# ΕΠΛ 427: ΚΙΝΗΤΑ ΔΙΚΤΥΑ ΥΠΟΛΟΓΙΣΤΩΝ (MOBILE NETWORKS)

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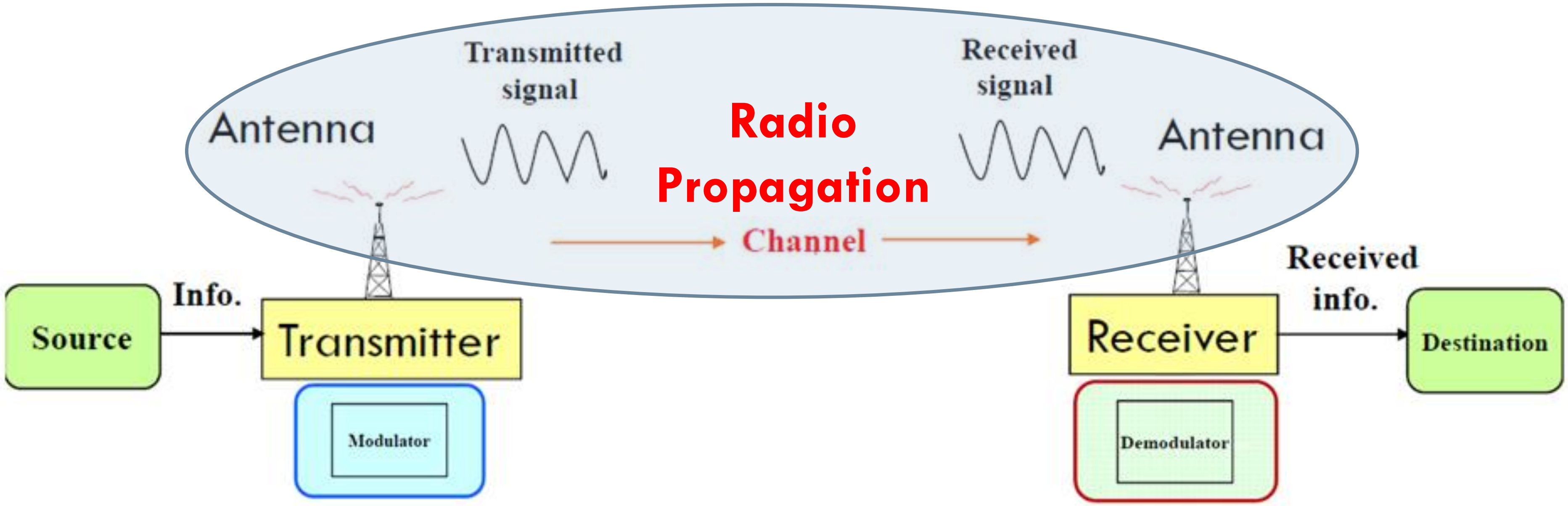
**Πανεπιστήμιο Κύπρου - Τμήμα Πληροφορικής**

Radio Propagation (Ασύρματη Διάδοση Σήματος)

# Recall (Process and Elements of Radio Transmission - Διαδικασία και στοιχεία Ασύρματης Διάδοσης Σήματος)





# Topics Discussed



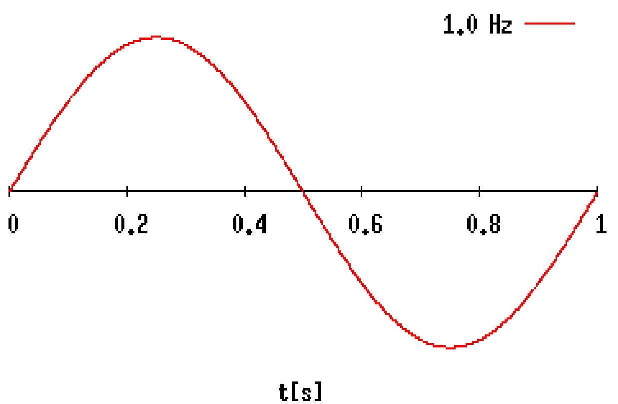
- Electromagnetic waves, Radio waves, Radio wave types
- Relation between: Frequency, Period and Wavelength
- Relation between Carrier Signal (Μεταφορέας Σήματος), Modulation (Διαμόρφωση Σήματος), Carrier Frequency (Συχνότητα Μεταφορέα) and Bandwidth (Εύρος Ζώνης)
- Decibel (dB), dBm, dBw
- Noise, SNR, Interference, SINR
- Radio Propagation
- Delay Spread
- Doppler Effect or Doppler Shift
- Signal Attenuation, Path loss
- Antennas

# Electromagnetic Waves Ηλεκτρομαγνητικά Κύματα



- **Heinrich Hertz** was the first person who **successfully demonstrated the presence of electromagnetic waves (απέδειξε την παρουσία των ηλεκτρομαγνητικών κυμάτων)**, by building a device (antenna) that could produce and detect radio waves **(around 1888)**.
- His undertakings earned him the **honor of having his surname** assigned to the **international unit of frequency (Hertz)**
  - **Hertz**: How many times the wave is repeated (oscillated – ταλαντώνεται) in 1 second

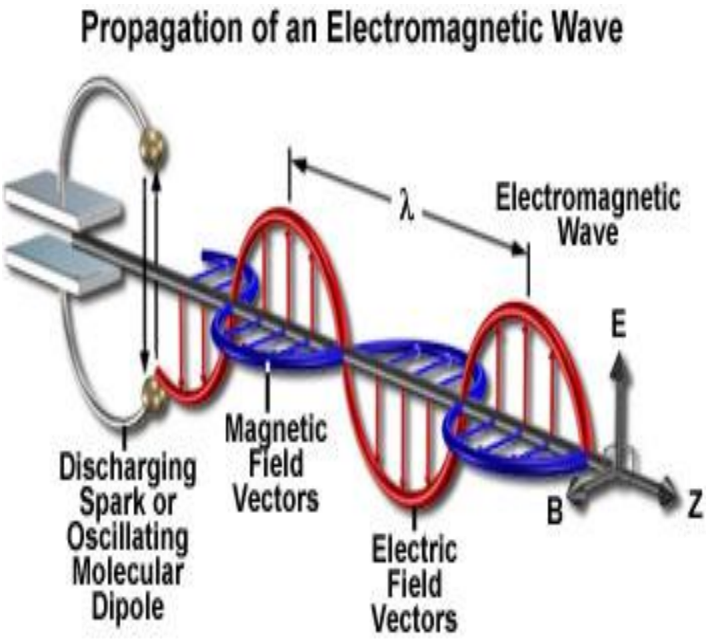
**Example: 1 Hz → 1 complete oscillation of the wave in a period of 1 second**



# Electromagnetic Waves
# Ηλεκτρομαγνητικά Κύματα

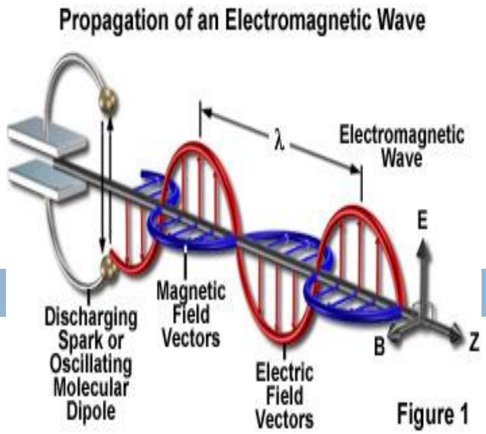


- **The electromagnetic wave always** propagates **in a direction (Z) that is oriented by the vibrations (διαδίδεται σε κατεύθυνση Z η οποία προσανατολίζεται από τις ταλαντώσεις)** of **both** the **Electric (E)** and **Magnetic (B) oscillating field** vectors.
  - The **Electric Field (E)** and **Magnetic Field (B)** vectors of the wave **are in directions perpendicular** (i.e., at right angle - κάθετα) **to the direction of wave propagation (Z)**
- **The Electric Field (E)** and **Magnetic Field (B)** are also **perpendicular to each other** and **vibrate in phase (ταλαντεύονται έχοντας την ίδια φάση)** following the mathematical form of a **Sine wave**.
- For **simplicity** reasons, **the two vectors** representing the electric and magnetic oscillating fields of electromagnetic waves are **often omitted** (παραλείπονται), and assumed that **there is only one vector**.



# 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)**.

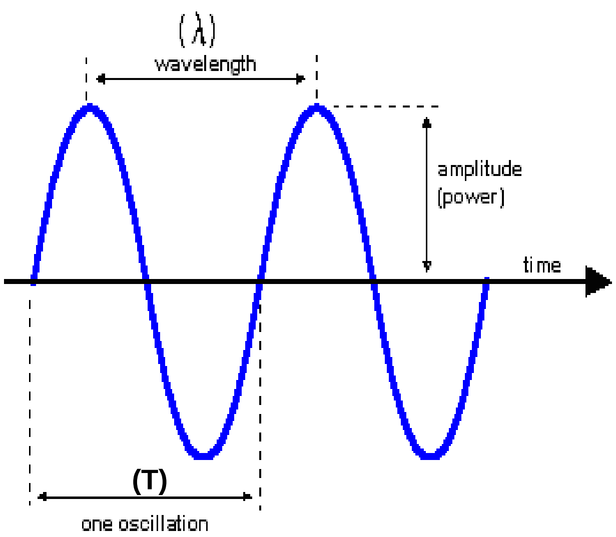
# Electromagnetic Waves
# Ηλεκτρομαγνητικά Κύματα



- **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) = (3x$10^8$ 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

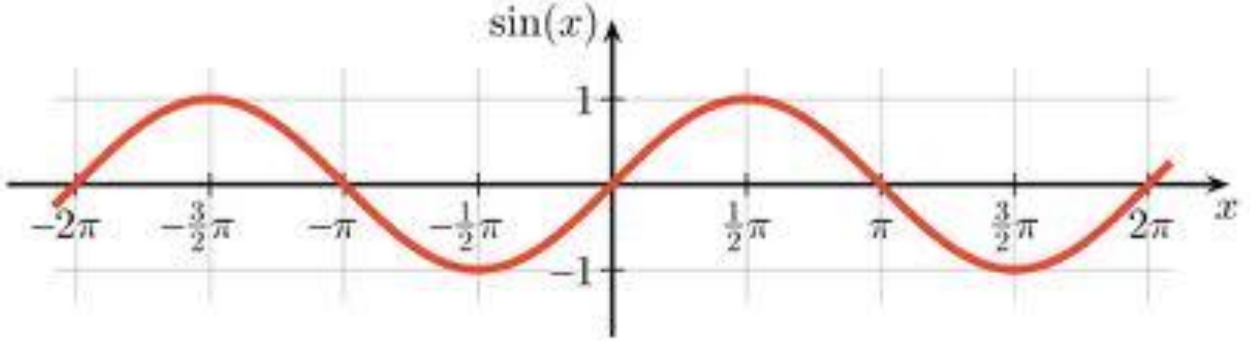


- **Relationship** between the **Frequency (f)** and the **Period (T)** of the wave:
  - **Frequency** (total number of oscillations performed in one second)
  - **Period** (time required for one complete oscillation)
  - **Period (T)= 1/Frequency (f)**
  - **Examples:**
    - **Frequency** = 60 Hz →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

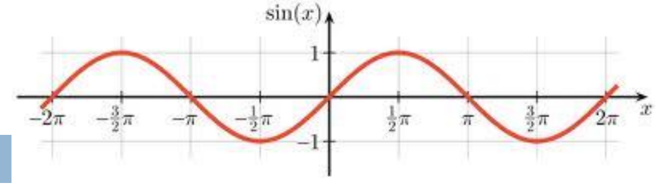


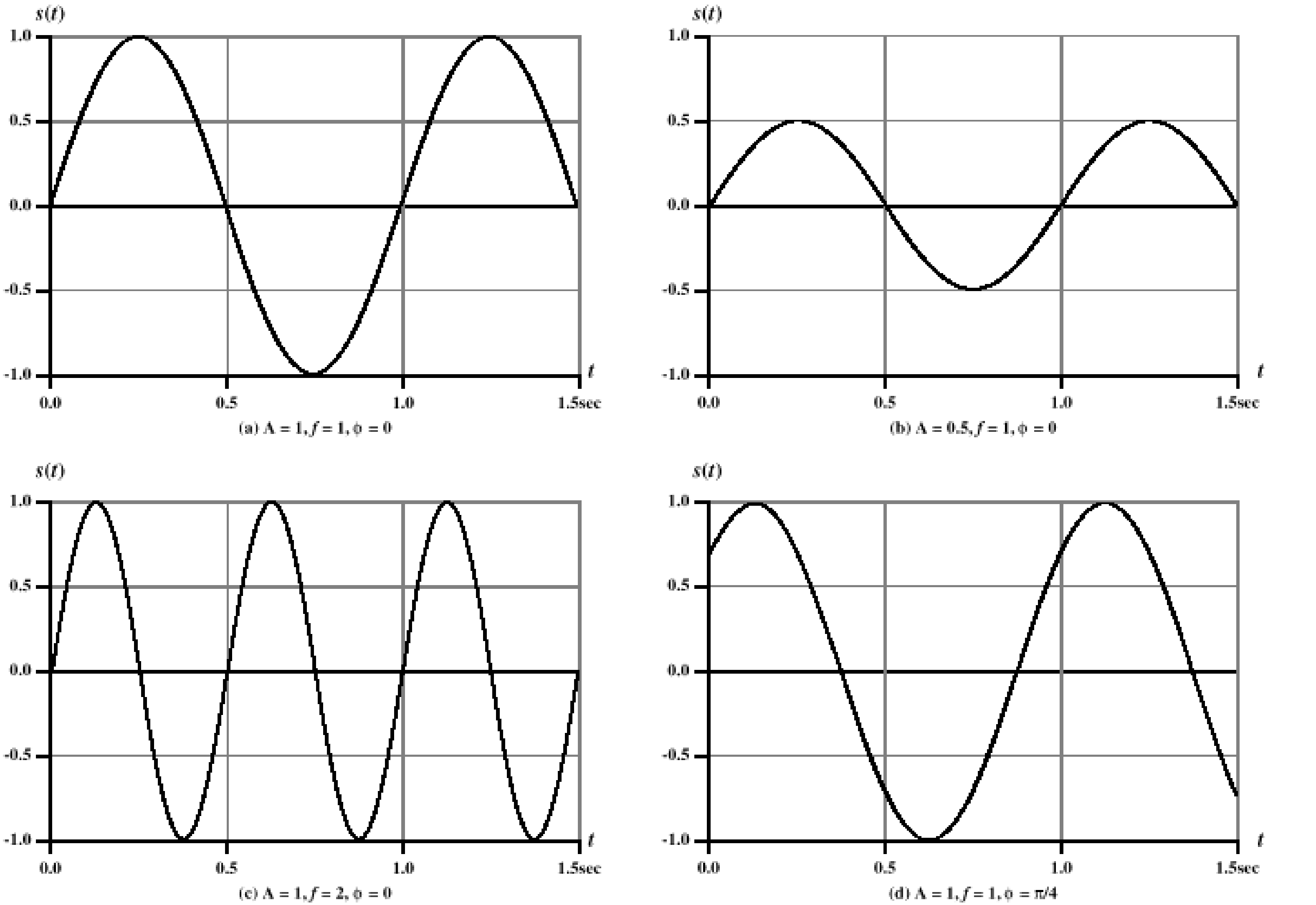

- The picture in the next slide shows the **effect of varying each of the three parameters** (**A**, **f** and **ϕ**)
  - (a) A = 1, f = 1 Hz, ϕ = 0; thus T = 1s
  - (b) Reduced peak amplitude; A=0.5, f = 1 Hz, ϕ = 0
  - (c) Increased frequency; A = 1, f = 2 Hz, ϕ = 0; thus T = 0.5s
  - (d) Phase shift;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

(b) A = 0.5, f = 1, φ = 0

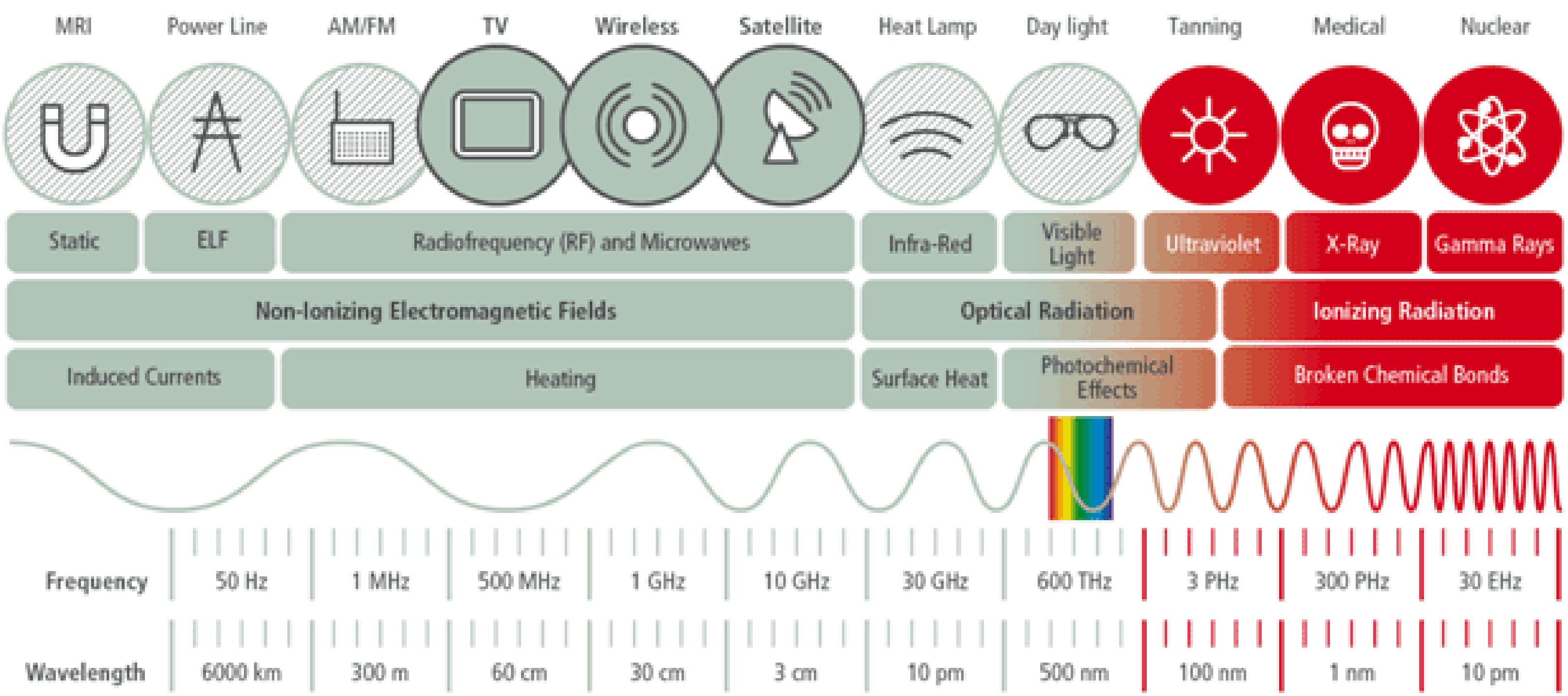
(c) A = 1, f = 2, φ = 0

(d) A = 1, f = 1, φ = π/4

# The Electromagnetic Spectrum
# Το Ηλεκτρομαγνητικό Φάσμα

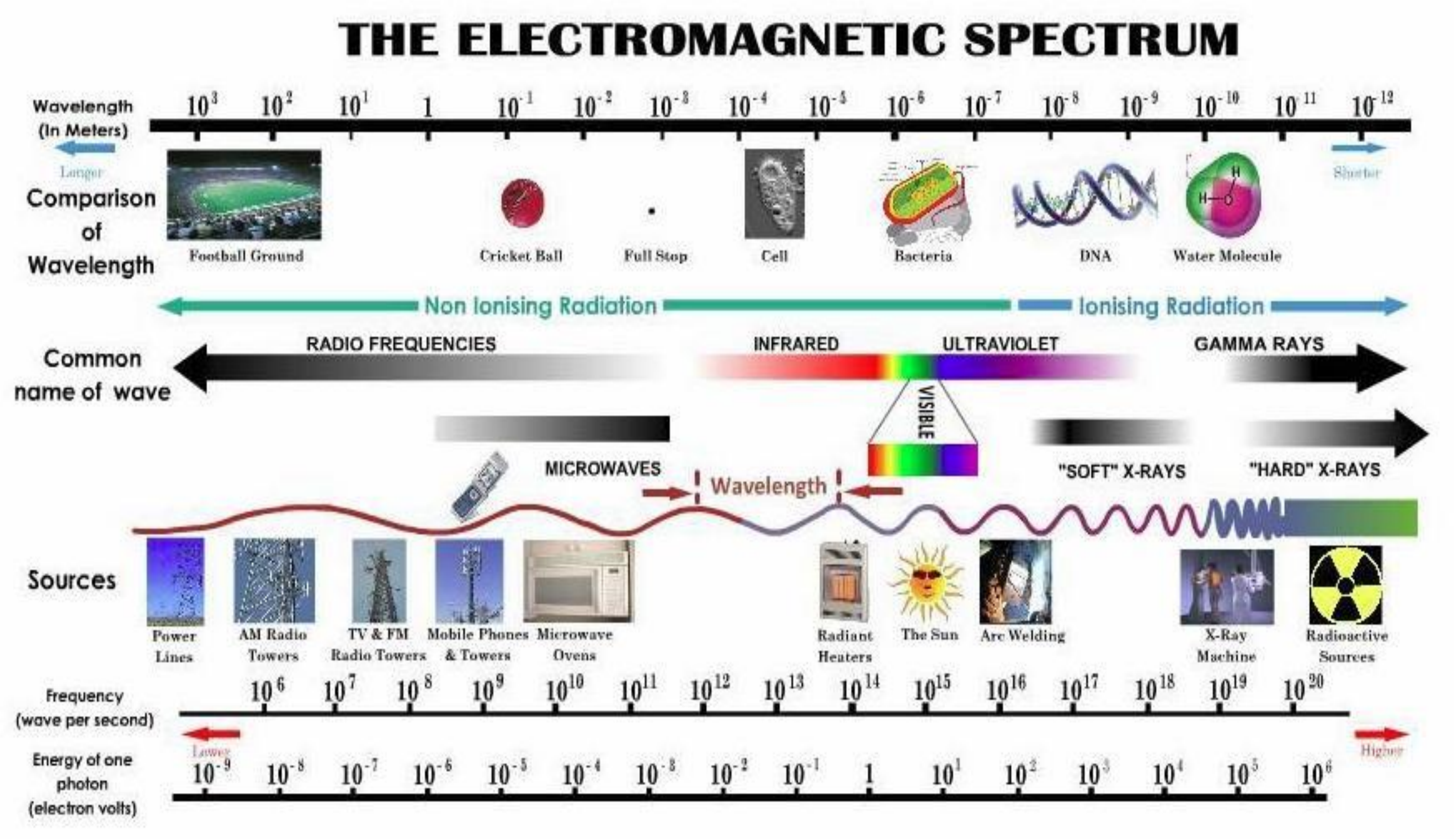


- The "**electromagnetic spectrum**“ is a term used to describe the **entire range (πεδίο) of frequencies** of electromagnetic radiation (ηλεκτρομαγνητικής εκπομπής) from zero to infinity.
- **Spectrum (Φάσμα)** represents a spread (range) of frequencies.



# The Electromagnetic Spectrum
# Το Ηλεκτρομαγνητικό Φάσμα





# 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**.

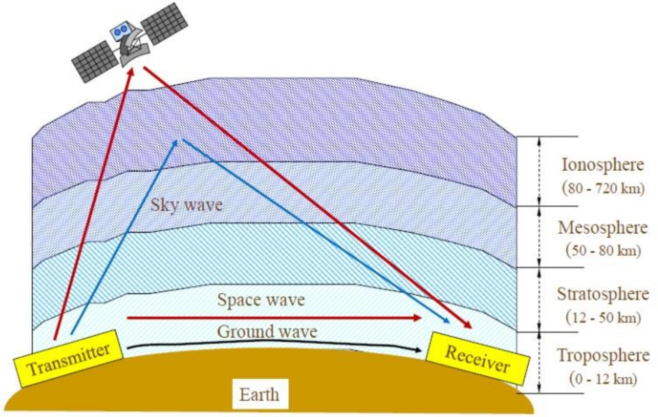
# Radio Waves (Ραδιοκύματα)



- **Radio waves** are electromagnetic waves with **wavelengths above 1 mm**. (**All electromagnetic waves at frequencies less than 300 GHz**).
- In this range, Radio waves are **suitable for communications**.
  - Broadcast (audio) Radio, Television, Mobile Phones, Satellite links.
- Most forms of wireless communication involve radio waves, and the words **'wireless'** and **'radio'** are often **synonymous**.

# Radio Waves Types

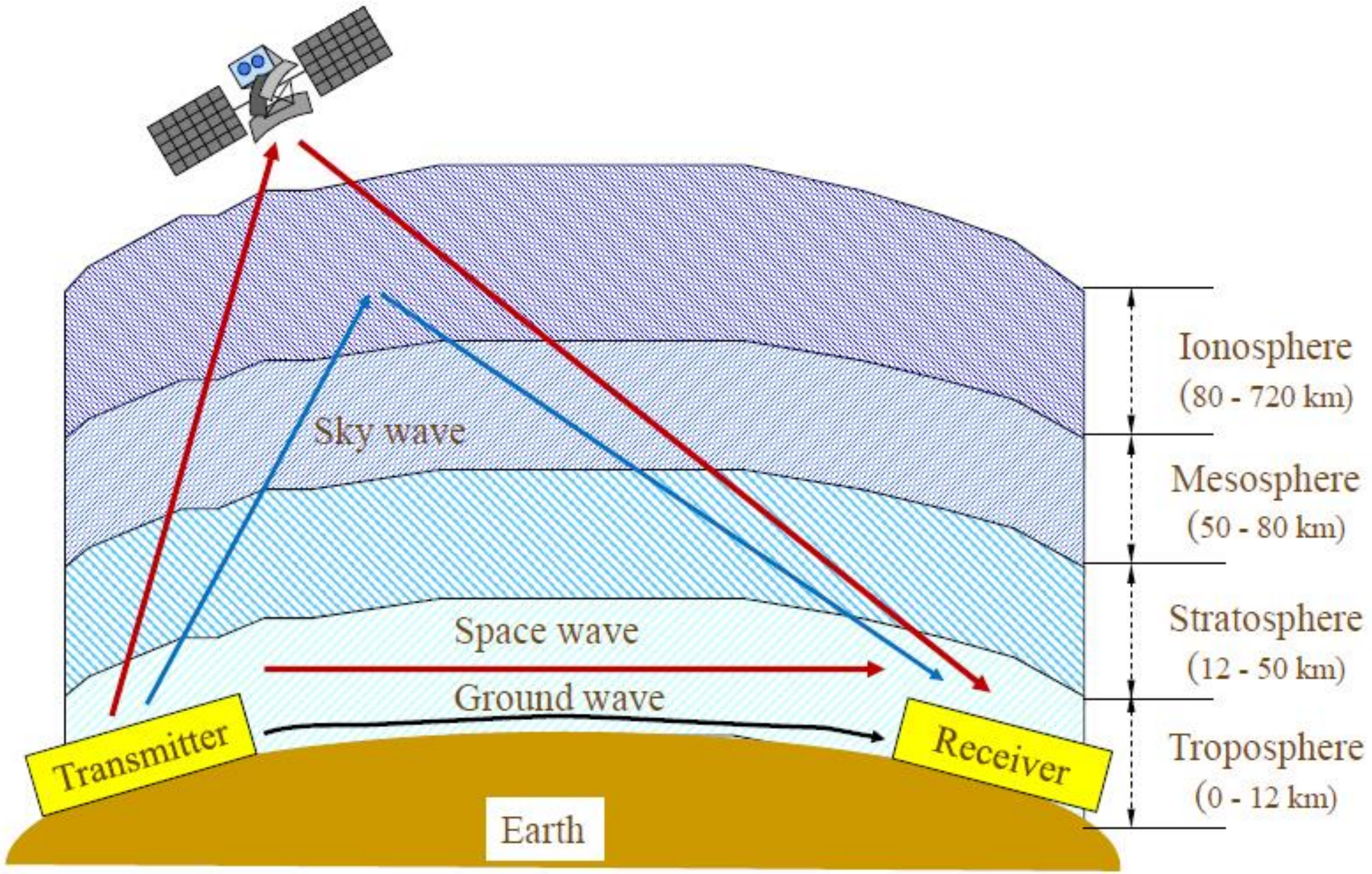





- **Ground Wave (<2 MHz):** Waves with low frequencies that **follow the earth's surface** and can **propagate long distances**
  - AM Radio (Low Frequency, Medium Frequency)
- **Sky Wave (2–30 MHz):** Waves that are reflected (αντανακλώνται) at the ionosphere.
  - Bounce (Αναπηδούν) back and forth **between the ionosphere** and the **earth's surface**, travelling **around the world**.
  - International Radio Broadcasts, Military Communications, Long Distance Aircraft and ship communication
- **Space Wave (>30 MHz):** Waves having high frequencies (>30MHz) and travel either directly or can travel after reflecting (αντανάκλαση) from earth's surface to the troposphere surface of earth.
  - VHF, UHF Television, Cellular phone systems, Satellite systems, Radar.

# Radio Waves Types





# Radio Frequency Bands



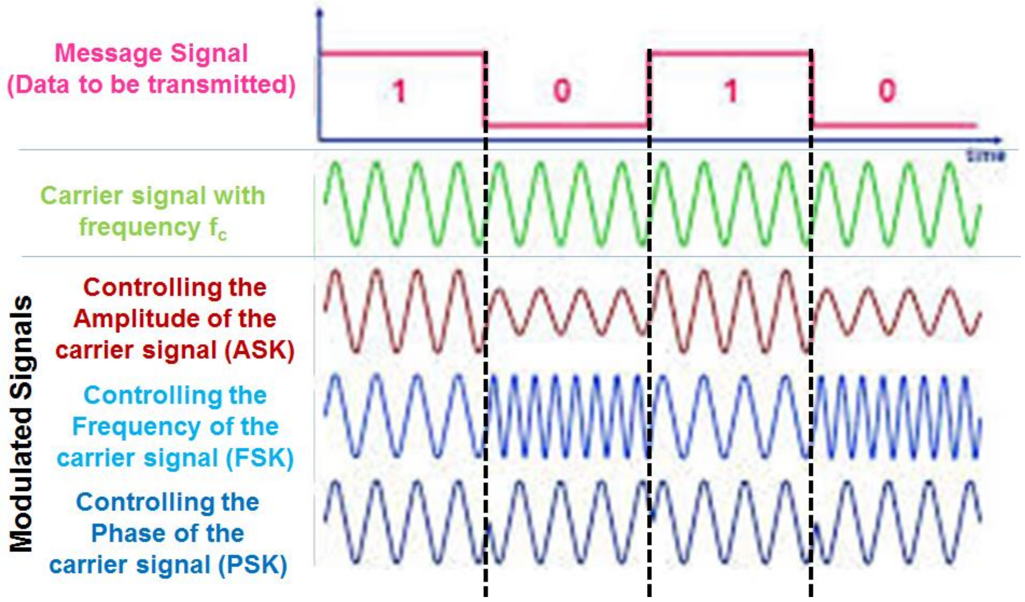
| Classification Band | Initials | Frequency Range | Characteristics |
|---|---|---|---|
| Extremely low | ELF | < 300 Hz | Ground wave |
| Infra low | ILF | 300 Hz - 3 kHz | |
| Very low | VLF | 3 kHz - 30 kHz | |
| Low | LF | 30 kHz - 300 kHz | |
| Medium | MF | 300 kHz - 3 MHz | Ground/Sky wave |
| High | HF | 3 MHz - 30 MHz | Sky wave |
| Very high | VHF | 30 MHz - 300 MHz | Space wave |
| Ultra high | UHF | 300 MHz - 3 GHz | |
| Super high | SHF | 3 GHz - 30 GHz | |
| Extremely high | EHF | 30 GHz - 300 GHz | |
| Tremendously high | THF | 300 GHz - 3000 GHz | |

- **NOTICE:**
  - In this course, we are primarily concerned Space waves, and we discuss the propagation properties, path losses, and other characteristics in these areas.
  - We are interested in propagation characteristics for waves with frequency in range: **few hundred of MHz to a few GHz**

# Carrier Signal, Modulation, Carrier Frequency and Bandwidth



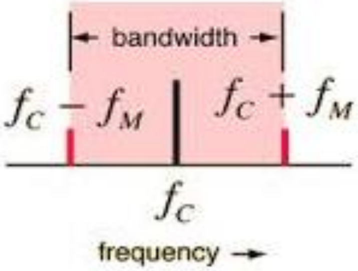
- **Carrier Signal (or Carrier Wave)** is a waveform (κυματομορφή) oscillated in a **certain frequency ($f_c$)** **(Carrier wave frequency)** that will be used to **carry the data (i.e., 1 or 0)**.
- However, to **carry data**, the **carrier wave** have to be **modulated in some way** in order to produce **the signal** that will **carry the data**. This process is called **Modulation**.



# 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 **$10 \times \log_{10}(100/1)$** = **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

# Decibel (dB)
# Decibel Conversion Table to Ratio



### Decibel Conversion Table

| dB | X | X | | dB | X |
|---|---|---|---|---|---|
| 10 dB | 10 | 10^1 | | 3 dB | 2 |
| 20 dB | 100 | 10^2 | | 6 dB | 4 |
| 30 dB | 1,000 | 10^3 | | 9 dB | 8 |
| 40 dB | 10,000 | 10^4 | | 12 dB | 16 |
| 50 dB | 100,000 | 10^5 | | 15 dB | 32 |
| 60 dB | 1,000,000 | 10^6 | | 18 dB | 64 |
| 70 dB | 10,000,000 | 10^7 | | 21 dB | 128 |
| 80 dB | 100,000,000 | 10^8 | | 24 dB | 256 |

### Negative Decibels

| dB | X | | dB | X |
|---|---|---|---|---|
| -10 dB | 1/10 | | -3 dB | 1/2 |
| -20 dB | 1/ 100 | | -6 dB | 1/4 |
| -30 dB | 1/ 1000 | | -9 dB | 1/8 |
| -40 dB | 1/ 10000 | | -12 dB | 1/16 |

# 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.**

# dBm and dBW
# Conversion Table to Watt

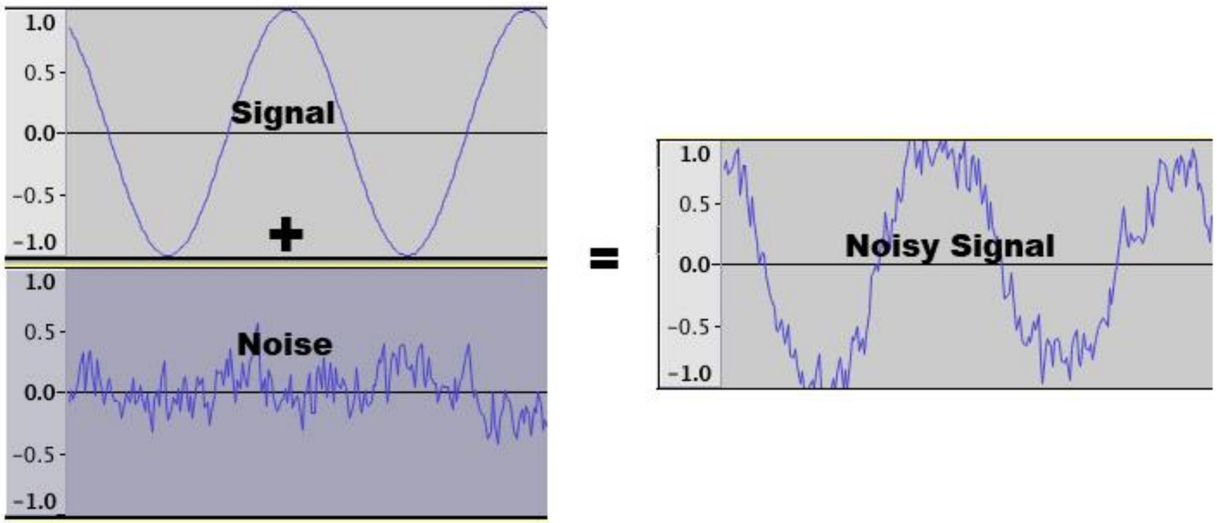


| Power (dBW) | Power (dBm) | Power (Watt) |
|---:|---:|---:|
| -30 dBW | 0 dBm | 1 mW |
| -20 dBW | 10 dBm | 10 mW |
| -10 dBW | 20 dBm | 100 mW |
| -1 dBW | 29 dBm | 0.794328 W |
| 0 dBW | 30 dBm | 1.000000 W |
| 1 dBW | 31 dBm | 1.258925 W |
| 10 dBW | 40 dBm | 10 W |
| 20 dBW | 50 dBm | 100 W |
| 30 dBW | 60 dBm | 1 kW |
| 40 dBW | 70 dBm | 10 kW |
| 50 dBW | 80 dBm | 100 kW |
| 60 dBW | 90 dBm | 1 MW |
| 70 dBW | 100 dBm | 10 MW |
| 80 dBW | 110 dBm | 100 MW |
| 90 dBW | 120 dBm | 1 GW |
| 100 dBW | 130 dBm | 10 GW |

# 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**

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

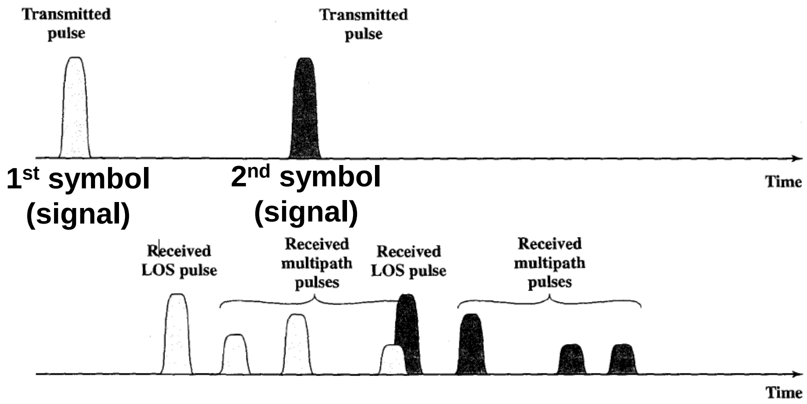
- A **high SNR** means **a high-quality signal**.
- If the **SNR is low the Receiver** may not be able to decode the signal correctly (resulting in data losses).

# 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

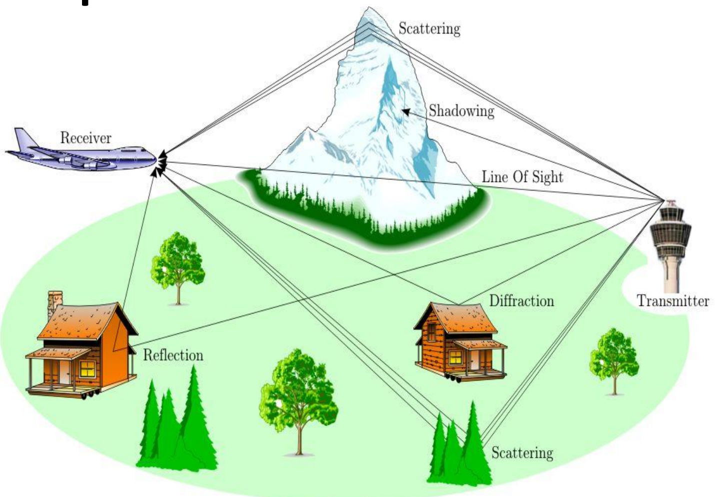


- **Radio propagation** is the **behavior of radio waves** when they are transmitted, or **propagated from one point on the Earth to another**, into the atmosphere **(Ασύρματη Διάδοση** είναι η συμπεριφορά των σημάτων (ραδιοκυμάτων) καθώς διαδίδονται **ασύρματα** στην ατμόσφαιρα από ένα σημείο της γης 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



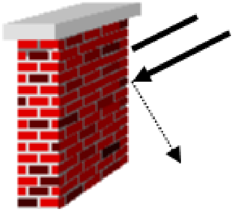
- ## Radio Propagation includes:
  - **Line of Sight (LOS) Transmissions (**Υπάρχει γραμμή ορατότητας μεταξύ Transmitter και Receiver**):** There is a **direct path (**Υπάρχει απευθείας μονοπάτι**) between Transmitter** and **Receiver** (no obstacles in the way).
  - **Non-Line of Sight (NLOS) Transmissions (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)**



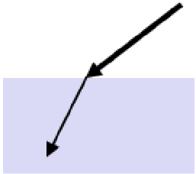
# Radio Propagation Phenomena
# Φαινόμενα Ασύρματης Διάδοσης

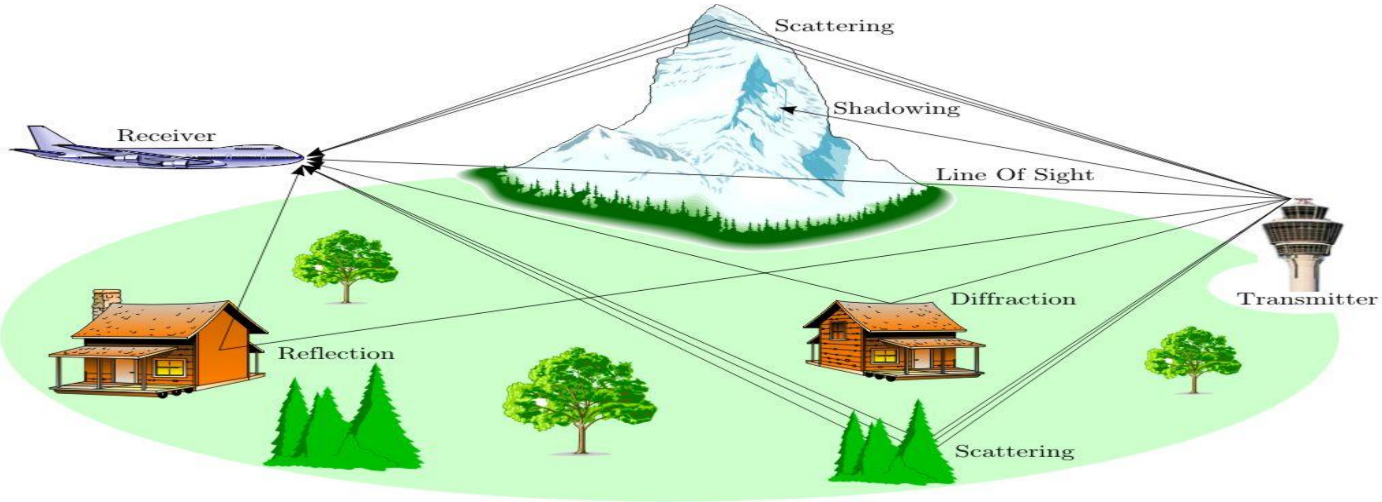


- **Radio Propagation Phenomena (I):**
  - **Shadowing (or blocking, επισκίαση):** The signal can be **blocked due to large obstacles**. The signal may not reach the Receiver.



  - **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)

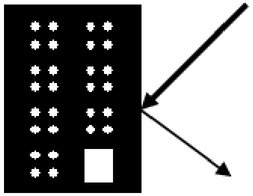


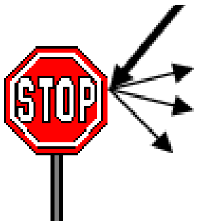


# Radio Propagation Phenomena
# Φαινόμενα Ασύρματης Διάδοσης



- **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).

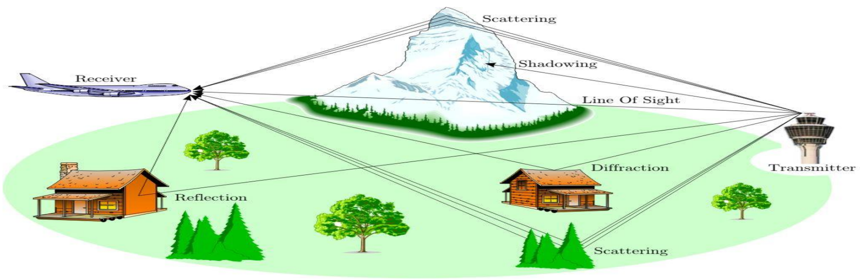






  - **Scattering (Διασκόρπιση)**: The incoming signal is **scattered into several weaker** outgoing signals**.**
  - **Diffraction (Περίθλαση):** Signals can be deflected (αποστρακίζονται) at the edge of a mountain (or other **surfaces with** sharp irregular edges) and **propagate in different directions** (Waves bend around the obstacle and move in different directions).

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

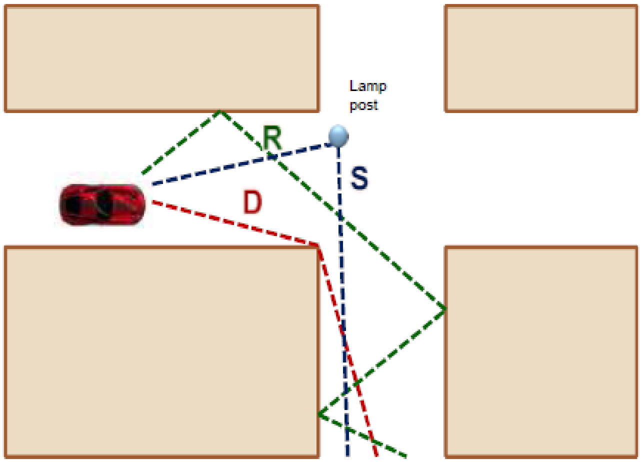


# Radio Propagation Phenomena
# Φαινόμενα Ασύρματης Διάδοσης



- **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!!!***

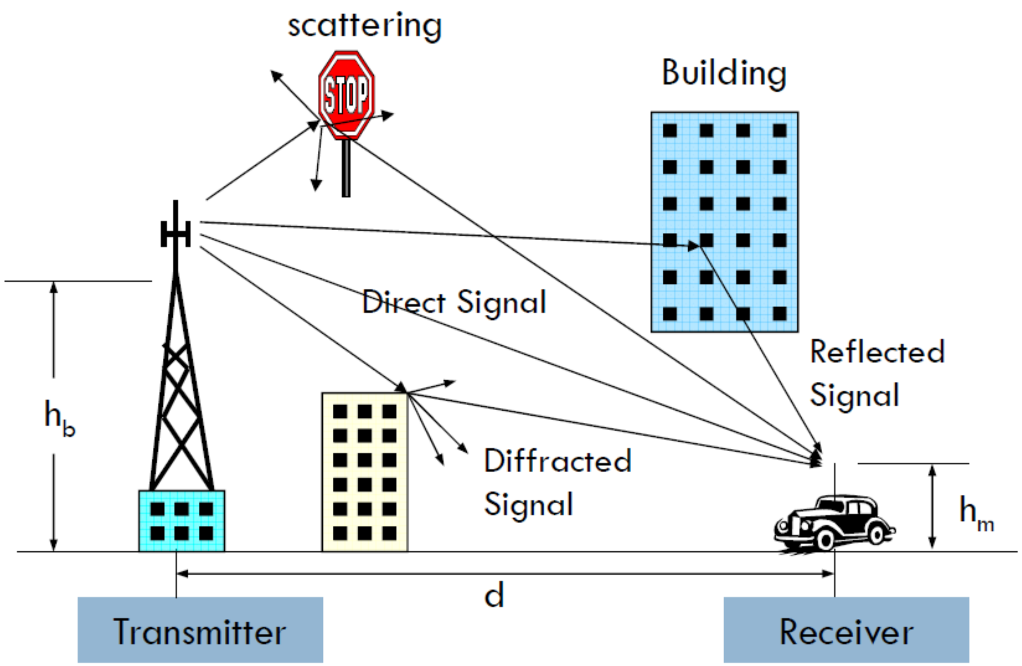
***Οδηγούν στην Πολυδιαδρομική Μετάδοση!***

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

# Multipath Propagation Effects
# Επιπτώσεις Πολύδιαδρομικής Διάδοσης



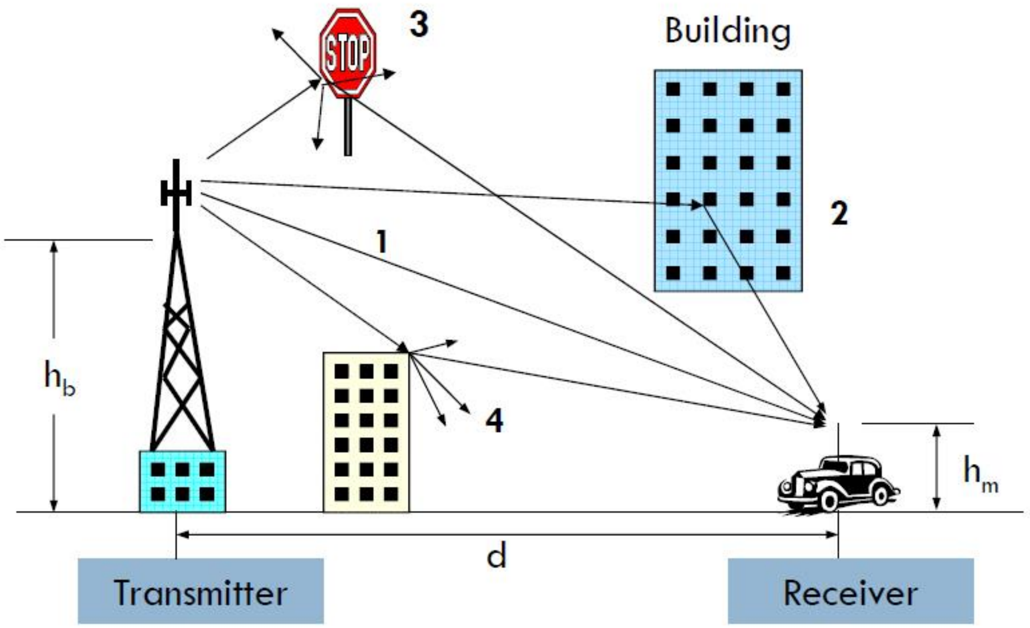
- **Transmission paths** between **Sender** and **Receiver** could be:
  - **Direct Paths (Απευθείας Μονοπάτια)** → **LOS** between Transmitter and Receiver.
  - **Indirect Paths (Έμμεσα Μονοπάτια)** → Resulted by Scattering, Diffraction and Reflection by buildings, mountains, street signs, foliage,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

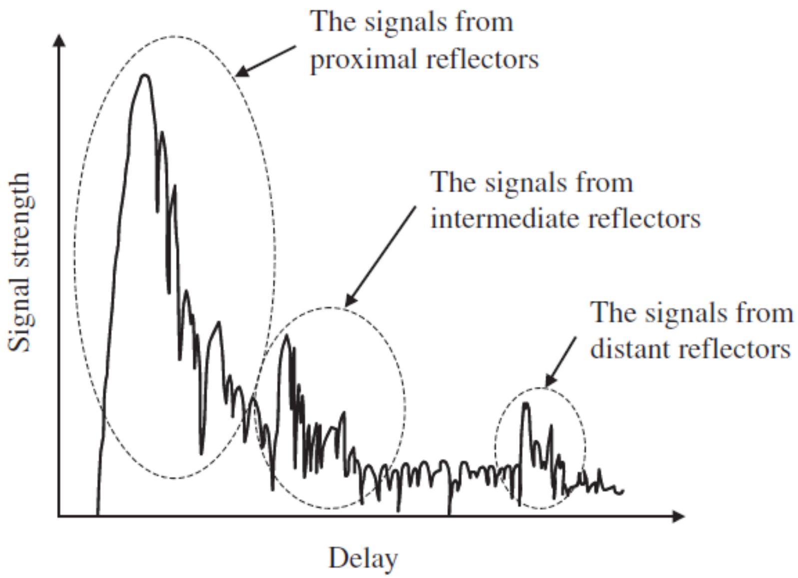
**Παρά τις επιπτώσεις της, είναι η Πολυδιαδρομική Διάδοση που κάνει δυνατή τη διάδοση του σήματος σε περιπτώσεις που δεν υπάρχει γραμμή ορατότητας μεταξύ του Transmitter και του Receiver!!!**

# Multipath Propagation Effects
# Επιπτώσεις Πολύδιαδρομικής Διάδοσης



## Delay Spread

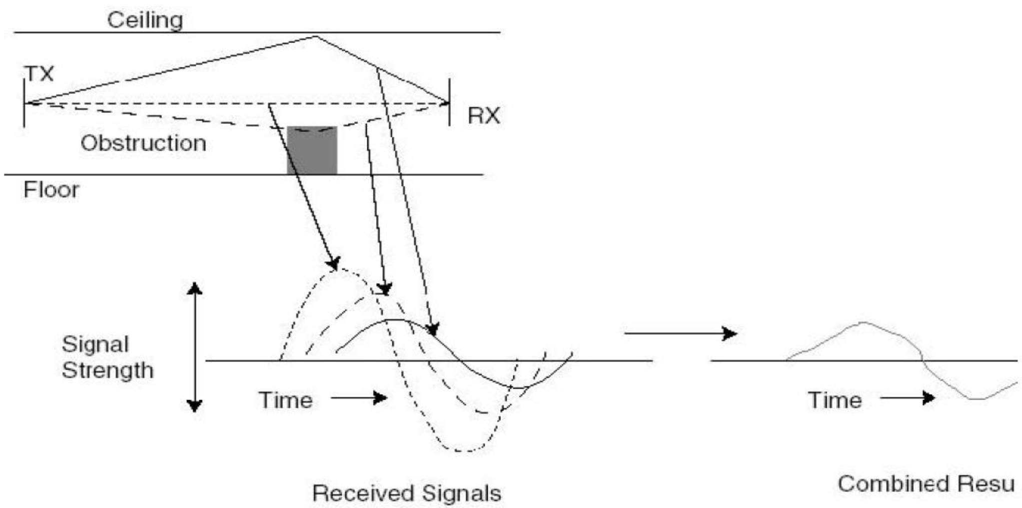
- When a signal propagates from a transmitter to a receiver, **the signal suffers one or more reflections (το σήμα ανταναλκάται αρκετές φορές)**.
  - This forces radio signals to **follow different paths** (Multipath Propagation).
- Since each path has a **different path length**, **the time of arrival** 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

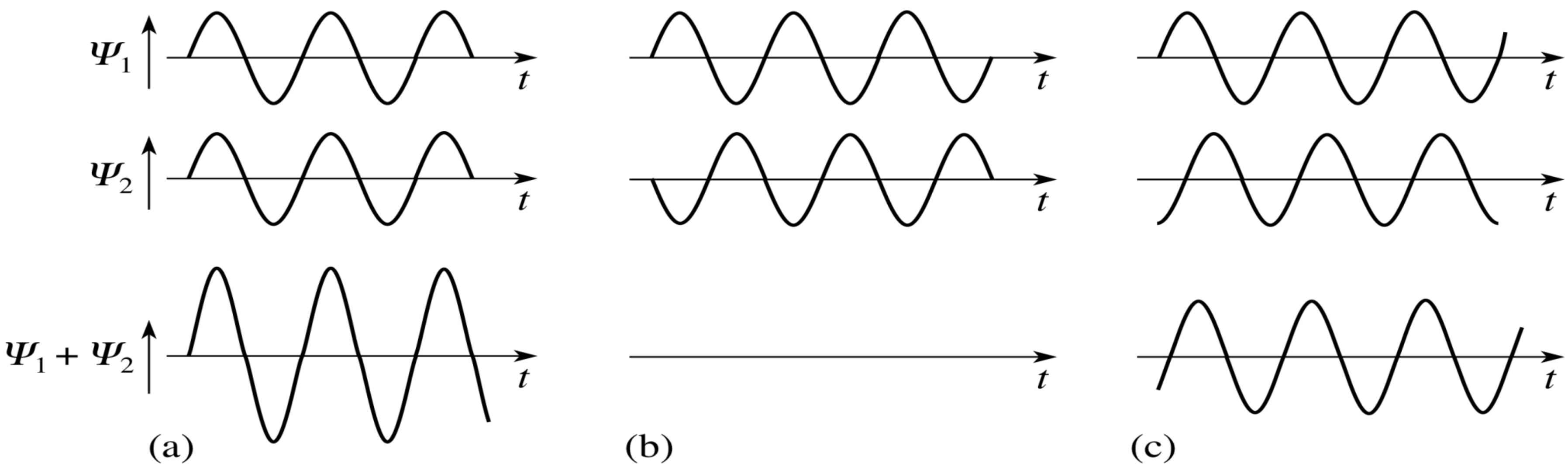


- ***Multipath Fading - Signal Properties, the phenomenon of interference***
  - When two or more waves propagates at the same space using the same frequency band, the **net amplitude at each point** is **the sum of the amplitudes** of the **individual waves (i.e., these two waves are combined)**.

**Constructive Interference**
*Signals are in phase*

**Destructive Interference**
*Signals are completely out of phase*

*Signals are slightly out of phase*

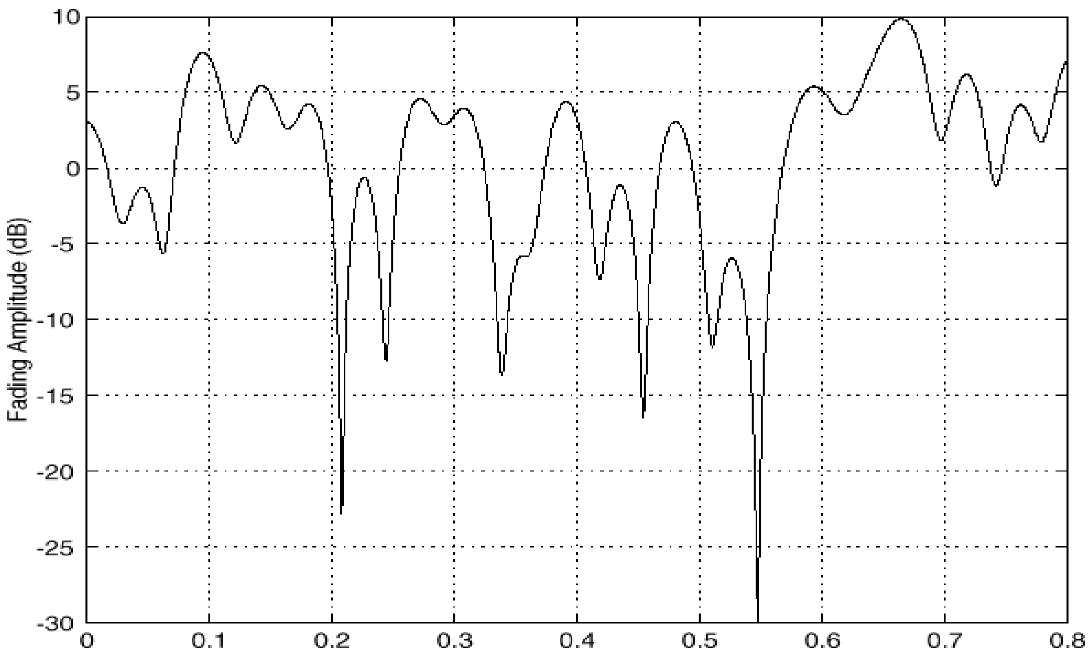


# Multipath Propagation Effects
# Επιπτώσεις Πολύδιαδρομικής Διάδοσης



- **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**.

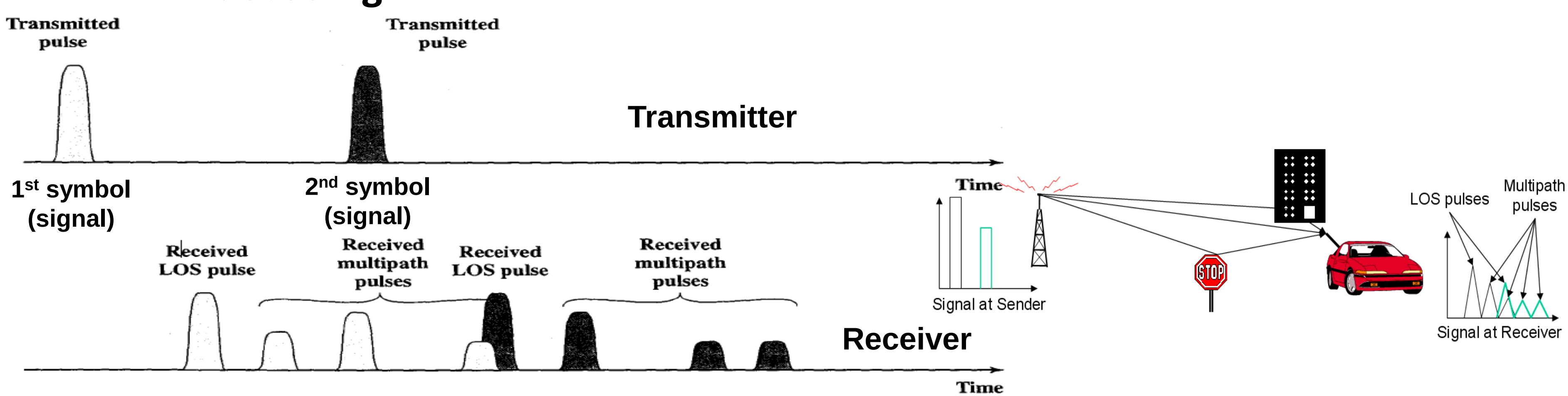
SNIR



# Multipath Propagation Effects
# Επιπτώσεις Πολύδιαδρομικής Διάδοσης



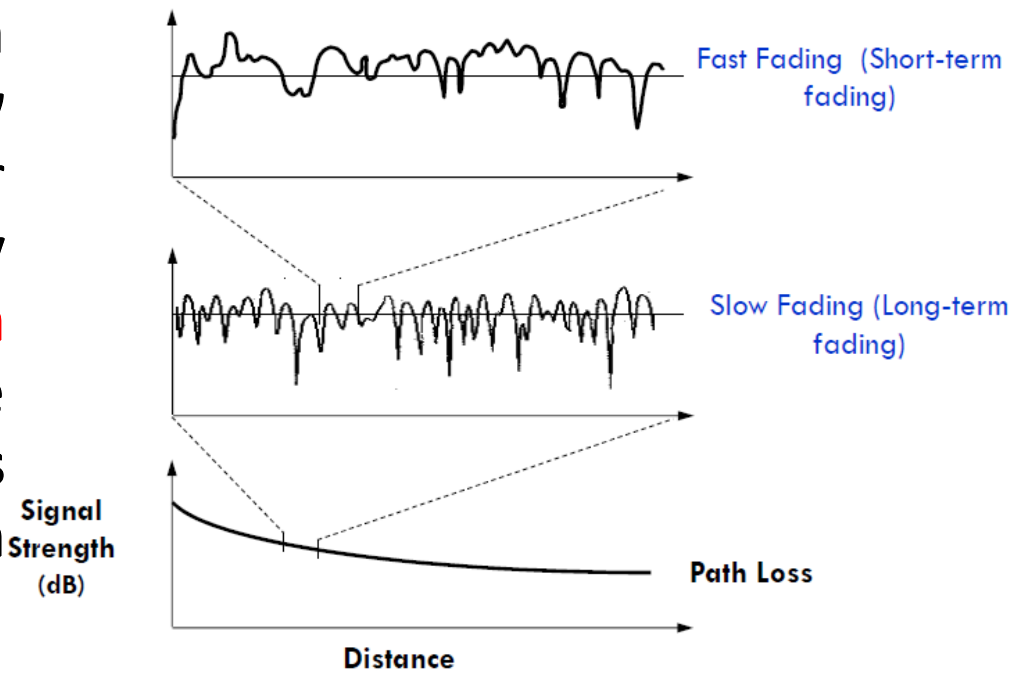
- **Inter-Symbol Interference (ISI)**
  - Due to **Delay spread**, the **energy indented for one symbol splits over to an adjacent symbol** (Η ενέργεια που προοριζόταν για ένα σήμα, διασκορπίζεται και ένα μέρος της συμπίπτει με την ενέργεια ενός άλλου σήματος**)** (appeared as Noise).
  - Due to this 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.**



# Slow Fading



- This fading is caused by phenomenon of **Shadowing (blocking)**.
- Usually associated with **moving away from the transmitter** and a **big obstacle** gets positioned **between** the **wireless device** and the **signal transmitter**, blocking (shadowing) the signal.
- Typically, senders can **compensate (μπορούν να αντισταθμίσουν)** for slow fading **by increasing transmission power** so that the **received signal always stays within certain limits**.



# 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

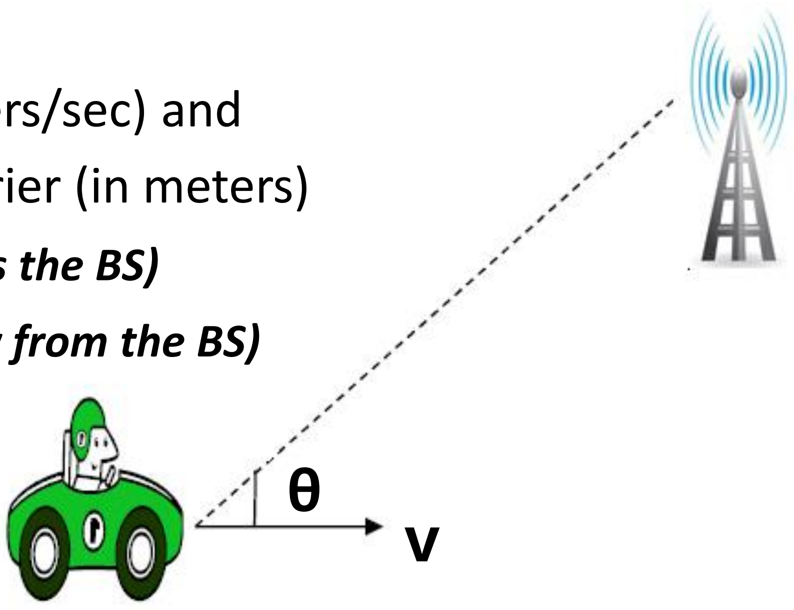


- The **frequency ($f_r$) that the moving user (the Receiver) will** experience is $f_r = f_c + f_d$

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

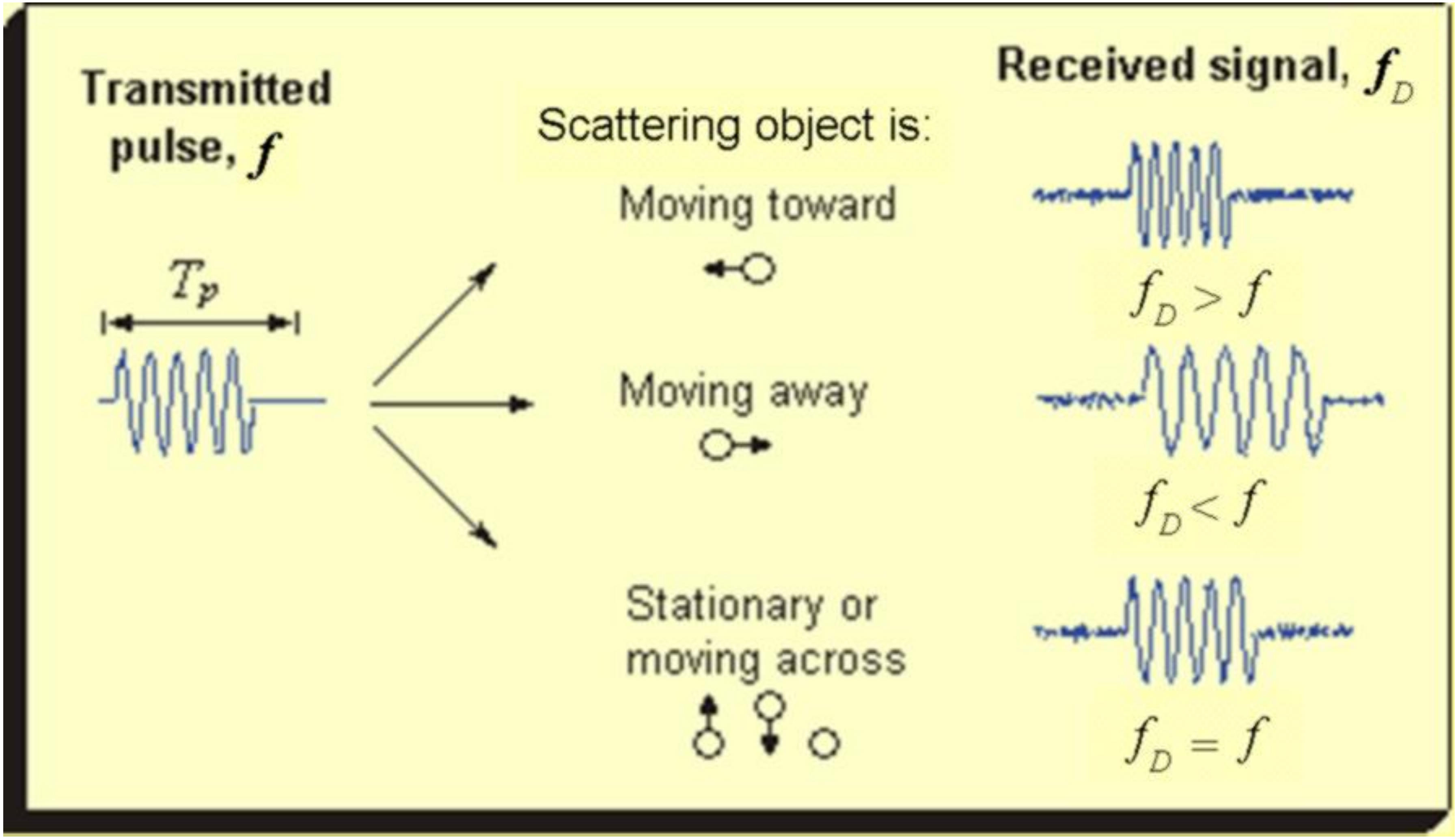
- **Doppler frequency** or **Doppler shift** is $f_d = \frac{v}{\lambda} \cos\theta$

**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





# 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 = 0°)*

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

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

# Doppler Effect



## ***Lets prove it!!! Is the equation correct?!!***

***Wave parameters:***

**_Frequency_ =** *100 MHz (100,000,000 Hz)* → ***Wavelength*** *= C/f = 3 meters*

***Period (T) =*** *1/f* → ***Period =*** *0.00000001 second*

***Speed of the User 60 Km/h*** → *16.6666666 meters/second*

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

*In a* ***Period (T)****, which is* ***0.00000001 second, the MS*** *based on its speed* ***will move 0.00000001666 meters*** *towards the BS*

***Thus the user will experience a wavelength of (3 meters - 0.00000001666 meters) instead of 3 meters.***

***Thus Wavelength' = 2.9999998334 meters***

***As W'=C/f '*** → ***f' = C/W'***

*Thus the new observed frequency* ***(f')*** *will be* ***300,000,000/2.9999998334 = 100,000,005.55 Hz***

***Therefore we will have a 5.55 Hz Doppler Shift***

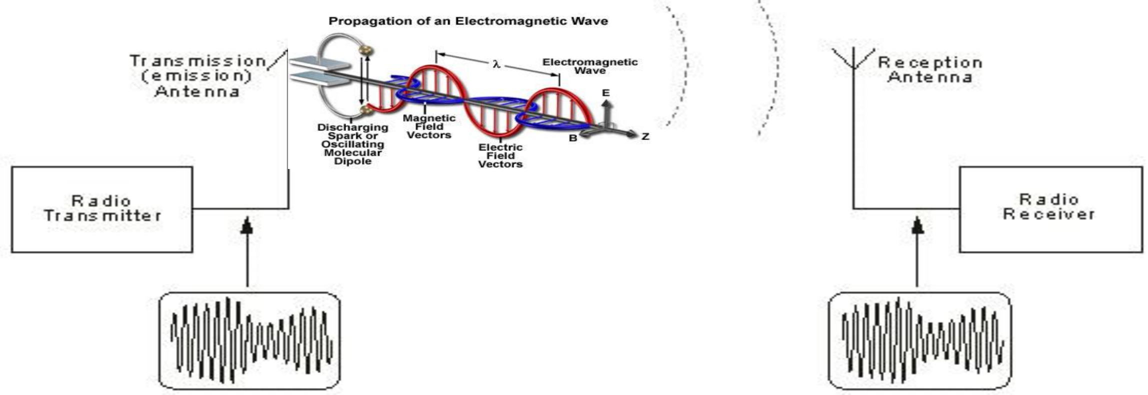
# Antennas



- 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

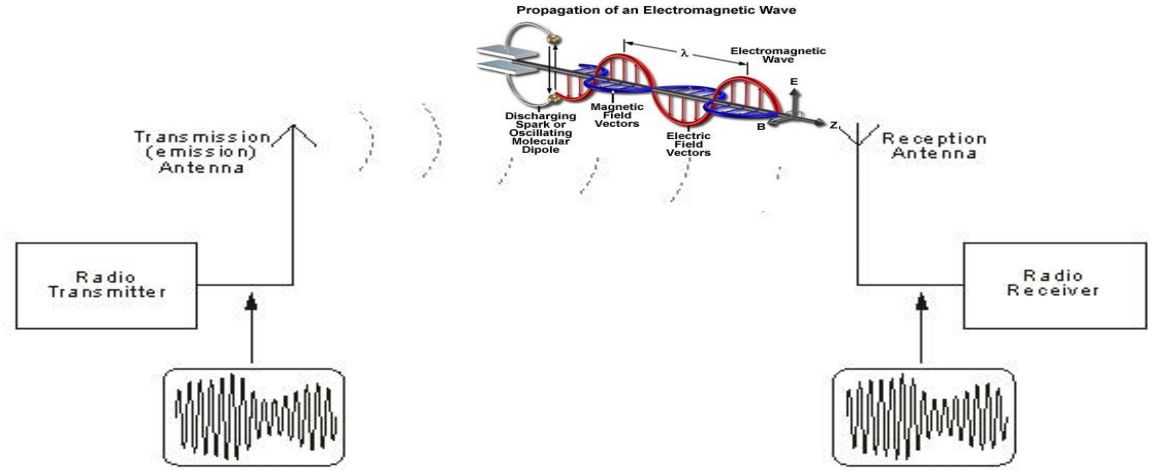





- Typically an antenna consists of an arrangement of **metallic conductors** (**“antenna elements”**) (**μια διάταξη μεταλλικών αγωγών**), **electrically connected (using a cable)** to the Receiver or the Transmitter.
- In **Transmission:**
  - The **Radio Transmitter** **applies** a **modulated** **oscillating 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)**.

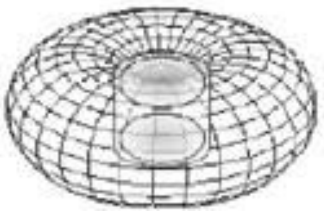
# Antennas



- **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 **$360^{o}$ στο οριζόντιο επίπεδο** και συνήθως περίπου **$75^{o}$ στο κάθετο επίπεδο** (υποθέτοντας φυσικά ότι το δίπολο στέκεται κατακόρυφα)

**Radiation Pattern**
**Διάγραμμα Ακτινοβολίας**

**Isotropic**



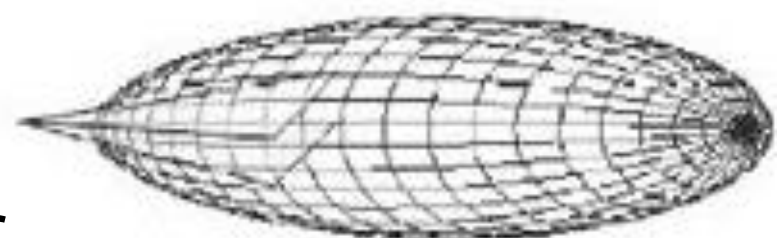
**Dipole**

# 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.

Dish Antenna

Focuses signals in a narrow range
Signals can be sent
over longer distances
-----
Must point at receiver

Omnidirectional Antenna

Signal spreads in all directions
Rapid signal attenuation
-----
No need to point at receiver

# Ερωτήσεις;

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# Additional Slides

# 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**.
    - When there are **multiple indirect paths (**όταν υπάρχουν πολλαπλές έμμεσες διαδρομές**)** between transmitter and receiver and **NO distinct dominant path** (και δεν υπάρχει απευθείας μονοπάτι μεταξύ του Transmitter και του Receiver), such as a **LOS path**, this kind of fading is known as **Rayleigh Fading**
    - When there is a **direct path in addition to a number of indirect multipath signals (**όταν υπάρχει και απευθείας μονοπάτι επιπρόσθετα με τις πολλαπλές έμμεσες διαδρομές**)**, this kind of fading is known as **Ricean Fading**.

# Multipath Propagation Effects
# Επιπτώσεις Πολύδιαδρομικής Διάδοσης



- **Multipath Fading** and **InterSymbol Interference** can be **mitigated** (μπορούν να μετριαστούν) by using for example:
  - **Multiple Input, Multiple Output (MIMO) technologies**: **Smart antenna technology**. Use of **multiple antennas** at **both** the **transmitter** and **receiver** to **improve communication performance**.
  - **Orthogonal Frequency Division Multiplexing (OFDM)**: A method of encoding digital data on **multiple carrier frequencies** **(multiple channels)**.
  - **Rake Receivers**: Uses **several sub-receivers (correlates),** called **fingers**, **each assigned to a different multipath component (**στο κάθε ένα από αυτά ανατίθεται ένα διαφορετικό συστατικό/μονοπάτι από τα διάφορα μονοπάτια που δημιουργούνται**)**. Each finger independently **decodes a single multipath component** which then the contribution of **all fingers are combined** in order to **make the most use** of the **different** transmission characteristics of each **transmission path**.

# Antenna Gain (G) – Κέρδος Κεραίας



- **Κέρδος Κεραίας (G) είναι ένας σχεσιακός τρόπος μέτρησης για να καθορίσουμε** το ποσό αύξησης στην ισχύ που μια κεραία εμφανίζεται να προσθέτει σε ένα σήμα RF (**Radio frequency**; is any of the electromagnetic wave frequencies that lie in the range extending from around 3 kHz to 300 GHz) .

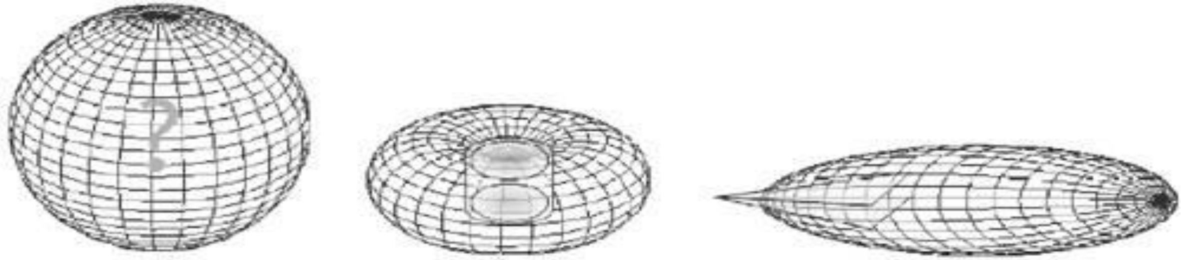
$$G = \frac{P_{directional}}{P_{isotropic}}$$

- Το **βασικό κέρδος** κεραιών συνήθως **έχει σχέση με την κατευθυντικότητα της κεραίας** και εκτιμάται **σε σύγκριση** με τις **ισοτροπικές κεραίες** οι όποιες **υποθετικά** εκπέμπουν το σήμα με την ίδια δύναμη σε όλες τις κατευθύνσεις χωρίς να έχουν απώλειες.
  - Η μονάδα που χρησιμοποιείται για να **συγκρίνει** το **επίπεδο ισχύος** μιας **δεδομένης κεραίας** με τη **θεωρητική ισοτροπική κεραία είναι το dBi** (έτσι προκύπτει η χρήση του i στο dBi; (Decibels relative to an isotropic radiator; decibels-isotropic))
  - **Η ισοτροπική κεραία** λέγεται ότι έχει εκτίμηση ισχύος **0 dBi**.

# Antenna Gain (G) – Κέρδος Κεραίας



- **Κεραίες Διπόλων (Κέρδος):**
  - Επειδή **η ακτίνα συγκεντρώνεται ελαφρώς στο κάθετο επίπεδο** (αυτό **οδηγεί σε περισσότερη συγκέντρωση ενεργείας** από ότι οι ισοτροπικές κεραίες), οι κεραίες διπόλων λέγεται να έχουν ένα **κέρδος 2.14 dBi** σε σύγκριση με τις ισοτροπικές κεραίες.
- **Κατευθυντικές Κεραίες (Κέρδος):**
  - Επειδή η ακτίνα **συγκεντρώνεται κατά πολύ και στο κάθετο και στο οριζόντιο επίπεδό** (αυτό **οδηγεί σε πολύ περισσότερη συγκέντρωση ενεργείας** από ότι οι κεραίες διπόλων), οι κατευθυντικές κεραίες λέγεται να έχουν ένα κέρδος **10 dBi** σε σύγκριση με τις ισοτροπικές κεραίες.



Isotropic (0 dBi) Dipole (2.2 dBi) Directional (10dBi)

# Antenna Gain (G) – Κέρδος Κεραίας



- As a **transmitting antenna**, the **Antenna Gain** describes how well the antenna **converts power received from the transmitter(Tx Power)** into radio waves headed in a specified direction.
  - **Effective Radiated Power (ERP)**

    = Tx Power of RF + **Antenna Gain** – Feed line Losses

- As a receiving antenna, the **Antenna Gain** describes **how well the antenna** converts **radio waves (**Rx Power of RF**)** arriving from a specified direction into **electrical power**.
  - **Received Signal Power** =

    = Rx Power of RF + **Antenna Gain** – Feed line Losses

* ***Feed Line Losses***: *All the energy that the Transmitter generates, travels to the antenna through the feed line. By the same token, all the signals picked up by your antenna must reach the Receiver through the same feed line. The most common type of feed line is coaxial cable.* ***The problem with any feed line is that it isn't perfect—it always loses a certain amount of the energy.***

# Antenna Gain (G) – Κέρδος Κεραίας



- The **receiving antenna** is characterized by its **Effective Aperture (Αποτελεσματικό Διάφραγμα) $A_{eff}$**, which **describes how well an antenna can pick up power from an incoming electromagnetic wave.**
  - For the receiving antennas, the **Effective Aperture** can be loosely defined as a **ratio** of the **Power absorbed ($P_A$) (Ισχύς που απορροφάται)** by the antenna, to the **Power occurring ($P_O$) (Ισχύς που εφαρμόζεται) on it by the radio wave**.

$$A_{eff} = P_A/P_O$$

# Antenna Gain (G) – Κέρδος Κεραίας



- Relationship between antenna gain (G) with $\mathbf{A_{eff}}$ and **Carrier frequency (f)**

$$G = \frac{4\pi A_{eff}}{\lambda^2} = \frac{4\pi f^2 A_{eff}}{c^2}$$

  - $\mathbf{A_{eff}}$: Effective aperture of absorption (Related to physical size and shape of antenna and antenna pattern)
    - **Higher for Directional Antennas**
  - **f:** Carrier frequency (in hertz)
    - The **higher the frequency the more the power** that can be **absorbed by the antenna**
  - **c**: Speed of light (≈ $3x10^8$ m/s or 300,000,000 m/s)
  - **λ:** Carrier wavelength (in meter)

# Radio Propagation Model



- A **radio propagation model** is used to predict (προβλέψει) the **received power** or the **path loss, based on the propagation environment. (**Ένα μοντέλο ασύρματης διάδοσης χρησιμοποιείται για να **προβλέψει** πόσο θα είναι το received power η πόση θα είναι η απώλεια στη δύναμη του σήματος, ανάλογα με το περιβάλλον στο οποίο διαδίδεται το σήμα)
- **Path loss** (απώλεια διαδρομής; or path attenuation) is the **reduction in power density (attenuation;** εξασθένιση**)** of an electromagnetic wave **as it propagates through space**.
  - **Path loss** may be due to many phenomena, such as free-space loss, refraction, diffraction, reflection, absorption, etc.

# Radio Propagation Model



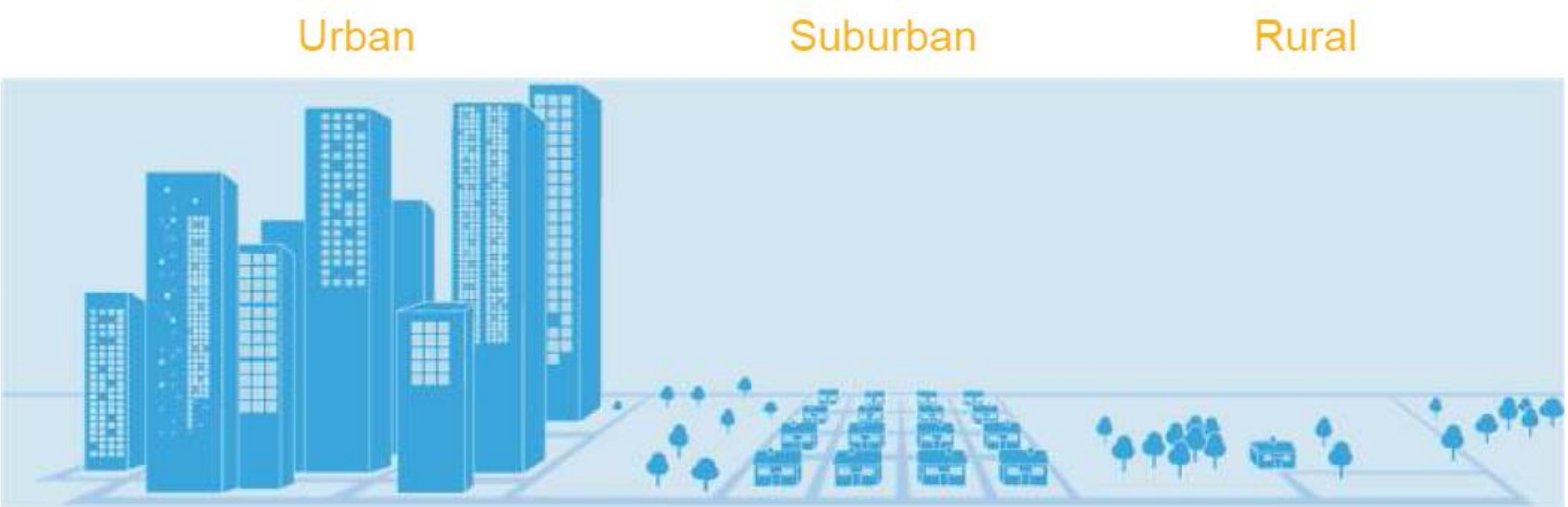
- A Radio Propagation Model can be used by **a Mobile Network Operator** for **Radio Network Planning** (Καθορισμός διάφορων παραμέτρων για τον σχεδιασμό του ασύρματου μέρους του Δικτύου**)**. E.g.:
  - **Determining** the **network design parameters**
    - Define the **number of transmitters** and their **location in the area**
    - **Define Antenna type** (i.e., Isotropic, Directional, etc.) **size** and **height**
  - **Determining** the **radio coverage area** of a **Transmitter** (a BS)
    - Determine the **transmitter power requirement**
    - Determine the **battery lifetime** (of the Terminal)
  - **Determining link performance**
    - Finding **modulation** and **coding schemes** to **improve the channel quality**
    - Determine the **maximum channel capacity**

# Radio Propagation Model



- **Different types of propagation models**
  - Free (Open) Space Propagation Model
  - Land Propagation Model
  - Empirical Models

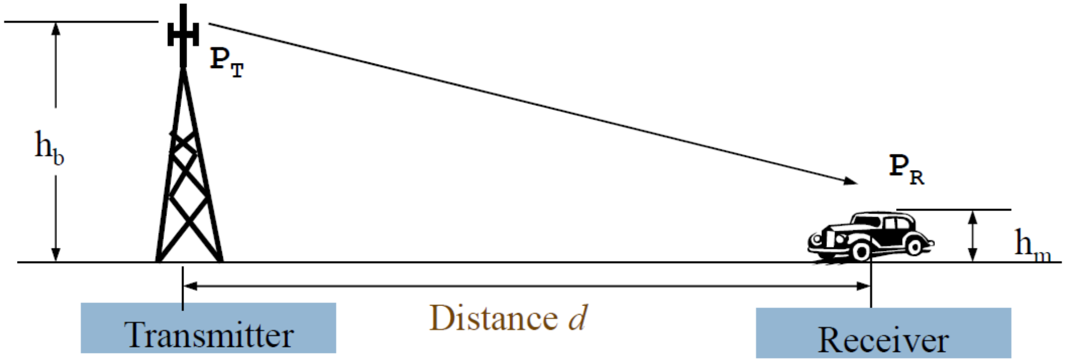
**Αστικές Περιοχές** | **Προαστιακές Περιοχές** | **Αγροτικές Περιοχές**



# Free Space Propagation Model



- Used to **predict the received signal strength** when the **transmitter** and **receiver have** a clear, **unobstructed (**χωρίς εμπόδια**) Line-Of-Sight (LOS) path** between them.
- The **free space model predicts** that received power decays **as a function** of the Transmitter-Receiver **separation distance (d)** raised to some power (εξασθενεί ως συνάρτηση της απόστασης **(d)** μεταξύ του Transmitter και του Receiver αυξημένη σε κάποια δύναμη**)**.
- **Power falls off** :
  - **Proportional** (αναλογικά) to $d^2$
  - **Inversely proportional** to $\boldsymbol{\lambda}^2$ (proportional to $\mathbf{f}^2$)



# Free Space Propagation Model



- The Free space **power received** by a receiver antenna separated from a radiating transmitter antenna by a **distance d** is given by **Friis free space equation**:
  - **$P_r$**: Signal power at receiving antenna
  - **$P_t$**: Signal power at transmitting antenna
  - **λ**: Carrier wavelength in meter
  - **$G_t$**: Transmitter antenna gain
  - **$G_r$**: Receiver antenna gain
  - **d**: Separation distance between antennas (T-R) in meter (>0)
  - **L**: Is **System Loss Factor (Συντελεστής απώλειας Συστήματος)** due to transmission line attenuation, filter losses, and antenna losses in the communication system not related to propagation (L >= 1)
    - L = 1 indicates no loss in system hardware (**in case of free space only**).

$$P_r = P_t \frac{G_t G_r \lambda^2}{(4\pi d)^2 L}$$

**Assuming that the radiated power is uniformly distributed over the surface of the sphere**

# Free Space Propagation Model – Path Loss Model



- Free space path loss **($L_{PF}$)** with ideal **isotropic antenna** (unity gain) can be calculated as:

$$L_{PF} = \frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2}$$

$$L_{PF\,dB} = 10\log\frac{P_t}{P_r} = 20\log\left(\frac{4\pi d}{\lambda}\right) = 20\log\left(\frac{4\pi f d}{c}\right)$$

$$L_{PF}(dB) = 32.45 + 20\log_{10} f_c(MHz) + 20\log_{10} d(km)$$

**Notes:**

$$L_P = \frac{P_t}{P_r} = \frac{(4\pi d)^2 L}{G_t G_r \lambda^2}$$

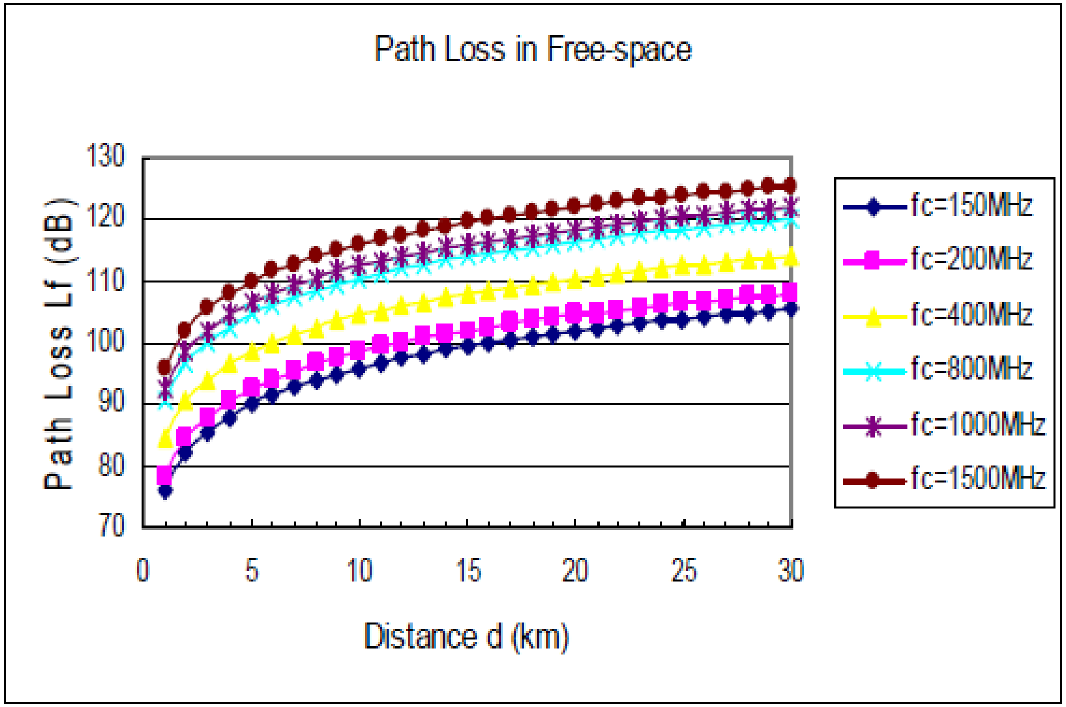
- For ideal isotropic antenna **$G_t = G_r = 1$**
- For free space **$L = 1$**

**Math Reminder:** $\log_a(b^c) = c\cdot\log_a b$, $\log_a(b) = \frac{\log_c b}{\log_c a}$, $\log_a(b\cdot c) = \log_a b + \log_a c$

# Free Space Propagation Model – Example of Path Loss Model



$$L_{PF}(dB) = 32.45 + 20\log_{10} f_c(MHz) + 20\log_{10} d(km)$$




- It is clear from the figure that the Path Loss increases when the Transmitter-Receiver separation **distance (d)** increases and also when the **carrier frequency increases**.

# Land Propagation Model



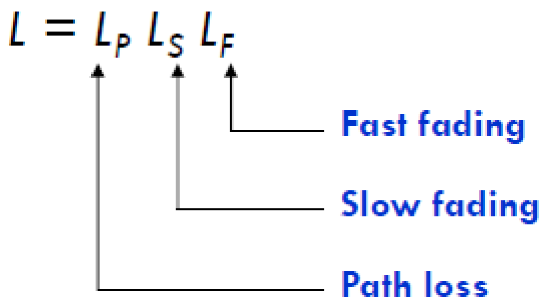
- A **land mobile radio channel** is characterized as a **multipath propagation channel with fading (πολύδιαδρομικά διαδιδόμενο κανάλι με εξασθένιση)** as it propagates from the Transmitter to the Receiver.
- That it is, the **signal reaches the destination using many different paths**, because of diffraction and reflection from various objects along the path of propagation.
- The **signal strength** and **quality** of received radio waves **vary** accordingly, as well as **the time to reach** the destination **changes**.
- This implies that the **wave propagation** in the multipath channel **depends** on the **actual environment**, including factors such as the **antenna height**, the **profile of the buildings**, **roads**, and the **terrain** (διαμόρφωση της περιοχής).

# Land Propagation Model



- The received signal power is: $P_r = \dfrac{G_t G_r P_t}{L}$

- In contrast with free space environment wave**, land mobile radio channel propagation** is **characterized** by three aspects: **path loss**, **slow fading (shadowing)**, and **fast fading**.




  - **$P_r$**: Signal power at receiving antenna
  - **$P_t$**: Signal power at transmitting antenna
  - **$G_t$**: Transmitter antenna gain
  - **$G_r$**: Receiver antenna gain

# Free Space and Land Propagation Models - **Problems**



- Simple theoretical models, **do not take into account many practical factor**, thus **resulting in bad accuracy**. E.g.:
  - **Rough terrain** (Άσχημη μορφολογία εδάφους), **Buildings**, **Refection**, **Moving vehicle**, **Shadowing**, etc.

- **Solution**: **Empirical Model (Εμπειρικά Μοντέλα)**
  - The word empirical denotes **information acquired** by means of **observation** **(παρατηρήσεις)** or **experimentation** **(measurements)** (πειραματισμούς και μετρήσεις).
  - **Empirical data** are data produced by an **observation** or **experiment**.

# Empirical Models



- **Empirical models** are based on **combination** of **measurement and theory (στηρίζονται σε ένα συνδυασμό μετρήσεων και θεωρίας)**.
- **Correction factors** are introduced to account for (Εισάγονται Διορθωτικοί Συντελεστές για να λάβουν υπόψη):
  - Terrain (γεωγραφική περιοχή) profile, Antenna heights, Building profiles, Road shape/orientation, Lakes, etc.

- Empirical Models for **outdoor** environments (**Commonly used in cellular system simulations**)
  - Okumura model
  - Hata model

- *Empirical Models for **indoor** environments*
  - *Saleh model*
  - *SIRCIM model*

# Okumura Model



- The **Okumura model** is a Radio propagation model that was **built using the data collected in the city of Tokyo**, Japan.
- The model is ideal for **using in cities with many Urban structures** but **not many tall blocking structures**.
- Predicts **average (median) path loss with an accuracy** within 10-14 dB in Urban and Suburban areas.
  - I.e., Common standard deviations (Κοινές τυπικές αποκλίσεις) between predicted and measured path loss values are around 10 dB to 14 dB.

# Okumura Model



- The Okumura model is formally expressed as:

$$L = L_{FSL} + A_{MU} - H_{MG} - H_{BG} - \sum K_{correction}$$

Where:

- **L** = The median path loss. Unit: Decibel (dB)
- **$L_{FSL}$** = The Free Space Loss. Unit: Decibel(dB)
- **$A_{MU}$** = Median attenuation. Unit: Decibel(dB)
- **$H_{MG}$** = Mobile station antenna height gain factor.
- **$H_{BG}$** = Base station antenna height gain factor.
- **$K_{correction}$** = **Correction factor gain** (such as type of environment, water surfaces, isolated obstacle etc.)

# Hata Model



- The **most widely used** radio frequency propagation model for **predicting the behavior of cellular transmissions in built up areas**.
- Also known as the **Okumura-Hata** model for **being a developed version of the Okumura Model**.
- This model **incorporates the graphical (plot) information (**ενσωματώνει τις χαρτογραφικές πληροφορίε**ς) from Okumura model** and **develops it further** to **realize the effects (να προσομοιώσει τις επιπτώσεις)** of **diffraction**, **reflection** and **scattering** caused by **city structures**.
- This model also has **two more varieties** for transmission in **Suburban Areas** (Προαστιακές Περιοχές) and **Open Areas (**e.g., Rural Areas; Αγροτικές Περιοχές**)**.

# Hata Model



- Hata Model for **Urban Areas** is formulated as:

$$L_U = 69.55 + 26.16 \log f - 13.82 \log h_B - C_H + [44.9 - 6.55 \log h_B] \log d$$

***Where***:

*For small or medium sized city:* $C_H = 0.8 + (1.1 \log f - 0.7) h_M - 1.56 \log f$

*For large cities:* $C_H = \begin{cases} 8.29 (\log(1.54 h_M))^2 - 1.1 & \text{, if } 150 \leq f \leq 200 \\ 3.2 (\log(11.75 h_M))^2 - 4.97 & \text{, if } 200 < f \leq 1500 \end{cases}$

$L_U$ = Path loss in Urban Areas. Unit: decibel (dB)

$h_B$ = Height of base station Antenna. Unit: meter (m)

$h_M$ = Height of mobile station Antenna. Unit: meter (m

$f$ = Frequency of Transmission. Unit: megahertz(MHz).

$C_H$ = Antenna height correction factor

# Hata Model



- Hata Model for **Suburban Areas** is formulated as:

$$L_{PS}(dB) = L_{PU}(dB) - 2\left[\log_{10}\frac{f_c(MHz)}{28}\right]^2 - 5.4$$

- Hata Model for **Open Areas** is formulated as:

$$L_{PO}(dB) = L_{PU}(dB) - 4.78\left[\log_{10} f_c(MHz)\right]^2 + 18.33\log_{10} f_c(MHz) - 40.94$$

- **Hata Model Limitation**: Although based on the Okumura Model, the Hata model **does not go beyond 1500 MHz** while **Okumura** provides support for **up to 1920 MHz**.