is encoded using the same **Spreading Code.**
  - During Spreading, data bit 0 is represented as -1 and data bit 1 is represented as +1.

Spread Spectrum Techniques
Τεχνικές Διασποράς Φάσματος

Example: We want to transmit **Data = (0, 1)** using the **Spreading Code = (1, 1, 1, -1, 1, -1, -1, -1)**

- Data = (-1, +1)

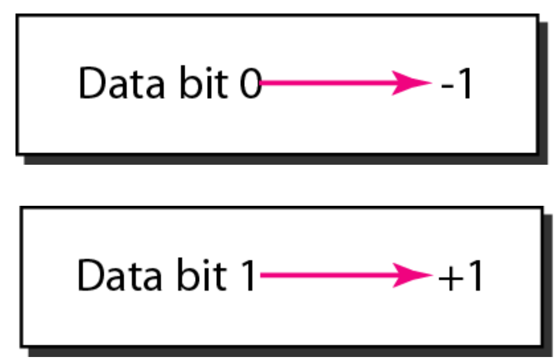
  Data bit 0 → -1 | Data bit 1 → +1

- **Bit 0** will be encoded and transmitted using the following **chip sequence**:
  - (-1).(1, 1, 1, -1, 1, -1, -1, -1) = **(-1, -1, -1, 1, -1, 1, 1, 1)**
- **Bit 1** will be encoded and transmitted using the following **chip sequence**:
  - (+1). (1, 1, 1, -1, 1, -1, -1, -1) = **(1, 1, 1, -1, 1, -1, -1, -1)**

Spread Spectrum Techniques
Spreading and Despreading

Example: Spreading

Step	Encode Sender (Spreading)
0	Spreading Code (SC) = (1, 1, 1, -1, 1, -1, -1, -1), Data = (0, 1) → Data' (-1, +1)
1	Encode (Spread) Data' = ((-1 . SC), (+1 . SC)) = ((-1, -1, -1, 1, -1, 1, 1,1), (1, 1, 1, -1, 1, -1, -1,-1))
2	Spread Data = (-1, -1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, 1, -1, -1, -1)



Spread Spectrum Techniques
Spreading and Despreading

- **The Receiver** will use the **same Spreading Code** to Despread (Decode) the chip sequence received.
- Example: The Receiver receives the chip sequence

  (-1, -1, -1, 1, -1, 1, 1, 1)

- Decoding of the chip sequence (applying dot product) using the Spreading Code (1, 1, 1, -1, 1, -1, -1, -1):
  - (-1, -1, -1, 1, -1, 1, 1, 1).(1, 1, 1, -1, 1, -1, -1, -1) =
  - = (-1, -1, -1, -1, -1, -1, -1, -1) =
  - = (-8)

If **decoded data < 0**	→ Data bit **0**
If **decoded data > 0**	→ Data bit **1**
If **decoded data == 0**	→ **No data**

Spread Spectrum Techniques
Spreading and Despreading

Example: Despreading

Step	Decode Receiver (Despreading)
0	Spreading Code (SC)= (1, 1, 1, -1, 1, -1, -1, -1) Received Spread Data (RSD) = (-1, -1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, 1, -1, -1, -1)
1	Decode = RSD . SC = ((-1, -1, -1, 1, -1, 1, 1, 1), (1, 1, 1, -1, 1, -1, -1, -1)) . (1, 1, 1, -1, 1, -1, -1, -1) = ((-1-1-1-1-1-1-1-1), (1, 1, 1, 1, 1, 1, 1,1))
2	Decoded Data' = (-8 , 8) → Data (0, 1)

If **decoded data < 0** → Data bit **0**

If **decoded data > 0** → Data bit **1**

If **decoded data == 0** → **No data**

Spread Spectrum Techniques
Spreading Factor & Processing Gain

- As illustrated in the previous example, after despreading **the amplitude** of the signal **increases** by a **factor of 8** (**analogous to the length of the Spreading Code → this is called the Spreading Factor (SF)**)
- This effect is termed **'Processing Gain'** and is a **fundamental aspect** (είναι ένα θεμελιώδες στοιχείο) of all **Spread Spectrum** systems.

$$\textbf{Processing Gain}_{(dB)} = 10 \log_{10} (SF)$$

Spread Spectrum Techniques
Spreading Factor & Processing Gain

- In the previous example the **Processing Gain is 9dB** (**10 x $\log_{10}$(8)**) → This means that the **signal energy** can be **increased by 9dB** after despreading.

- Thus, assuming that the **minimum SNIR required by the Receiver (Demodulator) for decoding the signal correctly** is **5dB**, the **SNIR that the signal can have before despreading** is therefore **5 dB minus** the **Processing Gain** (i.e., **5dB – 9dB = – 4 dB**).

- **In other words, the signal power, can be 4 dB under the interference or thermal noise power, and the Receiver (Demodulator) can still decode the signal correctly.**

Spread Spectrum Techniques Spreading Factor & Processing Gain

- The **number of chips that will be used (i.e., the length of the Spreading Code)** to spread one bit of data is defined by the **Spreading Factor**.
- The Spreading Factor is given by:

$$Spreading\_Factor = \frac{Chip\_Rate}{Bit\_Rate}$$

Spread Spectrum Techniques
Spreading Factor & Processing Gain

- Using **W-CDMA** (Wideband-Code Division Multiple Access, which is used in 3G Networks) we have **5Mhz** carrier bandwidth and a **Chip Rate of 3.84 Mcps** to Spread the data.
  - Note: **CDMA** uses a carrier bandwidth of **1.25 MHz** and a **Chip Rate of 1.22Mcps.**
- Thus, if we transmit a video clip with **Bit Rate of 128Kbps** the **Spreading Factor** will be:

$$Spreading\_Factor = \frac{3{,}840{,}000 chips/\sec}{128{,}000 bits/\sec} = 30$$

- **Each bit** will be **spread** using a **Spreading Code of length 30**.
- **Processing Gain = 10 x $\log_{10}(30)$ = 14.77 dB**

Spread Spectrum Techniques
Spreading Factor & Processing Gain

- **Processing Gain** allows the **received signal power** to be **under the interference or thermal noise power (i.e., improves reception)**, and the **Receiver can still detect the signal**.
  - **Detection of a Spread signal** is **difficult without knowledge** of the **Spreading Code**.
  - Spread Spectrum systems **originated** in **military applications** as it is very **difficult to interfere with** **(**πολύ δύσκολα παρεμβάλλεται**)** and **difficult to identify the signal** **(**πολύ δύσκολα αναγνωρίζεται η πληροφορία που μεταφέρει το σήμα**)** **without knowing** the **Spreading Code**.

Spread Spectrum Techniques Advantages

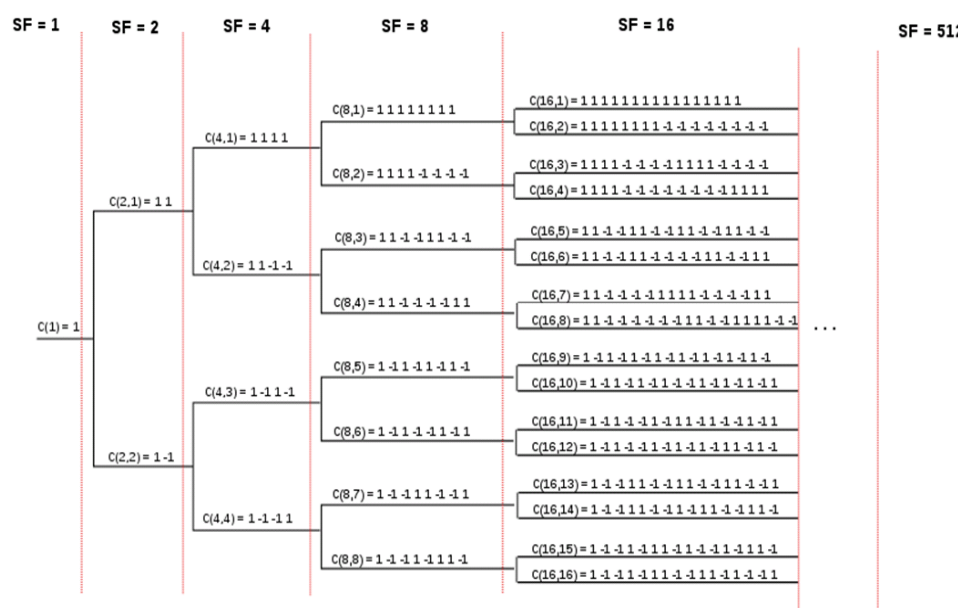
- **Several advantages** can be gained from this **apparent waste of spectrum (από αυτή την προφανή "σπατάλη" του φάσματος)** by this approach:
  - The signals **gains immunity from various kinds of noise and interference** (Τα σήματα αποκτούν μεγαλύτερη ανοσία στο θόρυβο και στις παρεμβολές) – Due to the **Processing Gain** that can be achieved
    - The earliest applications of spread spectrum were military, where it was used for its **immunity to jamming** (ανοσία σε θόρυβο και παρεμβολές με σκοπό το μπλοκάρισμα των καναλιών).

Spread Spectrum Techniques Advantages

- It can also be used **for hiding and encrypting signals** (Χρησιμοποιούνται για **απόκρυψη** και **κρυπτογράφηση** των σημάτων).
  - Only a recipient who **knows the spreading code can recover the encoded** information.
- **Several users can independently use the same bandwidth at the same time** with **very little interference**.
  - This property is **used in cellular telephony applications (e.g., in UMTS Networks)**, with a technique known as **Code Division Multiple Access (CDMA)**.

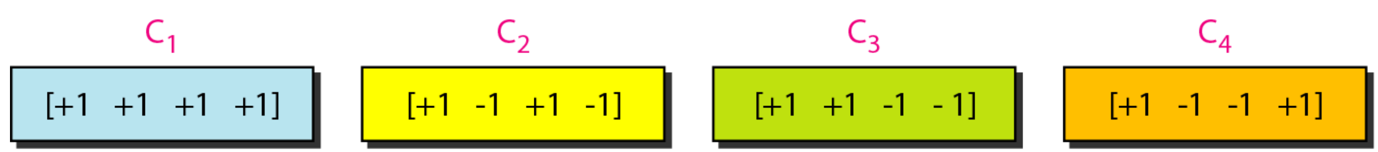
Code Division Multiple Access (CDMA)

- Divides up a radio channel **not by frequency** (as in FDMA), **not by time** (as in TDMA), but instead by using **Code Sequences (Spreading Codes)** for **each user**.
- **Guard Spaces (For keeping the different channels independent)** are realized **by using codes** with the necessary 'distance' in code space, e.g., **Orthogonal Codes**.
- These codes are derived from an **Orthogonal Variable Spreading Factor (OVSF)** code tree, and **each user is given a different, unique code**.



Code Division Multiple Access

- ## Orthogonal Codes
  - Orthogonal codes have a **cross-correlation equal to zero**; in other words, they **do not interfere with each other**
  - Their **dot product** (*operation of vectors*) is **equal to zero**
  - An example of orthogonal codes (vectors) is provided below:
    - C1 = (1, 1, 1, 1),
    - C2 = (1, -1, 1, -1),
    - C3 = (1, 1, -1, -1),
    - C4 = (1, -1, -1, 1),
  - These vectors (codes) will be **assigned to individual users** and are called the **Spreading Codes**



Code Division Multiple Access

- **Orthogonal Codes Examples:**
  - Question 1: Is SC1 = (1, -1, 1, -1) and SC2 = (1, 1, -1, -1), orthogonal?
  - Answer 1: For these two Spreading Codes to be orthogonal their dot product (SC1 . SC2) must be equal to 0.

$$(1, -1, 1, -1) \cdot (1, 1, -1, -1) = (+1 -1 -1 +1) = 0$$

Their dot product is equal to 0, therefore these two Spreading Codes are orthogonal

Code Division Multiple Access

- **Orthogonal Codes Examples:**
  - Question 2: Is SC1 = (1, -1, 1, -1) and SC2 = (1, -1, -1, -1), orthogonal?
  - Answer 2: For these two Spreading Codes to be orthogonal their dot product (SC1 . SC2) must be equal to 0.

$$(1, -1, 1, -1) \cdot (1, -1, -1, -1) = (+1 +1 -1 +1) = +2$$

Their dot product is not equal to 0, therefore these two Spreading Codes are NOT orthogonal

Code Division Multiple Access - Example of Spreading and Despreading a Signal

- Each user is associated with a different Spreading Code, say **C**
- **During the Spreading of the Data bits:**
  - **Data bit 0** will be represented as **-1**
  - **Data bit 1** will be represented as **+1**
- For example:
  - **C = (1, -1, -1, 1)** (this is the **Spreading Code** and in this case the **Spreading Factor** is equal with **4**)
  - The **Data Bit Stream** (1, 0, 1, 1) would correspond to (C, -C, C, C)
  - The **Spread Data** will be:
    - ((1, -1, -1, 1), (-1, 1, 1, -1), (1, -1, -1, 1), (1, -1, -1, 1)).

Code Division Multiple Access -

Example of Spreading and Despreading a Signal

- **Example of encoding (Spreading) and decoding (Despreading) a signal**
  - “**Sender 1**” has a
    - Spreading Code (C_1) = (1, -1, -1, 1)
    - Data (D_1) = (1, 0, 1, 1), and
  - “**Sender 2**”
    - Spreading Code (C_2) = (1, 1, -1, -1)
    - Data (D_2) = (0, 0, 1, 1), and
  - Both senders **transmit simultaneously**

Code Division Multiple Access -

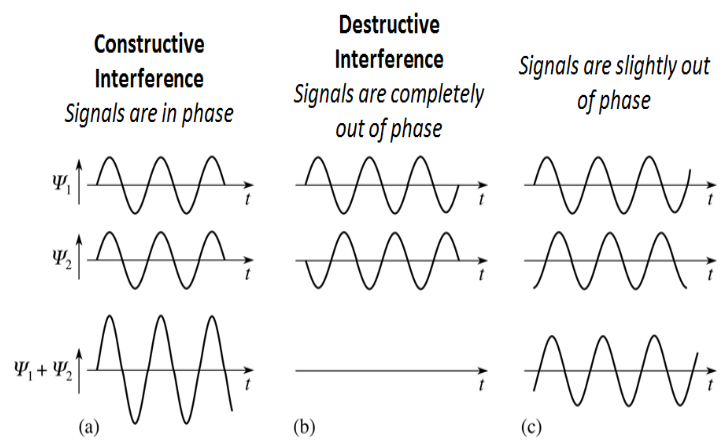
Example of Spreading and Despreading a Signal

Step	Encode Sender 1 (Spreading)
0	C_1 = (1, -1, -1, 1), D_1 = (1, 0, 1, 1)
1	Encode 1 = (C_1, -C_1, C_1, C_1) = ((1, -1, -1, 1),(-1, 1, 1, -1),(1, -1, -1, 1),(1, -1, -1, 1))
2	Spread Signal 1 = (1, -1, -1, 1, -1, 1, 1, -1, 1, -1, -1, 1, 1, -1, -1, 1)

Step	Encode Sender 2 (Spreading)
0	C_2 = (1, 1, -1, -1), D_2 = (0, 0, 1, 1)
1	Encode 2 = (-C_2, -C_2, C_2, C_2) = ((-1, -1, 1, 1),(-1, -1, 1, 1), (1, 1, -1, -1), (1, 1, -1, -1))
2	Spread Signal 2 = (-1, -1, 1, 1, -1, -1, 1, 1, 1, 1, -1, -1, 1, 1, -1, -1)

Code Division Multiple Access - Example of Spreading and Despreading a Signal

- *The physical properties of interference say that if two signals at a point are in phase, they will "add up" to give twice the amplitude of each signal, but if they are out of phase, they will "subtract" and give a signal that is the difference of the amplitudes.*



- *Because Signal 1 and Signal 2* ***are transmitted at the same time using the same frequency band****, we'll add them together to model the* ***raw signal*** *in the air. This raw signal may be called an* ***Interference Pattern****.*
- **Interference Pattern**:

	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	1	-1	-1	1
+	-1	-1	1	1	-1	-1	1	1	1	1	-1	-1	1	1	-1	-1
	0	-2	0	2	-2	0	2	0	2	0	-2	0	2	0	-2	0

Code Division Multiple Access - Example of Spreading and Despreading a Signal

- **Question:** How does a Receiver make sense of this Interference Pattern?

- **Answer:** The receiver **knows the Spreading Codes of the senders.** Using these Spreading Codes on the received interference pattern can extract an intelligible signal for any known sender.

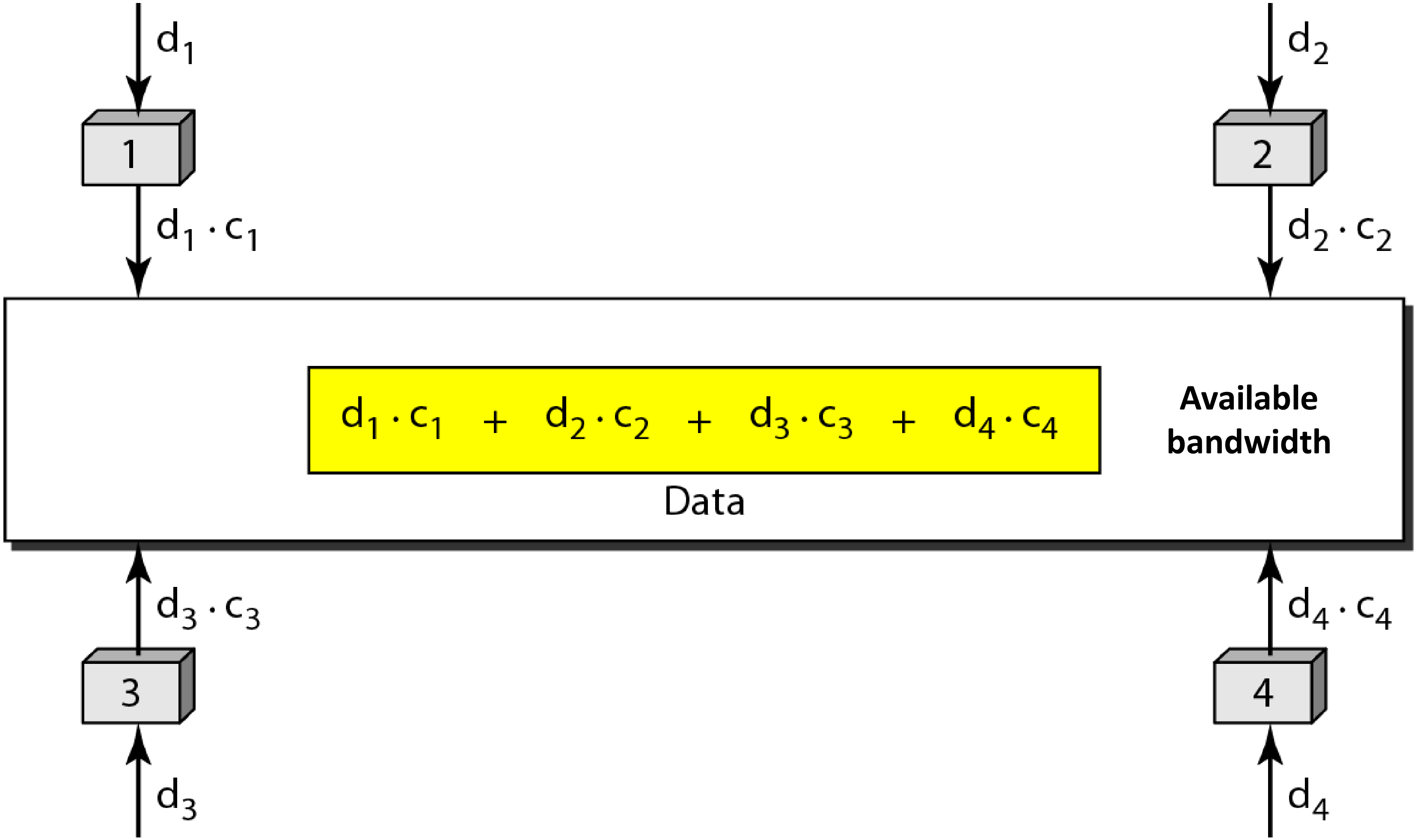
Code Division Multiple Access - Example of Spreading and Despreading a Signal

Step	Decode Sender 1 (Despreading)
0	C_1 = (1, -1, -1, 1), Interference Pattern = (0, -2, 0 ,2, -2, 0, 2, 0, 2, 0, -2, 0, 2, 0, -2, 0)
1	Decode 1 = Interference_Pattern . C_1 = ((0, -2, 0, 2), (-2, 0, 2, 0), (2, 0, -2, 0), (2, 0, -2, 0)).(1, -1, -1, 1) = ((0 + 2 + 0 + 2), (-2 + 0 - 2 + 0), (2 + 0 + 2 + 0), (2 + 0 + 2 + 0))
2	Data 1 = (4, -4, 4, 4) = (1, 0, 1, 1)

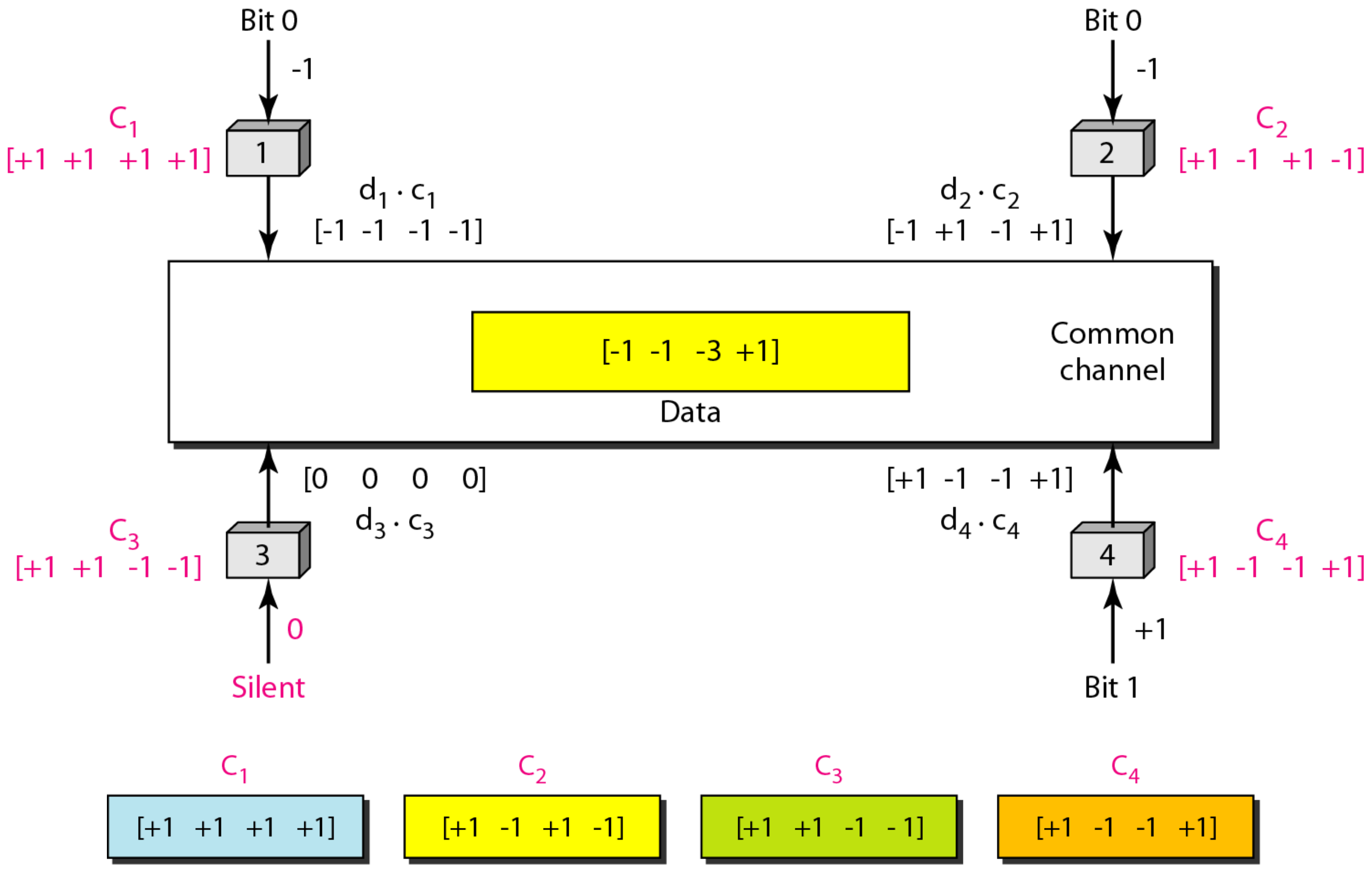
Step	Decode Sender 2 (Despreading)
0	C_2 = (1, 1, -1, -1), Interference Pattern = (0, -2, 0 , 2, -2, 0, 2, 0, 2, 0, -2, 0, 2, 0, -2, 0)
1	Decode 1 = Interference_Pattern . C_2 = ((0, -2, 0, 2),(-2, 0, 2, 0),(2, 0, -2, 0),(2, 0, -2, 0)).(1, 1, -1, -1) = ((0 - 2 + 0 - 2), (-2 + 0 - 2 + 0), (2 + 0 + 2 + 0), (2 + 0 + 2 + 0))
2	Data 2 =(-4, -4, 4, 4) = (0, 0, 1, 1)

Code Division Multiple Access

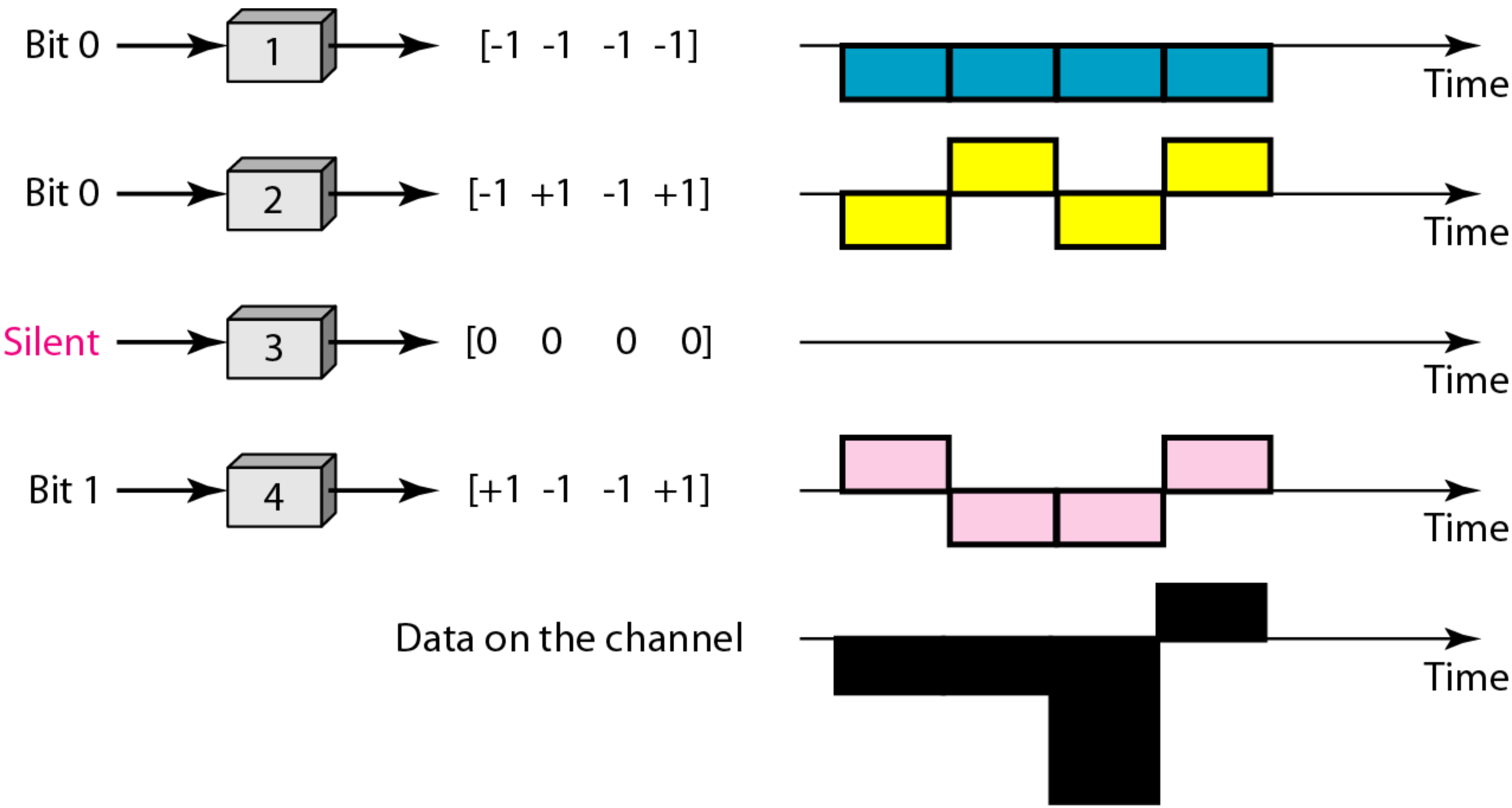
Example of Spreading and Despreading a Signal



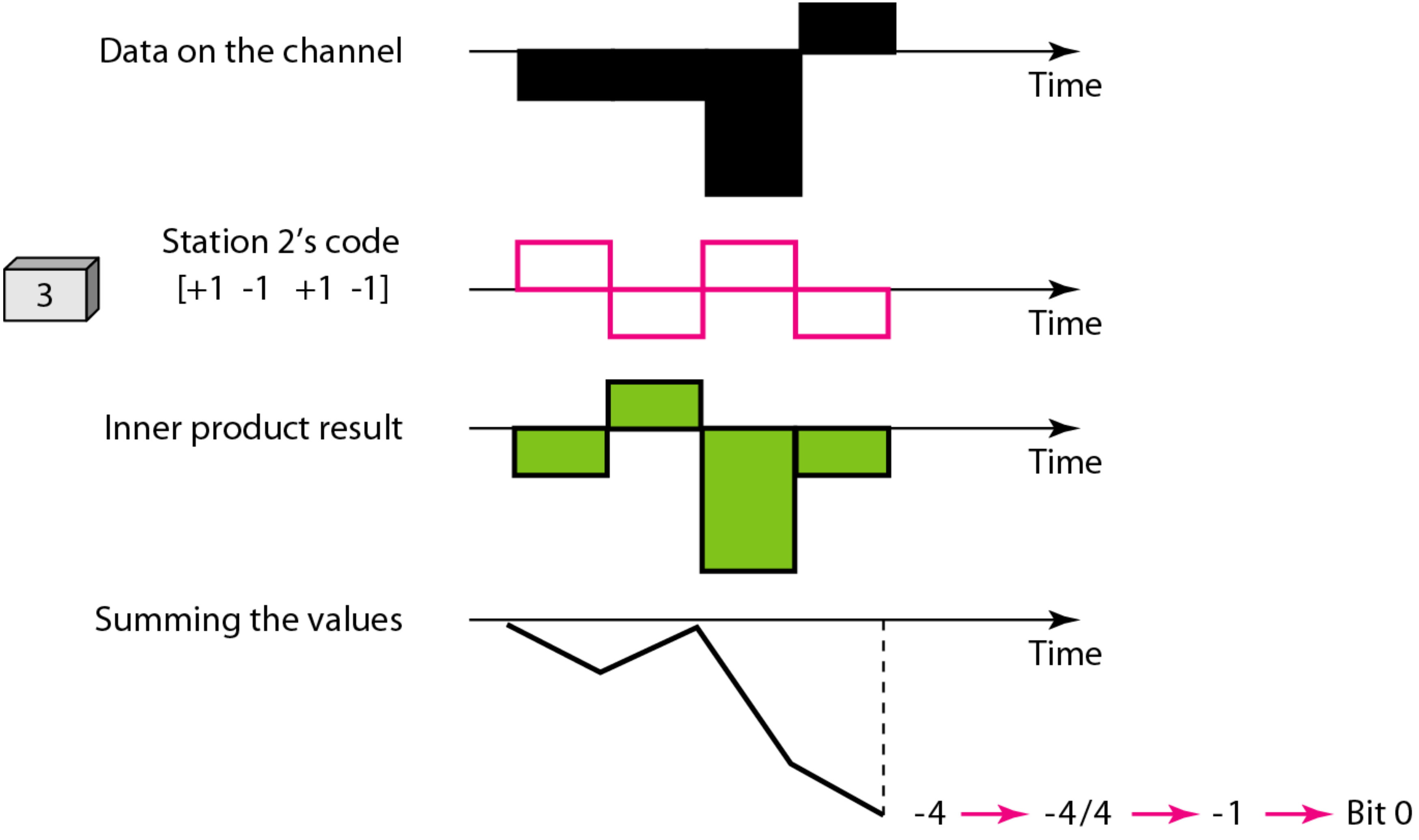
Code Division Multiple Access -
Example of Spreading and Despreading a Signal



Code Division Multiple Access - Example of Spreading and Despreading a Signal



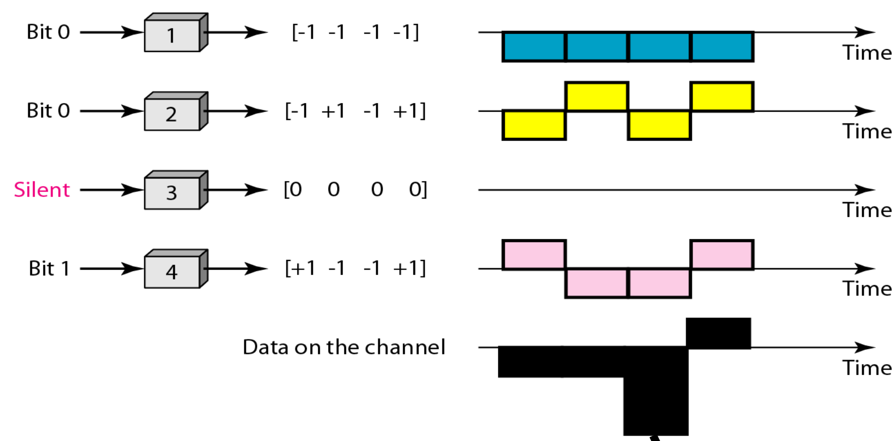
Code Division Multiple Access - Example of Spreading and Despreading a Signal



Code Division Multiple Access - Example of Spreading and Despreading a Signal

- **Question:** In the example provided Station 3 (S3) did not send any data to the channel. What will happen when the receiver, during Despreading, correlates the Spreading Code of S3 on the Interference Patter (i.e., the data on the channel)?

- **Answer:** When the receiver correlates the interference pattern with the Spreading Code of S3, the summing of the values of the despread signal will be equal to 0 → **Thus no data are included in the channel for S3.**



For example:

Interference Pattern: (-1, -1, -3, 1)

S3 → C_3 = (1, 1, -1, -1)

Despreading of S3:

(-1, -1, -3, 1) . (1, 1, -1, -1) =

= -1 -1 + 3 -1 = -3 + 3 = 0 → No Data

Code Division Multiple Access - Example of Spreading and Despreading a Signal

- **FOR HOME PRACTICE → Example of encoding (Spreading) and decoding (Despreading) a signal with 4 users →**
  - "**Sender 1**" has a
    - Spreading Code (C_1) = (1, 1, 1, 1), Data (D_1) = (0, 0)
  - "**Sender 2**"
    - Spreading Code (C_2) = (1, -1, 1, -1), Data (D_2) = (0, 1)
  - "**Sender 3**"
    - Spreading Code (C_3) = (1, 1, -1, -1), Data (D_3) = (1, 0)
  - "**Sender 4**"
    - Spreading Code (C_4) = (1, -1, -1, 1), Data (D_4) = (1, 1)
  - All senders **transmit simultaneously**

Code Division Multiple Access -

Example of Spreading and Despreading a Signal

- **Example of encoding (Spreading) and decoding (Despreading) a signal with 4 users,**
  - **"Sender 1" Spread Signal**:
    - (-1, -1, -1, -1, -1, -1, -1, -1)
  - **"Sender 2" Spread Signal:**
    - (-1, 1, -1, 1, 1, -1, 1, -1)
  - **"Sender 3" Spread Signal:**
    - (1, 1, -1, -1, -1, -1, 1, 1)
  - **"Sender 4" Spread Signal:**
    - (1, -1, -1, 1, 1, -1, -1, 1)

  - **Interference Pattern (We add all the signals together)**
    - **(0, 0, -4, 0, 0, -4, 0, 0)**

Code Division Multiple Access - Example of Spreading and Despreading a Signal

- **Example of encoding (Spreading) and decoding (Despreading) a signal with 4 users (Interference Pattern: (0, 0, -4, 0, 0, -4, 0, 0))**
-
  - **"Sender 1" Despread Signal (C_1 = (1, 1, 1, 1))**
    - ((0, 0, -4, 0), (0, -4, 0, 0)) . (1, 1, 1, 1) = (-4, -4) → **Data (0, 0)**
  - **"Sender 2" Despread Signal (C_2 = (1, -1, 1, -1))**
    - ((0, 0, -4, 0), (0, -4, 0, 0)). (1, -1, 1, -1) = (-4, +4) → **Data (0, 1)**
  - **"Sender 3" Despread Signal (C_3 = (1, 1, -1, -1))**
    - ((0, 0, -4, 0), (0, -4, 0, 0)) . (1, 1, -1, -1) = (+4, -4) → **Data (1, 0)**
  - **"Sender 4" Despread Signal (C_4 = (1, -1, -1, 1)):**
    - ((0, 0, -4, 0), (0, -4, 0, 0)) . (1, -1, -1, 1) = (+4, +4) → **Data (1, 1)**

Code Division Multiple Access

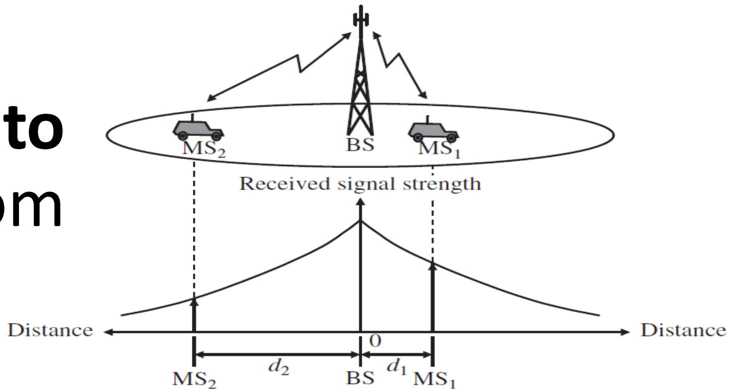
- In contrast with FDMA and TDMA which are **bandwidth and time limited**, CDMA is **interference limited**.
- Because **all users transmit on the same frequency and at the same time, internal interference generated by the users (related to the transmission power used by each one of them)** is the **most significant factor** in **determining system capacity** and **call quality**.
  - **Each user** is a **source of interference to all the other users** in the cell.

Code Division Multiple Access

- To increase capacity, the **transmit power for each user** must be **reduced to limit interference**.
- However, **the Received signal power (at the BS) should be enough to maintain the minimum required *SNIR needed by the Receiver, so as to decode the signal (symbol) correctly,*** for a **satisfactory call quality**.
- Thus, the goal is **all MSs' transmitted signals to reach the Base Station and received with about the same signal power (and equal to the minimum required SNIR) from the BS → Otherwise some signals could drown others.**

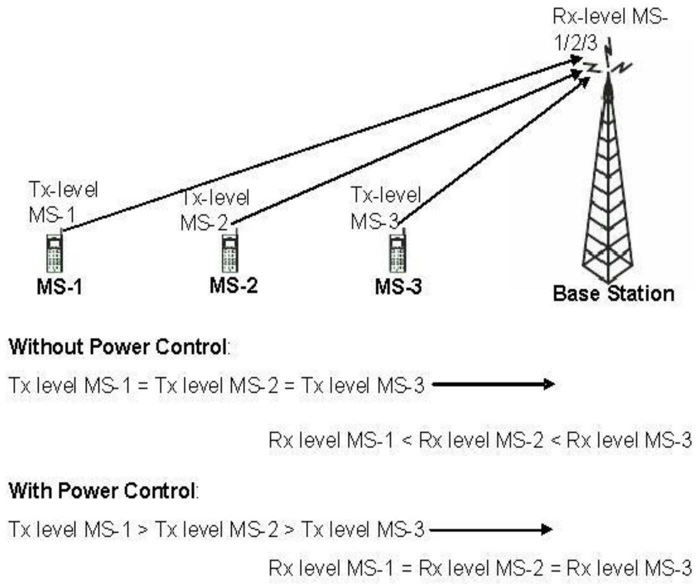
Code Division Multiple Access
Near Far Problem

- If all **MSs** **transmit** **with the** **same power**, **signals** transmitted from **MSs closest to the BS** will be **received with** **much larger power** than **signals** from **MSs further away**.
  - Due to the difference in the **path lengths** **higher propagation path loss** is **experienced** for **users further away from the BS.**
  - The **received SNIR** **for signals transmitted from** **MSs far from the BS** **will be** **low**.
- Thus, **signals** from **MSs close to the BS** will **drown out signals** from **MSs far away from the BS.**
- **Solution: Power Control!!!**



Code Division Multiple Access
Near Far Problem – Power Control

- **Power control is essential** in order to **maintain the transmission power levels used by the MSs to the lowest level necessary** → **Reduce interference to the minimum** and **maximize the capacity of the system**.



One of the main objectives of Power Control is to ensure that the power of all signals received at the BS is almost equal and at a lowest level aiming to reduce the interference to the minimum, however adequate for the Receiver to be able to decode the signal correctly (i.e., received signal SNIR ≈ minimum required SNIR).

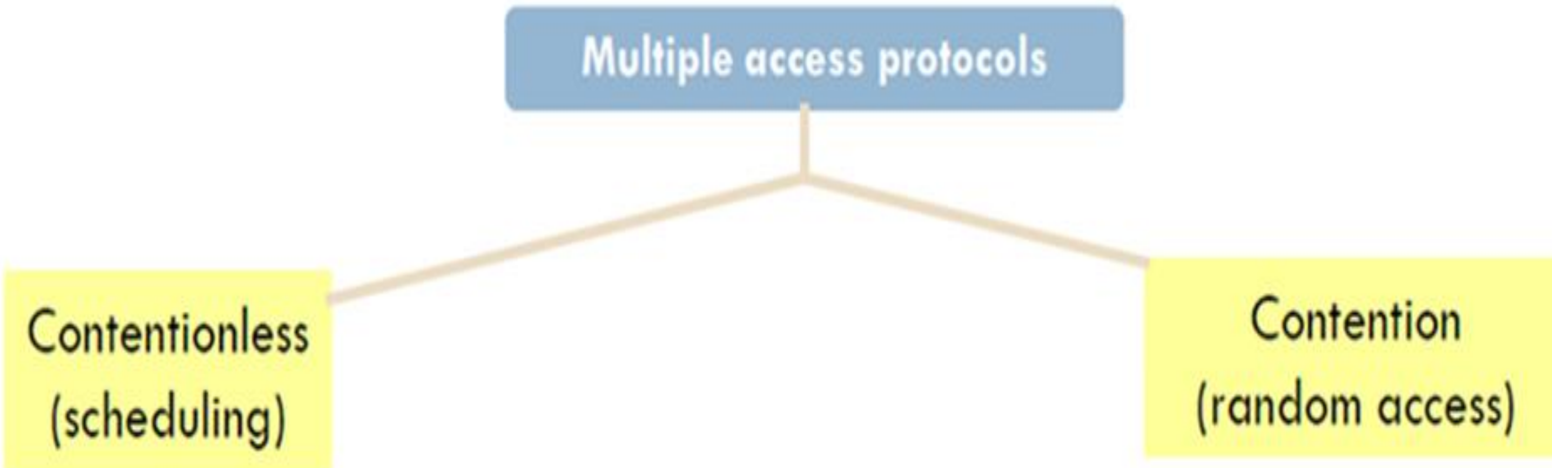
Multiple Access Control
Έλεγχος Πολλαπλής Πρόσβασης

- **Problem**: When two or more stations **using the same radio resources (i.e., frequency band or bandwidth or channel)**, **transmit their frames at the same time**, their **frames will collide** and the **radio resources will be wasted during the time collision** (Όταν δύο ή περισσότερα stations που χρησιμοποιούν τους ίδιους ασύρματους πόρους στείλουν τα frames τους την ίδια ώρα, τα frames των stations θα συγκρουστούν με αποτέλεσμα το διαθέσιμο εύρος ζώνης εκείνη τη χρονική περίοδο της σύγκρουσης να πάει χαμένο).
  - How to **coordinate the access** (Πώς να γίνει ο συντονισμός πρόσβασης) of multiple sending/receiving stations to the shared channel in **order to avoid collisions** and thus **avoid waste of the radio resources**???

Multiple Access Control
Έλεγχος Πολλαπλής Πρόσβασης

- **Solution**: We need a **protocol** to **coordinate the frame transmissions** of the active stations (Χρειαζόμαστε ένα πρωτόκολλο για να συντονίσει τις εκπομπές των active stations - **active stations** είναι αυτά που **έχουν frames έτοιμα να σταλούν**).
  - These protocols are called **Medium or Multiple Access Control (MAC) Protocols.**

Multiple Access Protocols Classification



Μη Ανταγωνιστικά

Ανταγωνιστικά

Multiple Access Protocols Contentionless-based

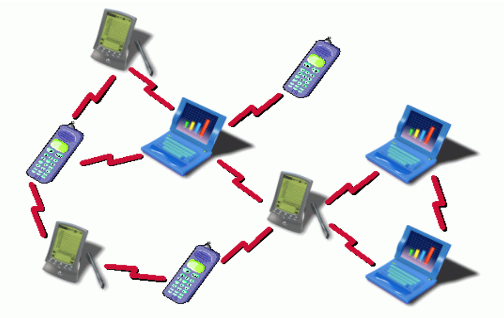
- **Contentionless-based (Μη Ανταγωνιστικά) Protocols:**
  - A **central controller** (Base Station or Access Point) **is needed** to **coordinate (**να συντονίσει**) the transmissions** of **all the stations.**
  - The **controller informs each station when** and **on which channel** it can **transmit its data.**
    - **So, each station has its own channel.**
    - **By doing this collisions can be avoided entirely**

  - With **Contentionless-based Protocols**, the stations transmit in an **orderly scheduled manner (**Τα stations εκπέμπουν με ένα μεθοδικό προγραμματισμένο τρόπο**)** so **every transmission** will **be successful (No collisions)**.

Multiple Access Protocols Contentionless-based

- **Contentionless-based (Μη Ανταγωνιστικά) Protocols:**
  - **Examples (Basic Channelization Protocols):**
    - **FDMA** (Frequency Division Multiple Access),
    - **TDMA** (Time Division Multiple Access),
    - **CDMA** (Code Division Multiple Access)
    - ***OFDMA*** *(Orthogonal Frequency Division Multiple Access)*
  - **Typically used in Infrastructure based Networks (e.g., WLANs, Cellular Networks, etc.)**

Multiple Access Protocols
Contention-based



- **Contention-based (Ανταγωνιστικά) Protocols:**
  - **No central controller** (No Base Station or Access Point) is **needed to coordinate** the transmissions of the stations.
  - **All stations transmit using the same channel**, **without having a central controller** to **coordinate** them.
  - If several stations **start their transmissions** more or less at the **same time**, **all of the transmissions will fail**.
  - These **contention-based protocols** **resolve the contention** **(**επιλύουν τον ανταγωνισμό**)** that occur **when several users want to transmit simultaneously** and a **central controller is not present**.

Multiple Access Protocols Contention-based

- **Contention-based (Ανταγωνιστικά) Protocols:**
  - The aim is to **minimize collisions** and **better utilize the bandwidth by determining**:
    - **When** a station **can use the channel**.
    - **What** a station **should do** when the **channel is busy.**
    - **What** a station **should do** when is **involved in a collision.**
  - Examples of Contention-based protocols are the **Random Access Protocols (Πρωτόκολλα Τυχαίας Πρόσβασης)**:
    - Pure (P) - ALOHA,
    - Slotted (S) - ALOHA,
    - Carrier Sense Multiple Access (CSMA) & its variants (και οι διαφορετικές εκδοχές του)

Multiple Access Protocols Contention-based

- **Contention-based (Ανταγωνιστικά) Protocols:**
  - Typically used in **Infrastructure-less based Networks (e.g., Ad Hoc Networks),** where all the stations transmit using **the same channel**.
  - Also can be used **in an infrastructure based network** (i.e., Cellular Network), for **exchanging control information** between a Mobile Station and the Base Station **before a (control and traffic) channel is established between them.**
    - **Note that, in infrastructure-based networks, before a control channel is established between the Base Station and the Mobile Station, the Base Station is not aware about the existence of the Mobile Station and thus have no control over it.**