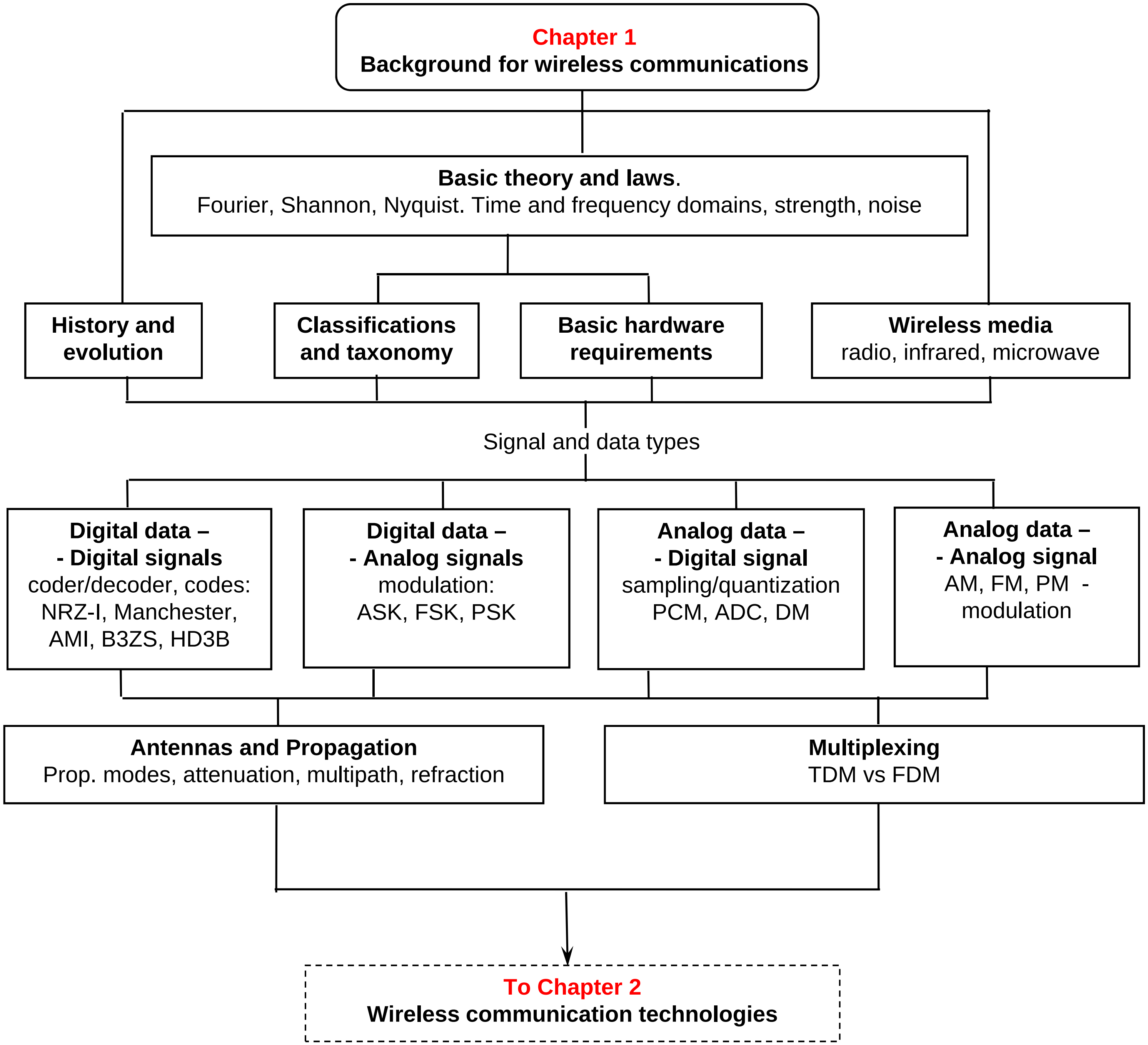

Chapter 1
Background for wireless communications
Basic theory and laws.
Fourier, Shannon, Nyquist. Time and frequency domains, strength, noise
History and evolution
Classifications and taxonomy
Basic hardware requirements
Wireless media
radio, infrared, microwave
Signal and data types
Digital data –
- Digital signals
coder/decoder, codes:
NRZ-I, Manchester,
AMI, B3ZS, HD3B
Digital data –
- Analog signals
modulation:
ASK, FSK, PSK
Analog data –
- Digital signal
sampling/quantization
PCM, ADC, DM
Analog data –
- Analog signal
AM, FM, PM -
modulation
Antennas and Propagation
Prop. modes, attenuation, multipath, refraction
Multiplexing
TDM vs FDM
To Chapter 2
Wireless communication technologies

1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

Due to rapid growth of mobile telephone use, various satellite useful services and wireless Internet, great changes in telecommunications and networking are occurred, particularly in

- satellite communications,
- wireless networking,
- optical communications
- radio frequency communications, and
- cellular technology.

The principal objective is to provide a comprehensive technical survey of wireless communications fundamental, wireless applications, and particularly, technology and architecture, wireless networking, design approaches, and applications

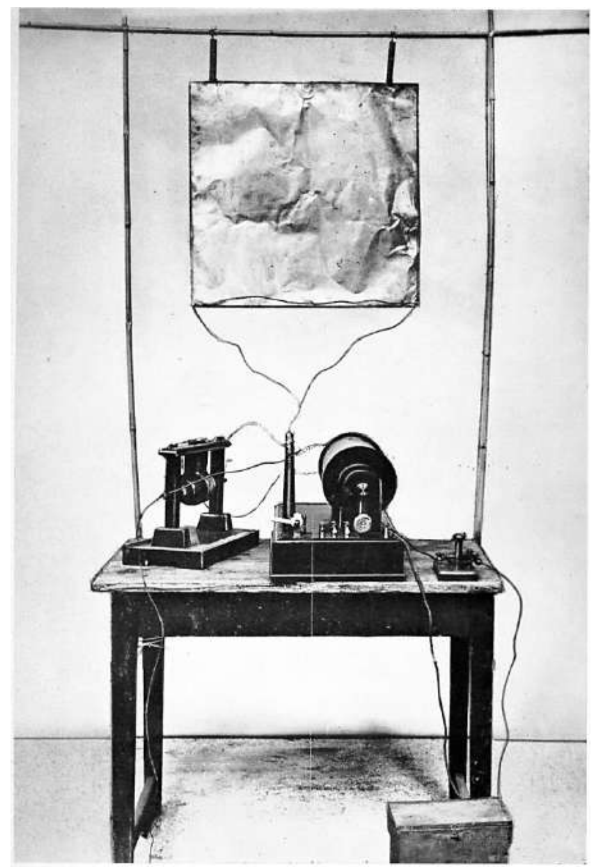
1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

Historical references:

- **1896** Guillermo (Guglielmo) Marconi proposed wireless telegraph.
- **1901** G. Marconi sent telegraphic alphanumerical character by encoded in analog signals across Atlantic Ocean from Cornwall to St. John's Newfoundland (1800 miles)

but

- Other countries, such as France and Russia, refused to recognize the patent by this invention, referring to previously published Alexander Popov research results
- The actual invention of radio communications more properly should be attributed to Nicola Tesla, who gave public demonstration in 1893. Marconi's patents were overturned in favor of Tesla in **1943**.



Marconi's first transmitter incorporating a monopole antenna. It consisted of an elevated copper sheet *(top)* connected to Righi spark gap *(left)* powered by an induction coil *(center)* with a telegraph key *(right)* to switch it on and off to spell out text messages in Morse code

1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

- **1921** First radiotelephonic system for Police Dept. in Detroit (2MHz)
- **1960** first launched satellite communications (240 voice channels)
- **70s** Bell Telephone designed MK (bandwidth 150MHz) and MJ (450 MHz) systems called IMTS (Improved Mobile Telephone System) – standard for mobile telephone.
- **1978** in Chicago Advanced Mobile Phone Service (900MHz) with 666 channels for 2 millions users (in 1983 -30 mil. users)
- **1979** in Japan first cellular system on 900MHz
- **1981** In Europe first experimental cellular system on 450MHz NMT (Nordic Mobile Telephone System)
- **1982** Generation a Working group of European governments Conference "Europeenne des Postes et Telecommunicationes CEPT" called GSM (Global System for Mobile Communication) for standardization which has been installed in **1993** as Pan European system for cellular communications

- For modern wireless mobile systems the DCS-1800 (Digital Cellular Service) system has been proposed operation on the band of personal equipment for communication (1800 and 1900 MHz)

1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

Taxonomy :

- **First generation:** IS-54 standard on TDM supporting analog and digital communications based on AMPS (Advanced Mobile Phone Service) offers CDPD (Cellular Digital Data Packet) with 19.2 Kbps
- **Second generation (1990s):** PCS IS-136 (Personal Communication Service) with best signaling on TDMA , and then PCS IS-95 on CDMA using the dedicated channels at 9.6Kbps to deliver the data service (max 384Kbps with EDGE - Enhanced Data Rates for GSM Evolution)
- **Third generation (2003):** International Mobile Communication IMT-2000 (US) and ITU/UMTS International Communication Union/Universal Mobile Telecommunications Systems (Europe) support voice and data (low and high speed) including the multimedia services oriented on circuit switching and packet switching and provide global networking and being developed around 2GHz frequency band with data rates about 2Mbps.
- **Fourth generation:** Carriers that use orthogonal frequency-division multiplexing (OFDM) instead of TDMA or CDMA are increasingly marketing their services as being 4G, even when their data speeds are not as fast as the ITU specifies that 4G network requires a mobile device to be able to exchange data at 100 Mbit/sec (3G network -3.84 Mbit/sec).

Although carriers still differ about whether to build 4G data networks using Long Term Evolution (LTE deployed in Oslo, Norway, and Stockholm, Sweden since 2009) or Worldwide Interoperability for Microwave Access WiMAX (based on 802.16 from 2008), all carriers seem to agree that OFDM is one of the chief indicators that a service can be legitimately marketed as being 4G. For 3G phones – up to 21Mbps, for 4G – 300Mbps –with theoretical 1.5Gbps).

- **Fifth generation:** expecting for 2020

1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

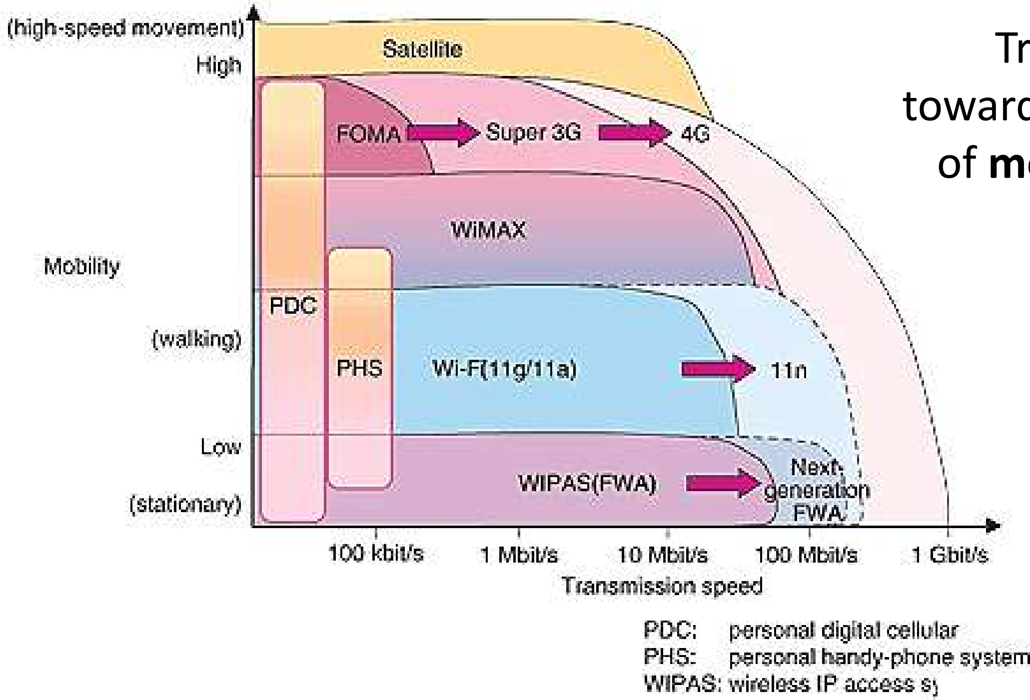
Actually,

- **Wireless networking** is implemented in WANs, MANs and LANs.
- **IEEE** has developed 802.11 as a standard for wireless LANs.
- **Bluetooth** industry consortium provides networking technologies.
- **WAP** (Wireless Application Protocol) **Forum** is developing a common protocol that allows devices with limited display and input capacities to access Internet.
- **Internet Engineering Task Force** (**IETF**) is developing a mobile IP standard that adapts the ubiquitous IP protocol to work within a mobile environment.

1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

- **Infrared Optical Communications** is alternative for microwave radio approaches due to:
- The **spectrum** of infrared is virtually **unlimited** – therefore high data rates
- The **spectrum** is not word wide **regulated**
- Using the useful properties of **optical communication** – diffusion, reflection, it does not penetrate the opaque objects (security, no interference)
- **Simple and inexpensive tool** (using signal intensity modulation, receiver must detect the amplitude and in RF communications phase and frequency)

1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

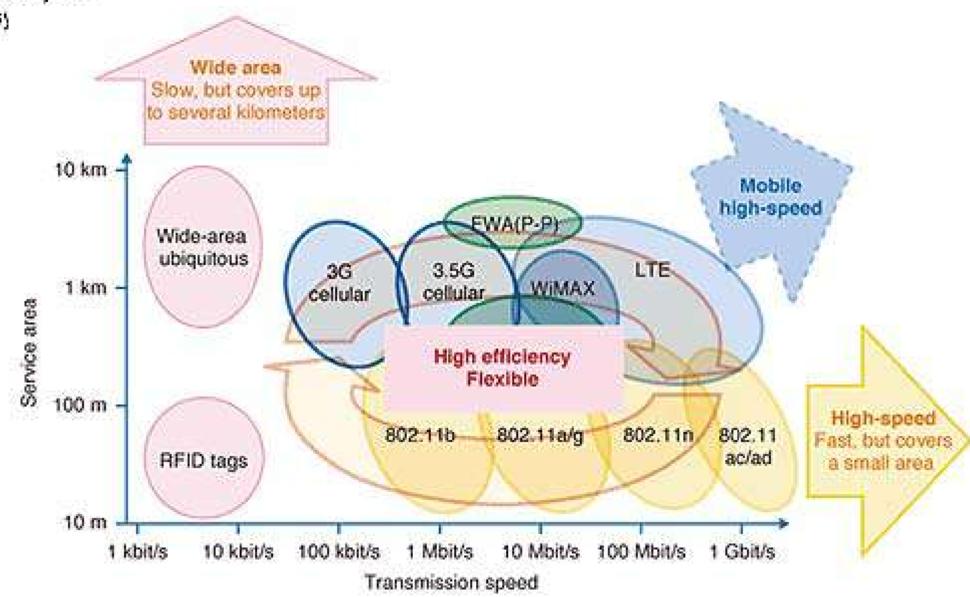


Trends in wireless access systems toward dramatic expansion of degree of **mobility** and **transmission speed**

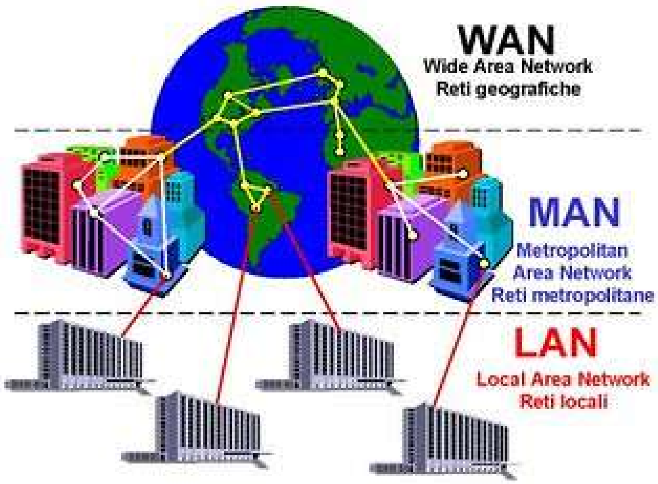
FOMA Freedom of Mobile Multimedia Access

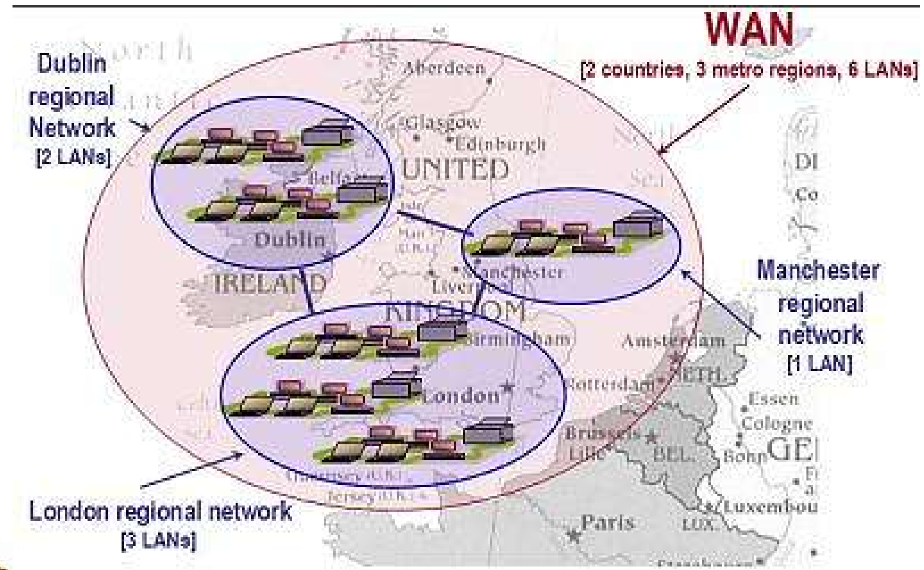
GPRS General Packet Radio Service

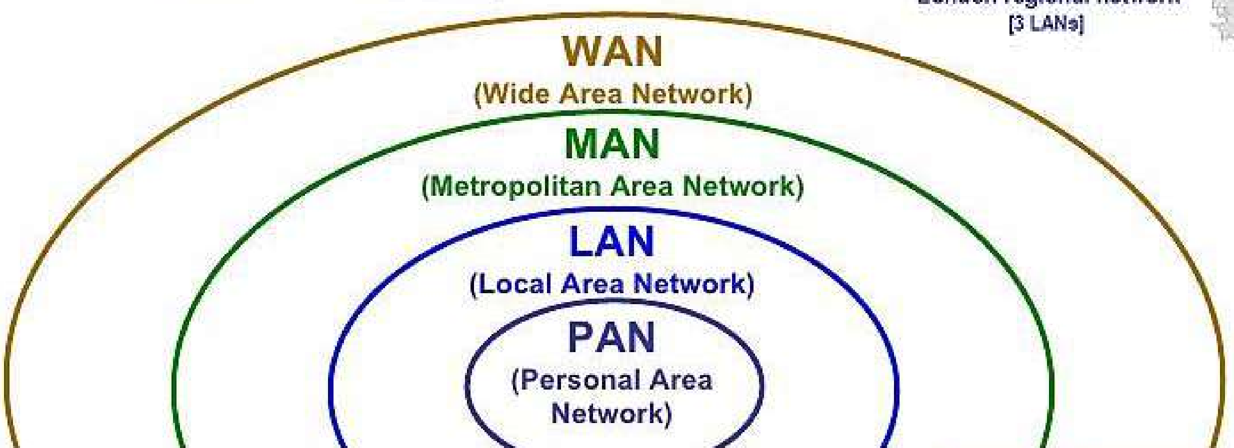
Trends in wireless access technologies toward expansion of **broadband and ubiquitous services**



1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

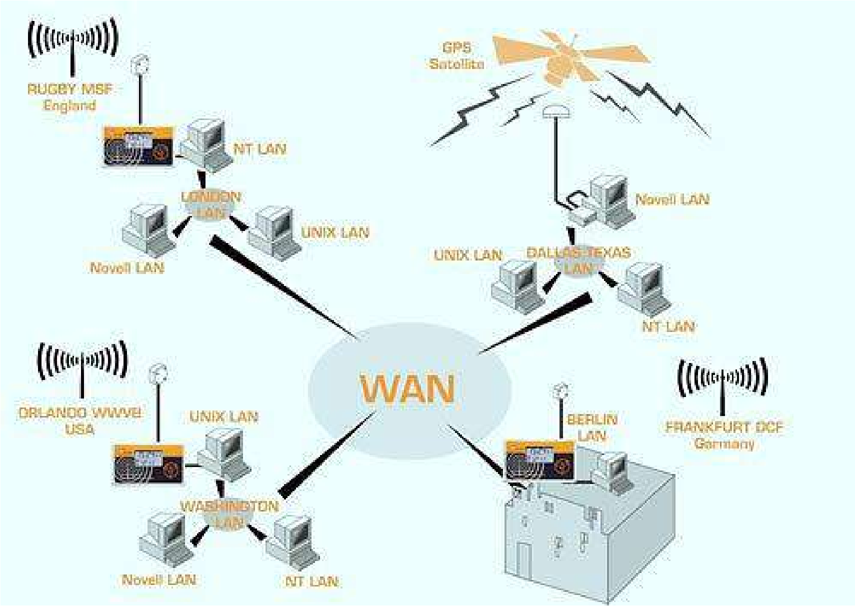


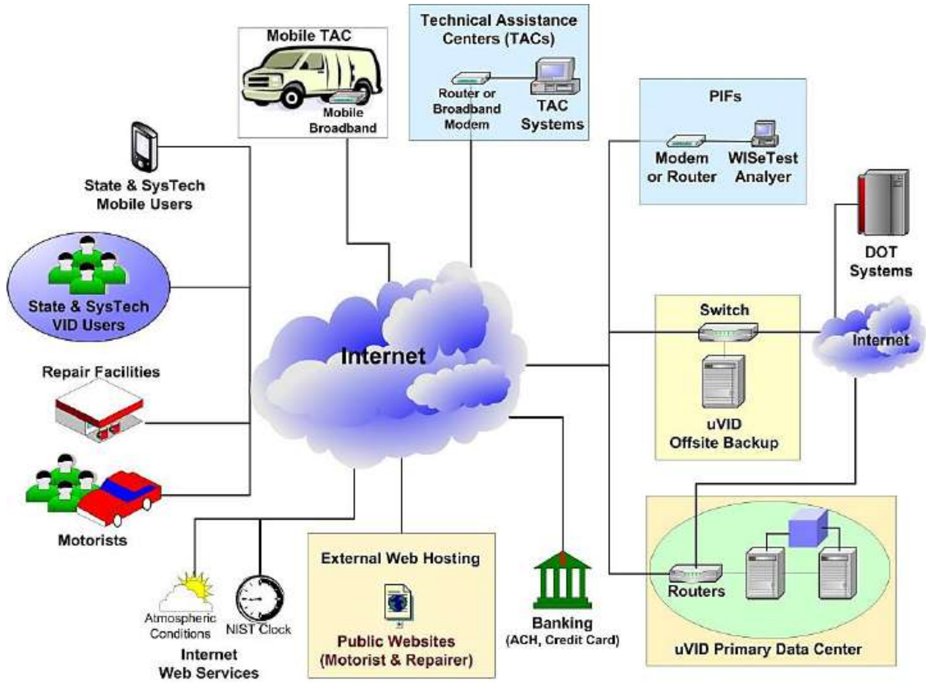


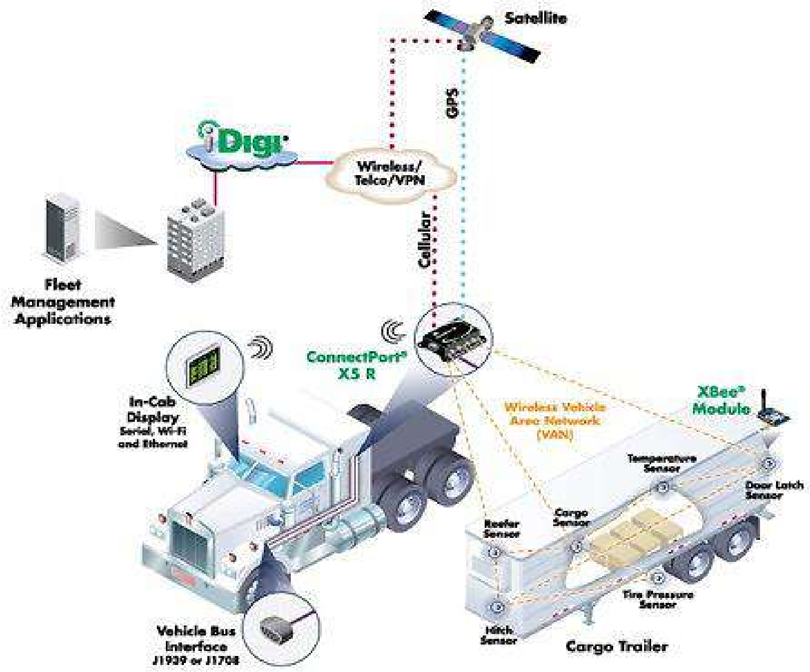


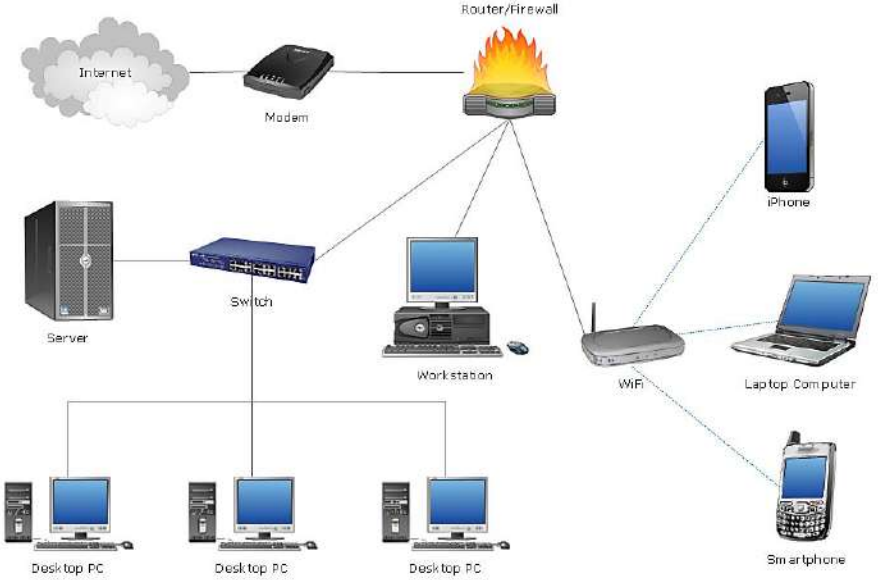
	PAN	LAN	MAN	WAN
Standards	Bluetooth, UWB	802.11 HiperLAN2	802.16 MMDS, LMDS	GSM, GPRS, CDMA, 2.5-3G, 802.16
Speed	< 1Mbps	11 to 54 Mbps	11 to 100+ Mbps	10 to 384Kbps
Range	Short	Medium	Medium-Long	Long
Applications	Peer-to-Peer Device-to-Device	Enterprise networks	T1 replacement, last mile access	PDAs, Mobile Phones, cellular access

1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION



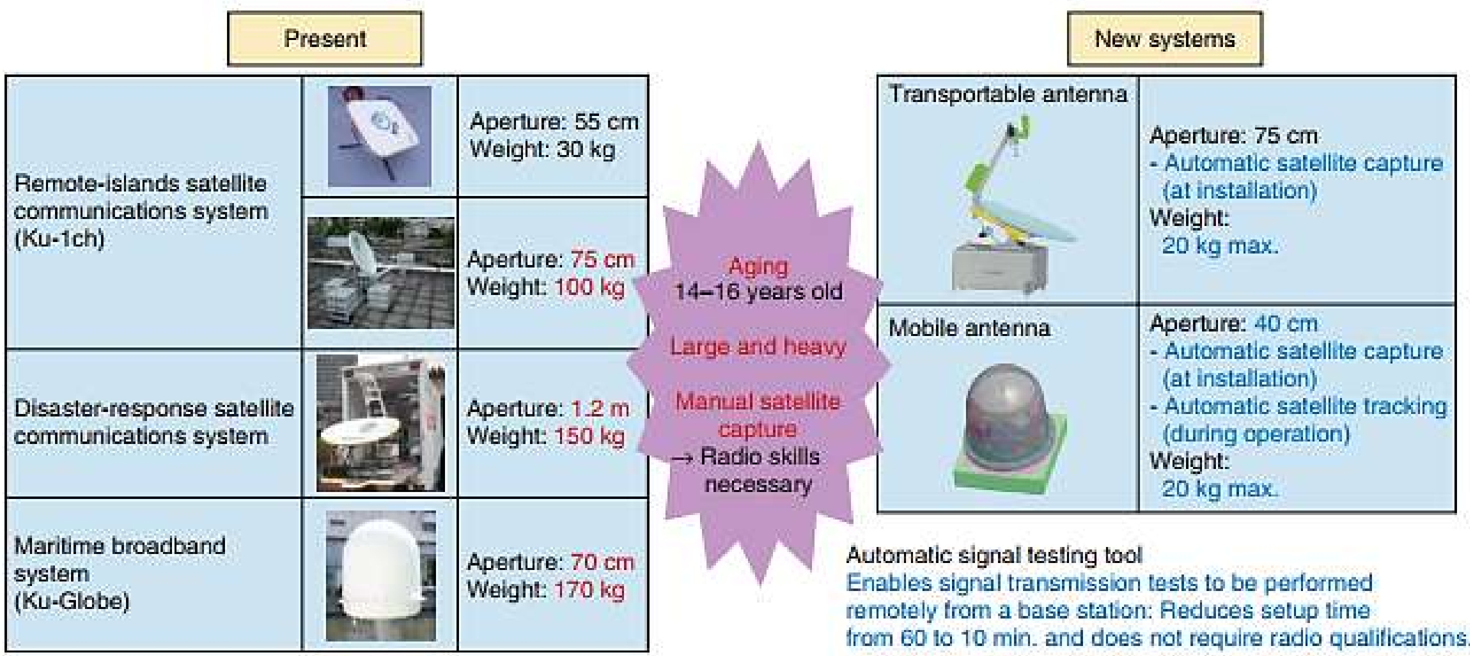






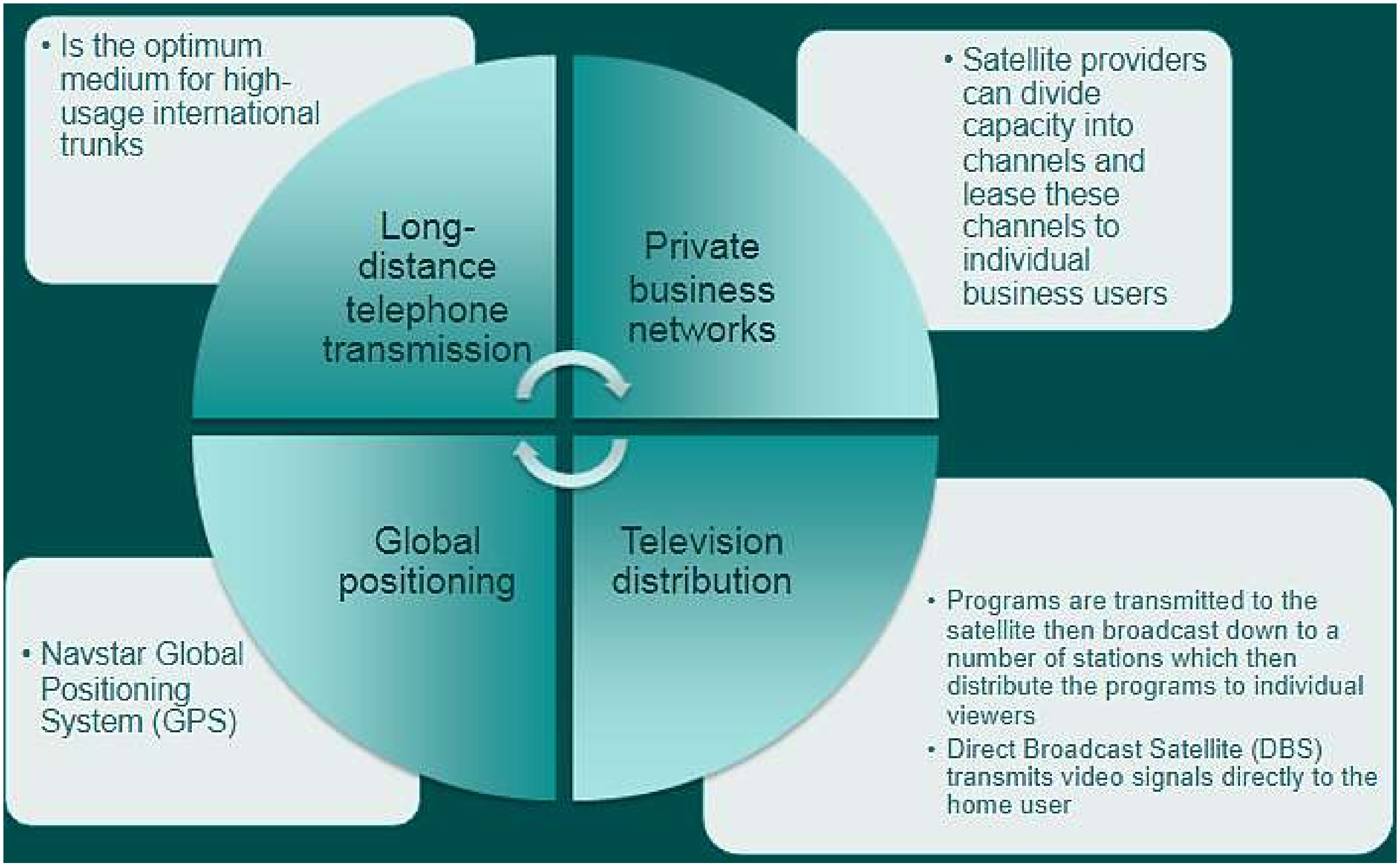
1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

- One key advantage of **satellite communications** is that a lifeline can be secured by simply setting up earth stations at number of points and then connecting them via satellite.
- However, most of facilities for existing earth stations are more 10 years old, too large and heavy to be easily transported.
- Moreover, their operation requires skilled radio technicians to orient the antenna in direction of satellite (manual satellite capture).
- In response to this situation, modern systems (transportable type and mobile type) are proposed that significantly smaller and lighter.



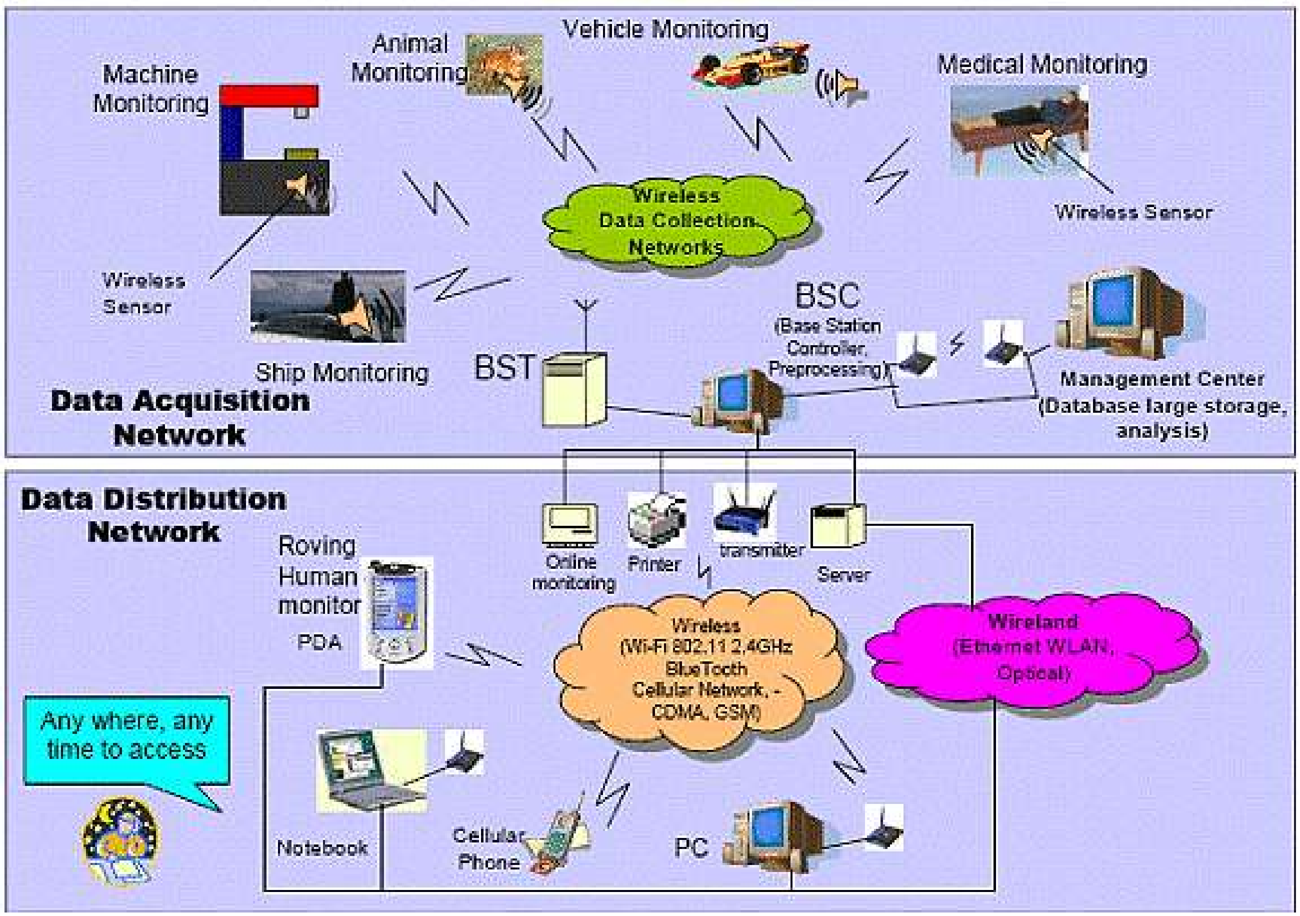
1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

The most important applications for satellites



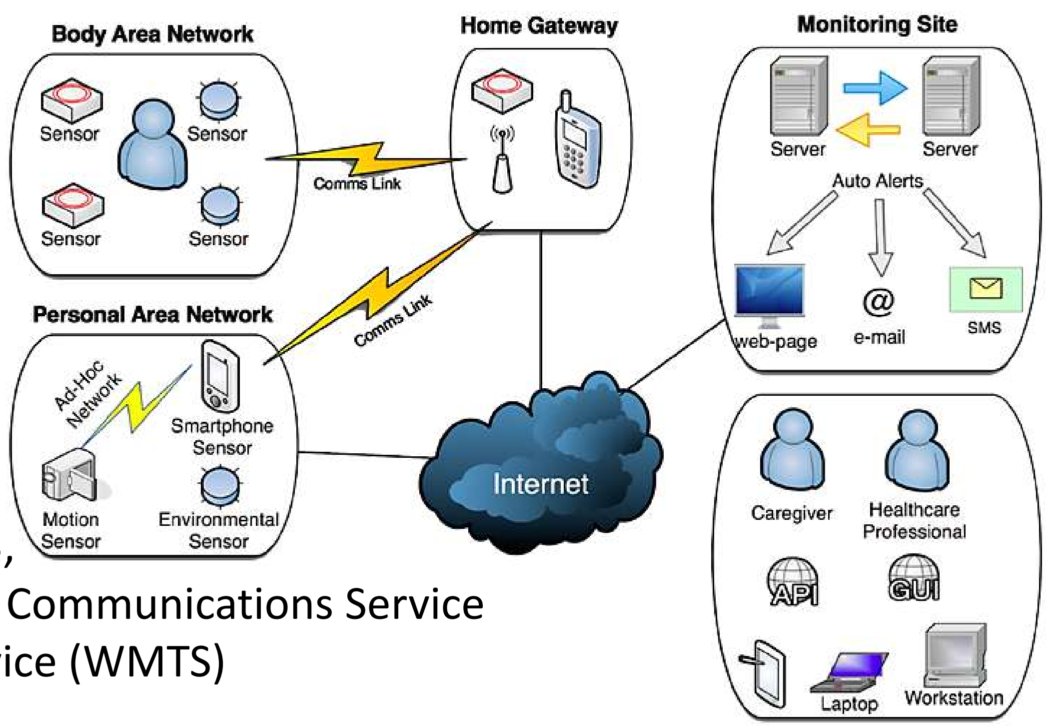
1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

- **Wireless sensor network** can be defined as network of devices that can communicate information gathered from a monitored field through wireless links.
- The data are forwarded through multiple nodes, and with a gateway, the data are connected to other networks



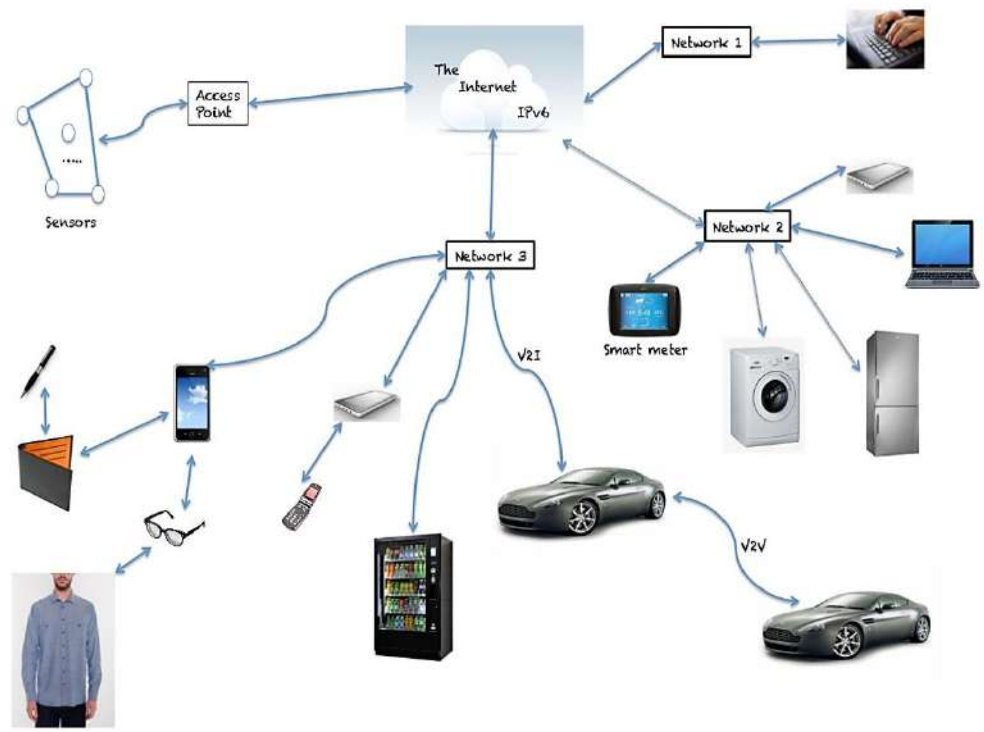
1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

- The development of wireless sensor networks (WSN) to monitor patient' s physical and biochemical parameters continuously establish a **health monitoring system** and the specific application of them, the body sensor network (BSN), provides a low cost homecare health monitoring system capable to detect and analyze abnormal situations and even enable the delivery of immediate health services.
- Most of the existing solutions include one or more types of **sensors carried by the patient**, forming a Body Area Network (BAN), and one or more types of sensors deployed in the environment forming a Personal Area Network (PAN). Data from BAN and PAN are connected via gateway nodes to large-scale networks
- One of critical requirements in wireless sensor networks is the **low power consumption**, which sets constraints in wireless sensors standard development and provides the interfaces to other network technologies.
- Some of these standards include IEEE 802.15.4, ZigBee, WirelessHART, ISA100.11, IETF 6LoWPAN, IEEE 802.15.3, Wibree, IEEE 802.15.1, Medical Implant Communications Service (MICS), Wireless Medical Telemetry Service (WMTS)



1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

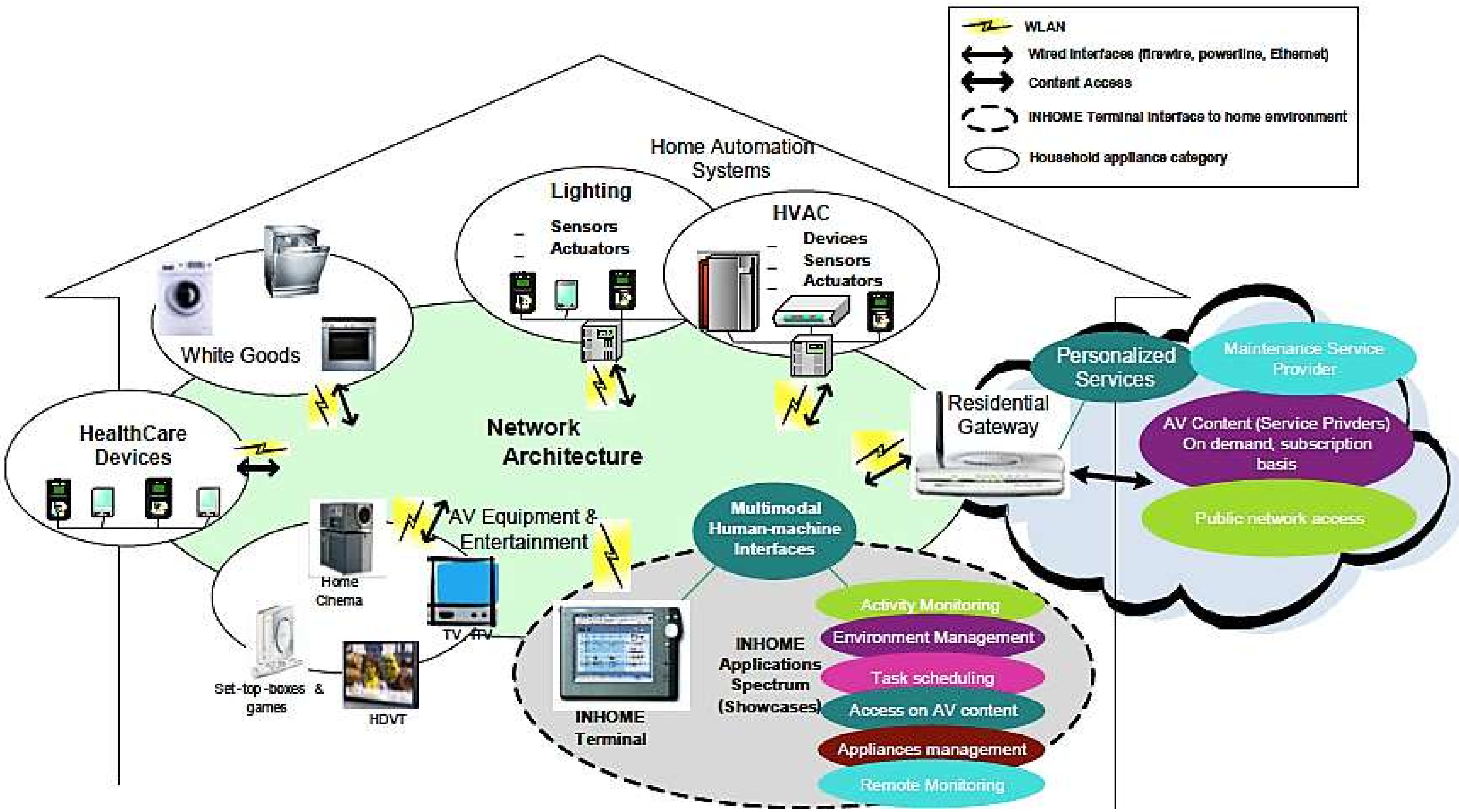
- As people use more electronic devices and with proliferation of smart connected peripherals including actuators and sensors, there is an ability to impart "**Internet of Things**" (IoT) supporting Machine-to-Machine (M2M) communications.
- IoT is evolution of existing internet, which will form integral part of future internet which is expected to be dynamic global network infrastructure with self configuring capabilities.
- It is predicted that number of M2M devices connected to Internet will range from 10 billion to 50 billion devices for year 2020, including different kinds of low bandwidth sensor and actuator to high bandwidth applications such as wireless HDMI multimedia transmission.



- According to Cisco, global mobile data traffic will increase 13 times between 2012 and 2017 reaching 11.2 ExaBytes per month by 2017 and mobile network connection speeds will increase 7 times by 2017.
- The average mobile network connection speed (526 kbps in 2012) will exceed 3.9 Mbps in 2017, according to Cisco.

1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

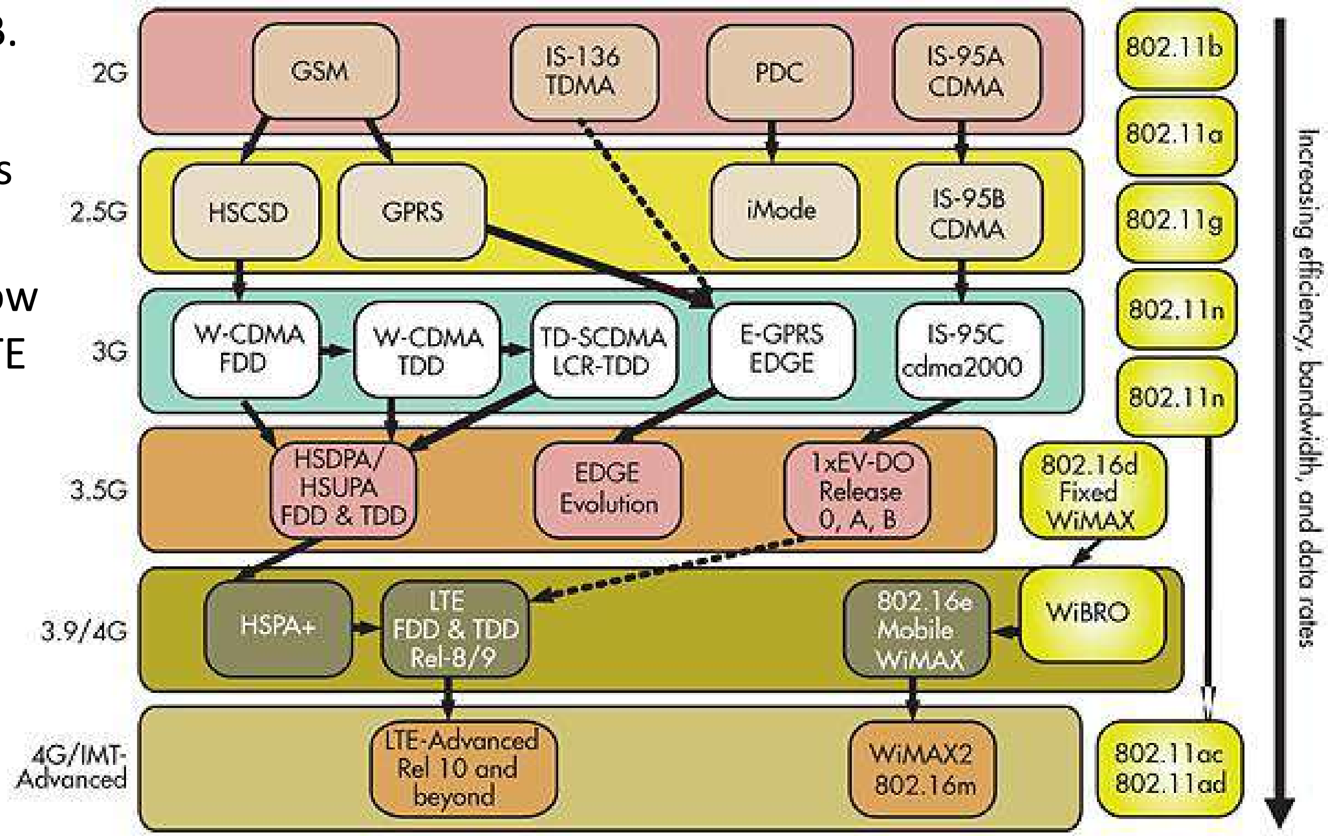
Domotic or smart home network architecture



1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

- Multiple **cell-phone technologies** designated by generations have led to LTE-A
- The **1G** was analog (FM) technology, which is no longer available. The 2G brought digital technology however, multiple incompatible **2G** standards were developed.
- The multiple **3G** standards were created next basically using WCDMA by the 3GPP (Generat. Partnership Proj.) and CDMA2000 by Qualcomm. Both have survived and are still used today.
- The 3G standards were updated into **3.5G**. WCDMA was upgraded to HSPA (high speed packet access), and CDMA2000 was expanded with 1xRTT EV-DO (radio transm tecch. with evol. data optimized) releases A and B.

  Both are still deployed.
- LTE long term evolution was created as upgrade to 3G.
- All cellular operators are now on path to implementing LTE
- While 3GPP still defines LTE as a **3.9G** technology, all of current LTE networks are marketed at **4G**.
- The real 4G as designated by 3GPP is LTE-A

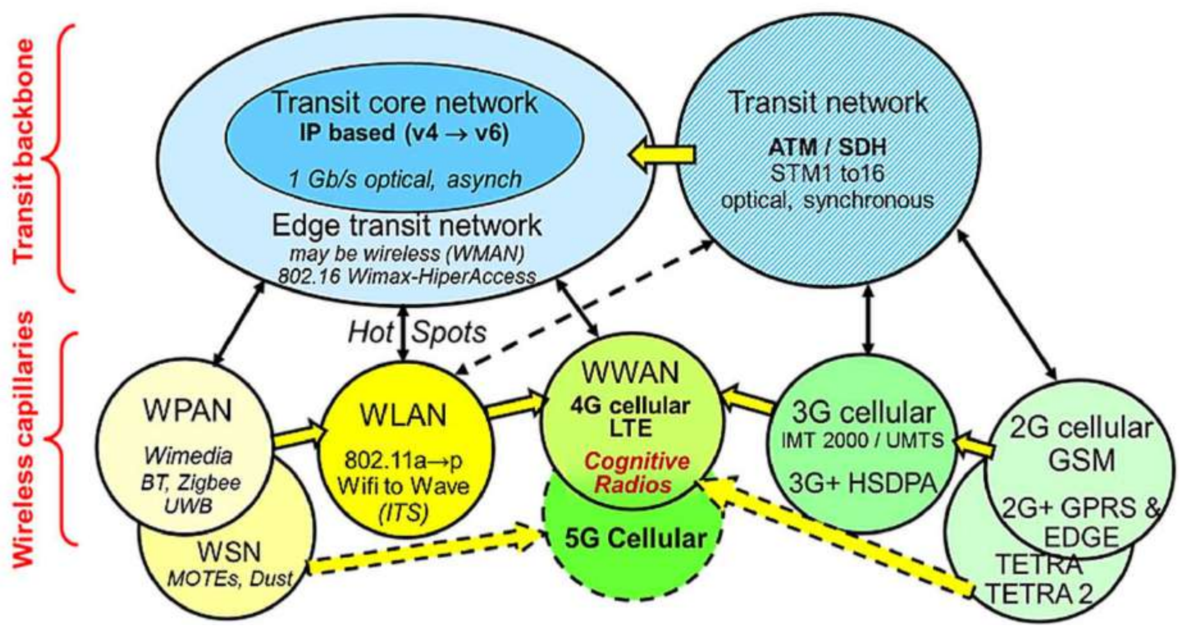


1.1 OBJECTIVES AND DESCRIPTION OF WIRELESS REVOLUTION

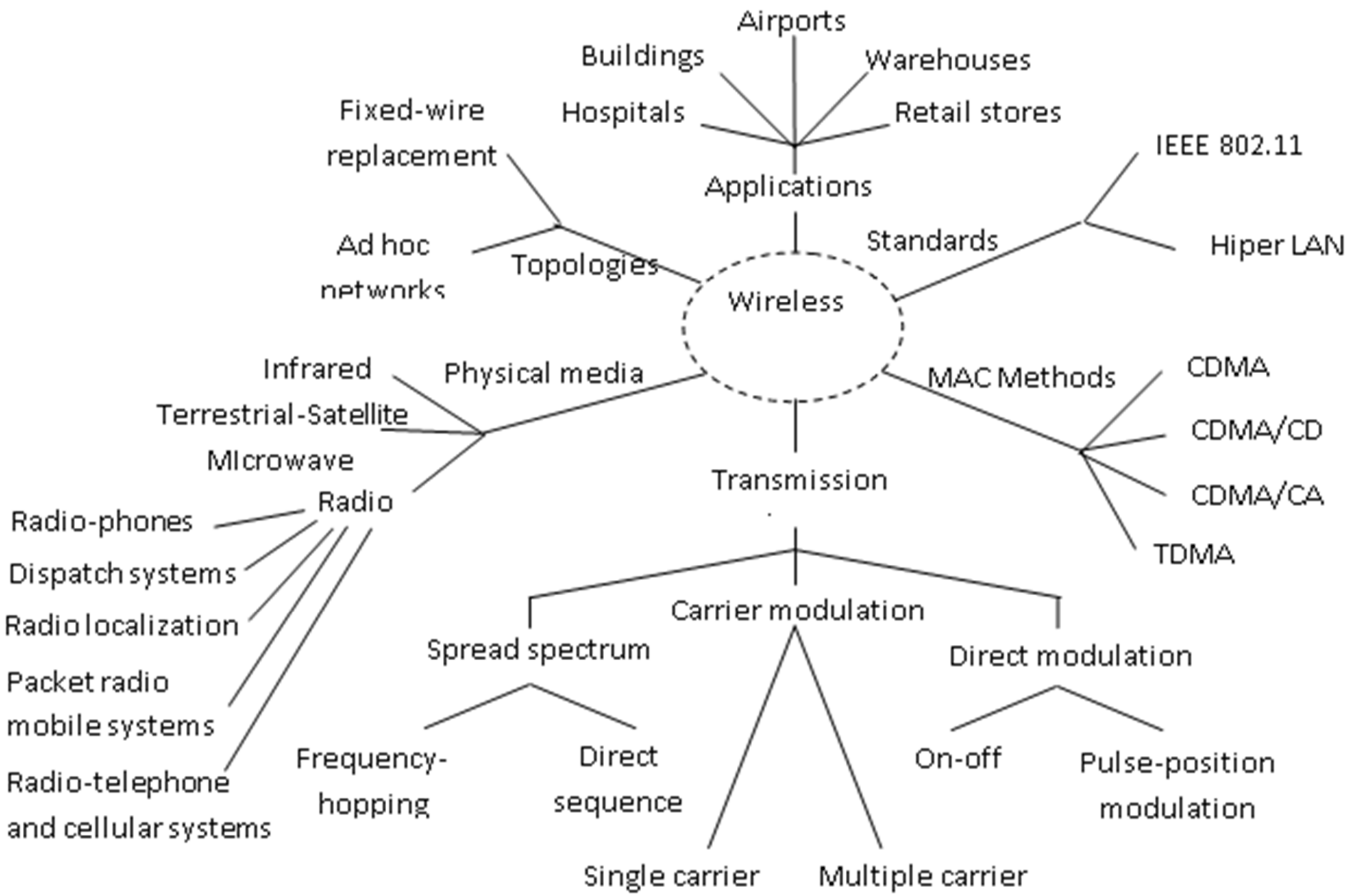
Standard **evolution and convergence** for wireless terrestrial networks

- The upper part shows evolution of transit networks from “Push-to talk” synchronous infrastructures to asynchronous full IPv6 switched infrastructures. Now, such infrastructures are based on meshed or fiber optics (mainly) and microwave links
- The lower part shows convergence of wireless distributing networks between 2 slopes: WxAN radio stations and cellular radiophone technologies, following international standards (ISO, ITU, 3GPP, ETSI, CEN, IEEE). In some cases, they have replaced previous wired technologies based on proprietary products or standards.
- In parallel with 2G (General Packet Radio Service & Enhanced Data Rates for GSM Evolution)

-4G Cellular slope and with the WxAN slope, there are similar evolutions respectively in Professional Mobile Radio (PMR) and in WSN (Wireless Sensor Networks)



1.2. CLASSIFICATION AND TECHNOLOGY ISSUES



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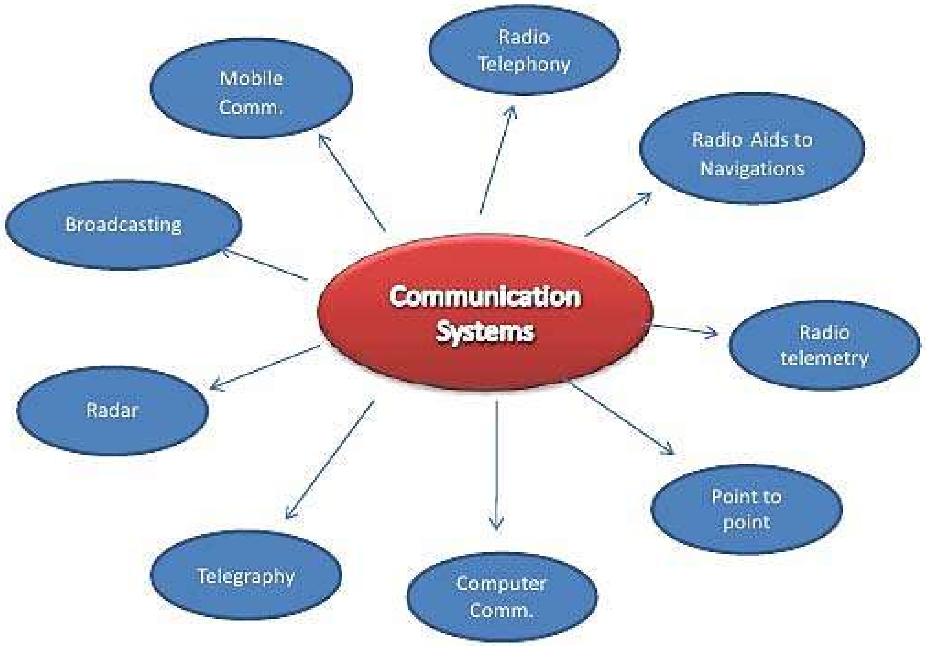
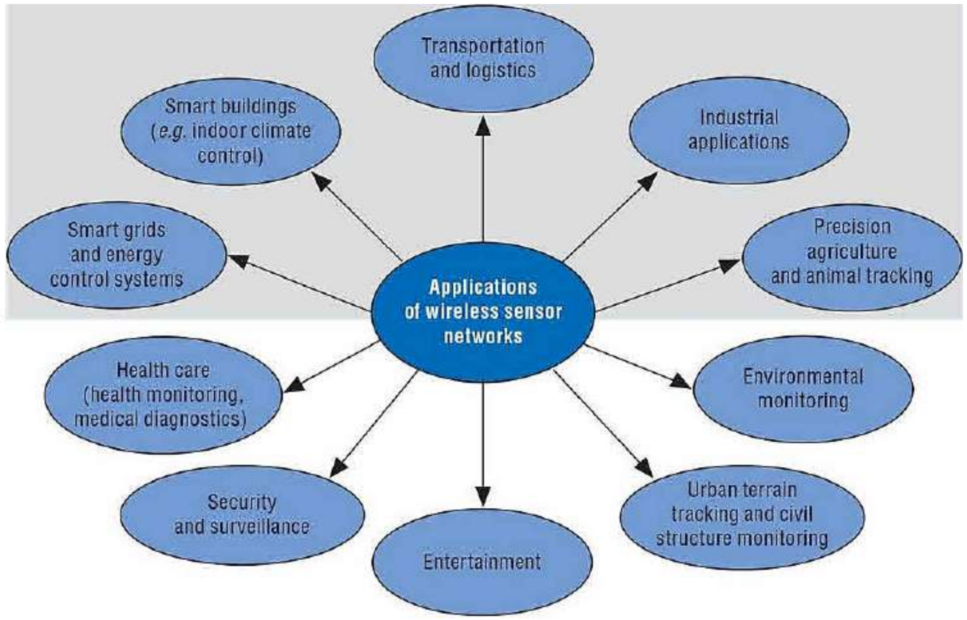




Frequency Band	Frequency	λ	Application
Very Low Frequency (VLF)	3 - 30 KHz	> 10000m	Telegraphy, human range frequency
Low Frequency (LF)	30-300 KHz	10000-1000m	Point to point, navigation
Medium Frequency (MF)	300K-3 MHz	1000-100m	AM radio broadcast, maritime/aeronautical mobile
High Frequency(HF)	3 - 30 MHz	100 - 10 m	Shortwave Broadcast Radio
Very high Frequency(VHF)	30 - 300 MHz	10 - 1 m	Low band: TV Band1- Channel 2-6, Mid band: FM radio, High Band: TV Band 2- Channel 7-13
Ultra High frequency (UHF)	300M - 1GHz	1 m - 10 cm	Mobile phone, Channel 14 - 70
Super high frequency (SHF)	3-30 GHz	0.01-0.001 m	satellite communucation, C-band, x-band,Ku-band, Ka-band.
Extremely High Frekuensi (EHF)	30 - 300 GHz	< 0.01m	Satellite, radar system, IR, UV, X-rays, Gamma Rays.

1.2. CLASSIFICATION AND TECHNOLOGY ISSUES

- In general, wireless communication infrastructure may be presented as:

a. Portable-to-fixed network wireless LAN and

b. Portable-to-portable network (on demand created self-contained **ad hoc wireless LAN)**:

PAU – Portable access unit,

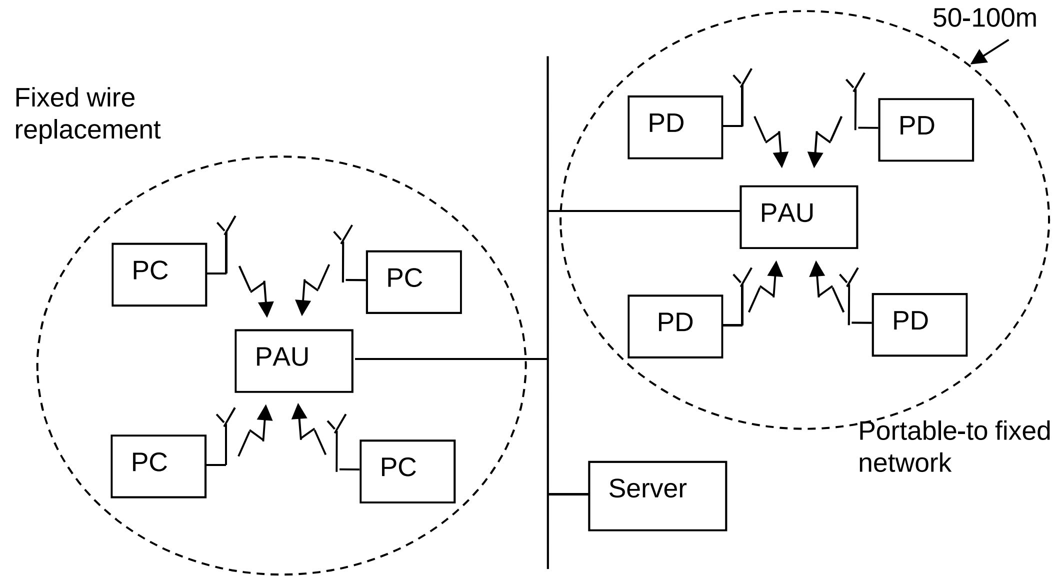
PD – Portable device,

PC – Personal Computer

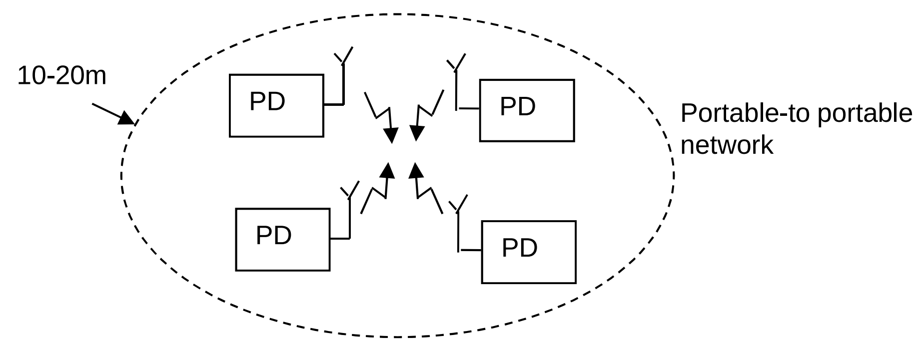
- As with wired LANs, there are a number of topologies, standards, transmission schemes, MAC methods, and applications.

- The particular case of mobile communication is the personal wireless devices which uses the RF transmission media

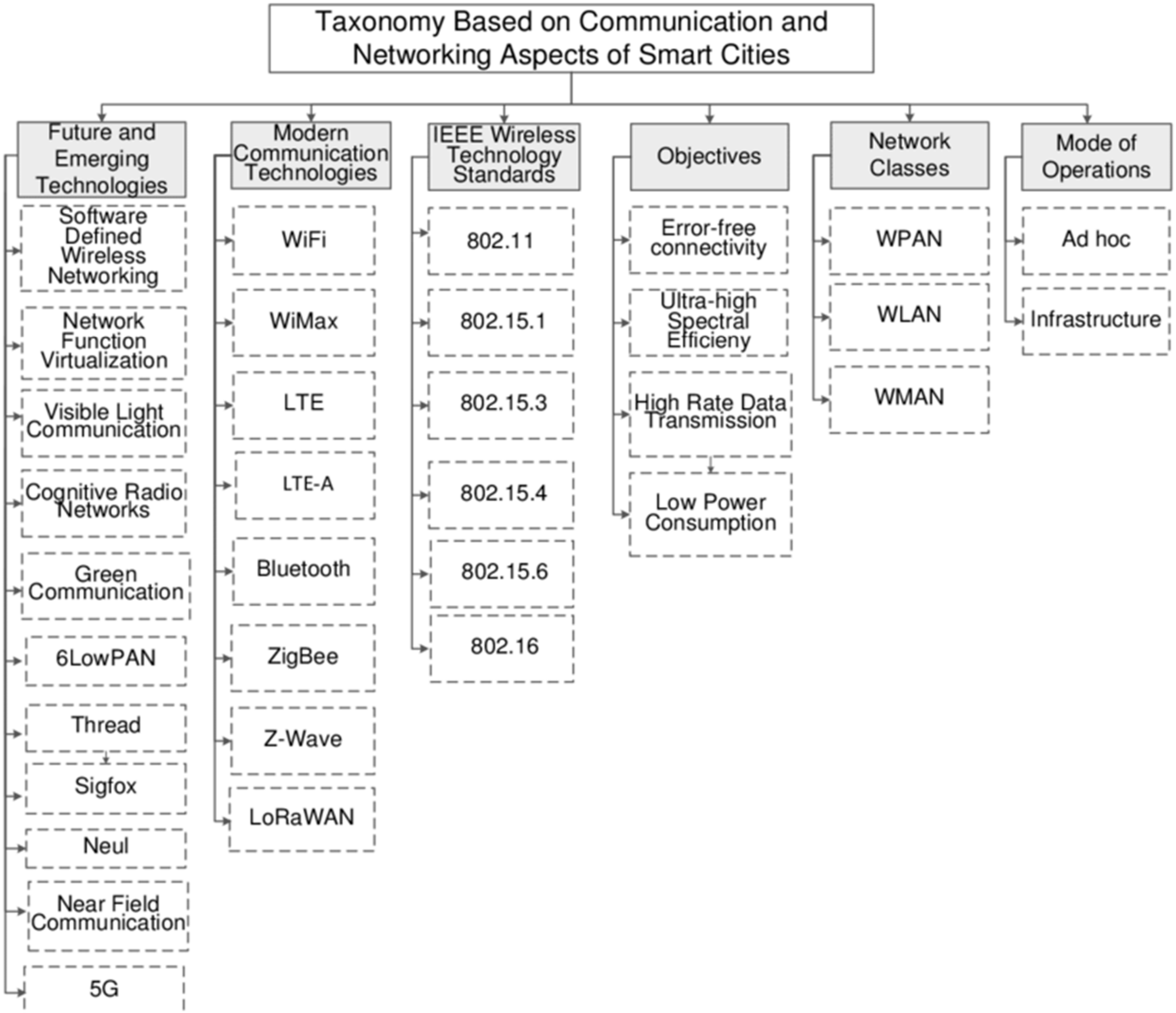
a)



b)



1.2. CLASSIFICATION AND TECHNOLOGY ISSUES

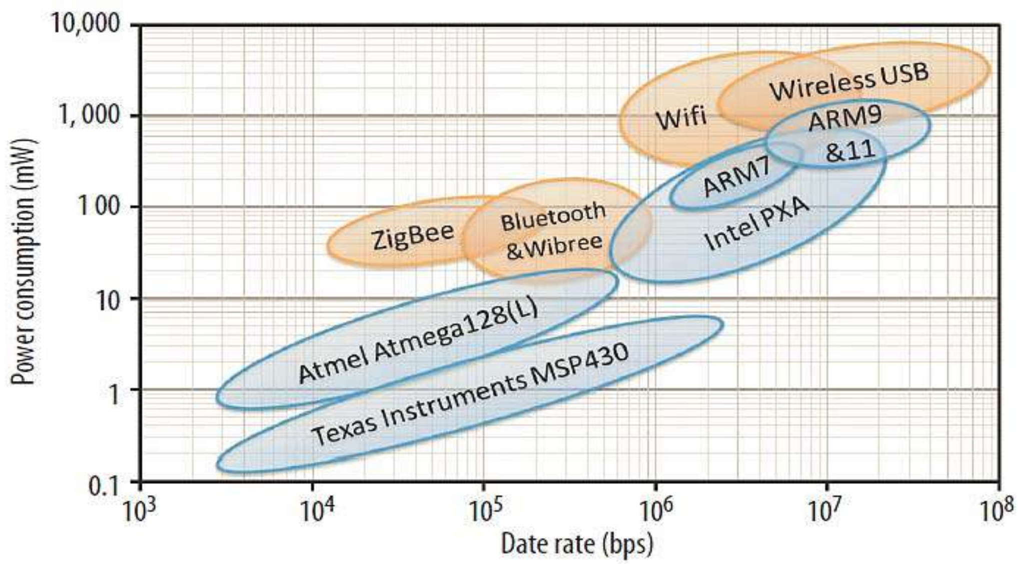


1.2. CLASSIFICATION AND TECHNOLOGY ISSUES

Standard/wireless technology	Used by user as	Operating band and data rate	Range (m)
IEEE 802.15.6 Body Area Network	Portable or Into	868/915MHz, 2.4GHz 76/101Kbps, 485Kbps	10
IEEE 802.15.4 Wireless Sensor Networks	Portable	868/915MHz, 2.4 GHz 20/40/250 Kbps	100
IEEE 802.15.4a ultra-wideband (UWB)	Portable	250–750 KHz/3.1–5 GHz/ 6–10.6 GHz, 675 Mbit/s	100
IEEE 802.15.1 Bluetooth v.4	Portable	2.4 GHz, 24 Mbps	100
IEEE 802.11 a/b/g/n/ac Wi-Fi	Access	5 /2.4 /2.4 /2.4 or 5 GHz 54/11/54/600Mps/6.93Gbps	120/140/140/250

Wireless technology standards and characteristics

Average power consumption of wireless transceivers and microcontrollers in Wireless Sensor Networks

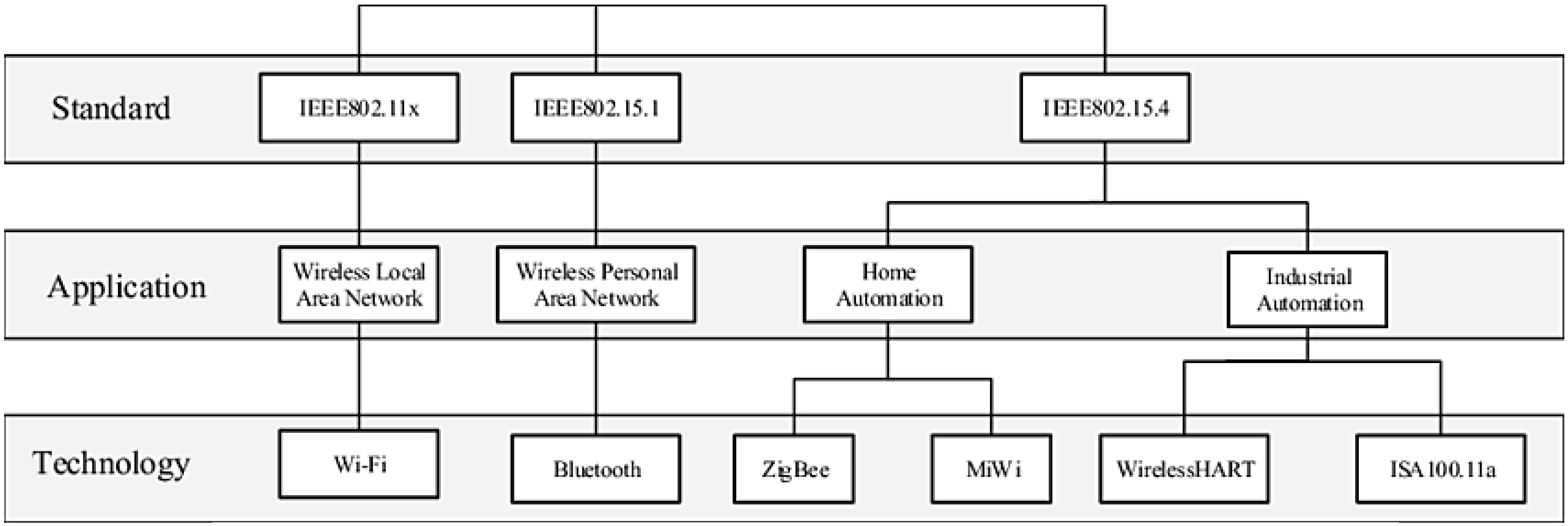


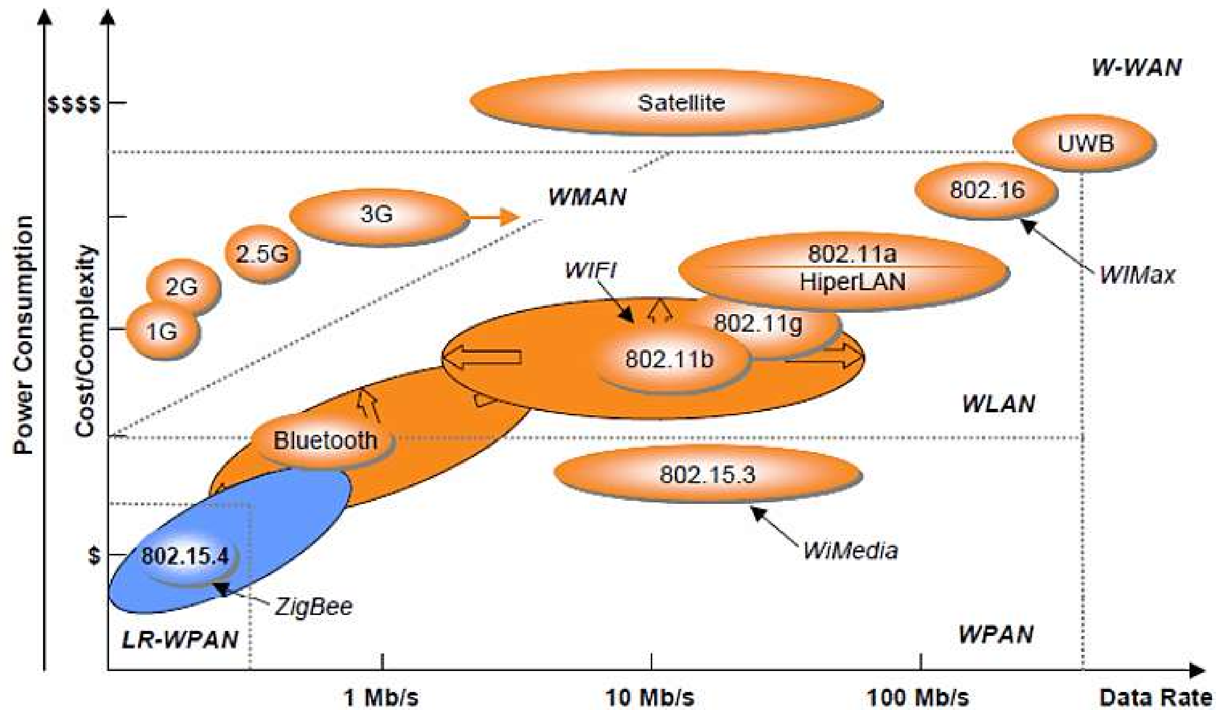
1.2. CLASSIFICATION AND TECHNOLOGY ISSUES

Wireless technology standards and characteristics

	Bluetooth	Wibree	ZigBee
Band	2.4 GHz	2.4 GHz	2.4 GHz,868 MHz,915 MHz
Antenna/HW	Shared		Independent
Power	100 mW	~10 mW	30 mW
Target Battery Life	days – months	1-2 years	6 months – 2 years
Range	10-30 m	10 m	10-75 m
Data Rate	1-3 Mbit/s	1 Mbit/s	25-250 Kbit/s
Component Cost	$3	Bluetooth + 20¢	$2
Network Topologies	Ad-hoc, point-to-point, star	Ad-hoc, point-to-point, star	Mesh, ad-hoc, star
Security	128-bit encryption	128-bit encryption	128-bit encryption
Time to Wake and Transmit	3 s	TBA	15 ms

1.2. CLASSIFICATION AND TECHNOLOGY ISSUES





1.3 DATA TRANSMISSION FUNDAMENTALS

Time domain and Frequency Domain Concepts

- Signal representation in Time domain: when $f(x)$ is continuous or discrete and well-behaved function, x is real variable representing either time or distance in one direction.
- Using Fourier's theorem which states that it is possible to form any one dimensional function $f(x)$ as summation of a series of sine and cosine terms of increasing frequency

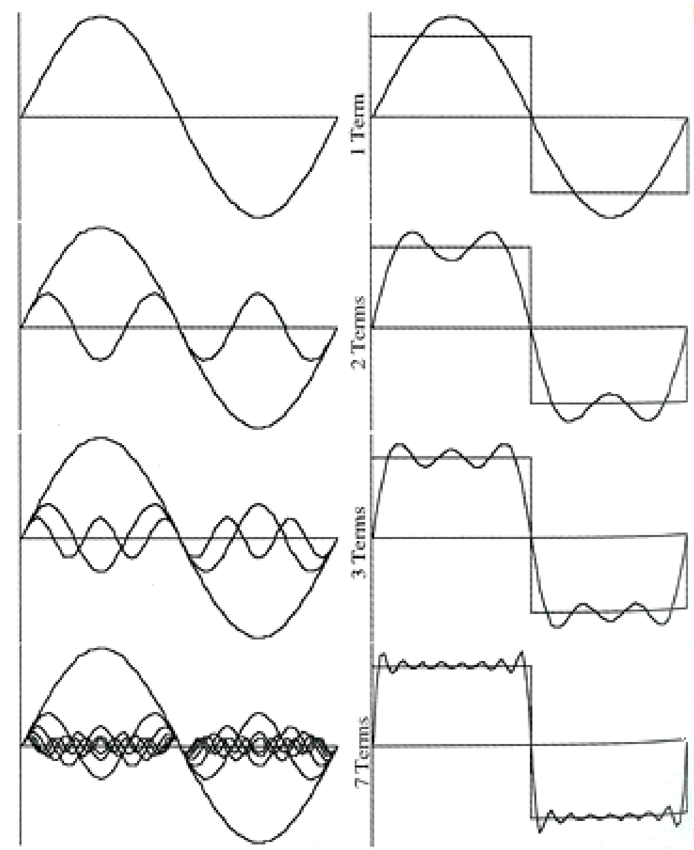
example:

$$f(t) = \sin(2\pi f t)$$

$$f(t) = \sin(2\pi f t) + 1/3\sin(2\pi 3 f t)$$

$$f(t) = \sin(2\pi f t) + 1/3\sin(2\pi 3 f t) + 1/5\sin(2\pi 5 f t)$$

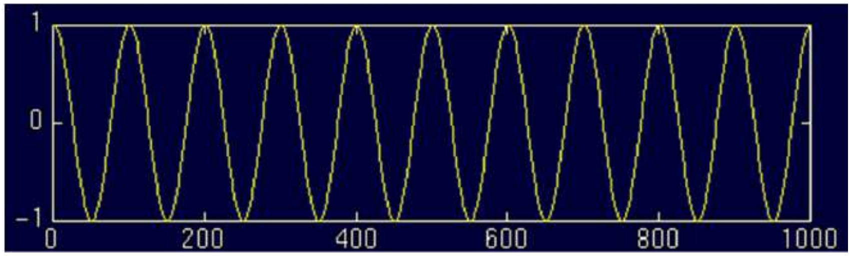
$$f(t) = \sin(2\pi f t) + 1/3\sin(2\pi 3 f t) + 1/5\sin(2\pi 5 f t) + 1/7\sin(2\pi 7 f t) + 1/9\sin(2\pi 9 f t) + 1/11\sin(2\pi 11 f t) + 1/13\sin(2\pi 13 f t)$$

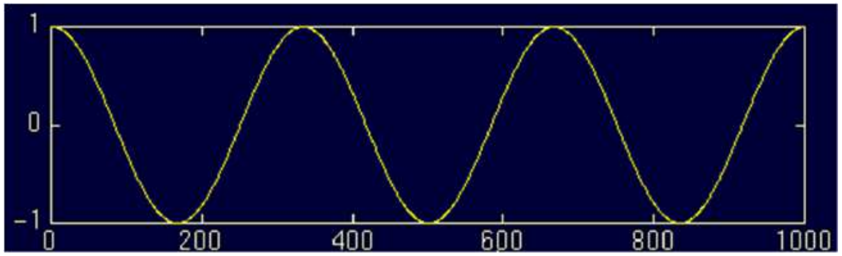


1.3 DATA TRANSMISSION FUNDAMENTALS

Time domain and Frequency Domain Concepts

- Time-amplitude representation (time-domain) representation is not always the best representation of signal for most signal processing related applications





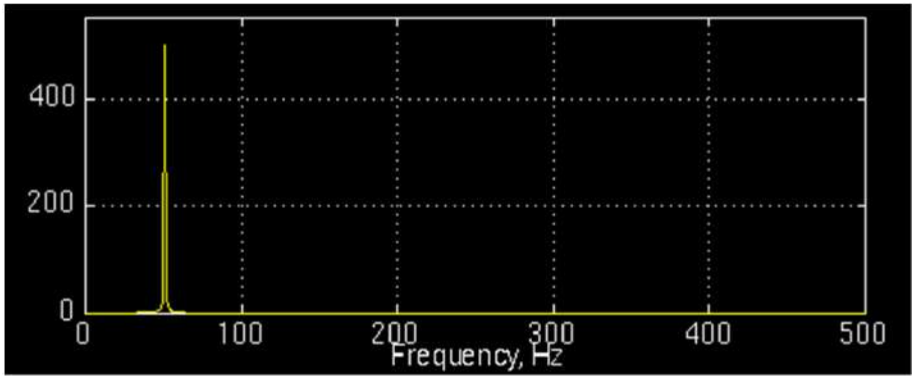
time-domain of $cos(2\pi 10t), f = 10\text{Hz}, T = \frac{1}{f} = 0.1\text{s}$. Time-domain signals are: _ ?_

- In many cases, the most distinguished information is hidden in the frequency content of the signal.
- The *frequency-domain (spectrum)* of a signal is basically the frequency components (spectral components) of that signal
- The Fourier transform (FT) of time-domain signal provides the frequency-amplitude representation of that signal indicating how much of each frequency exists in a signal

1.3 DATA TRANSMISSION FUNDAMENTALS

Time domain and Frequency Domain Concepts

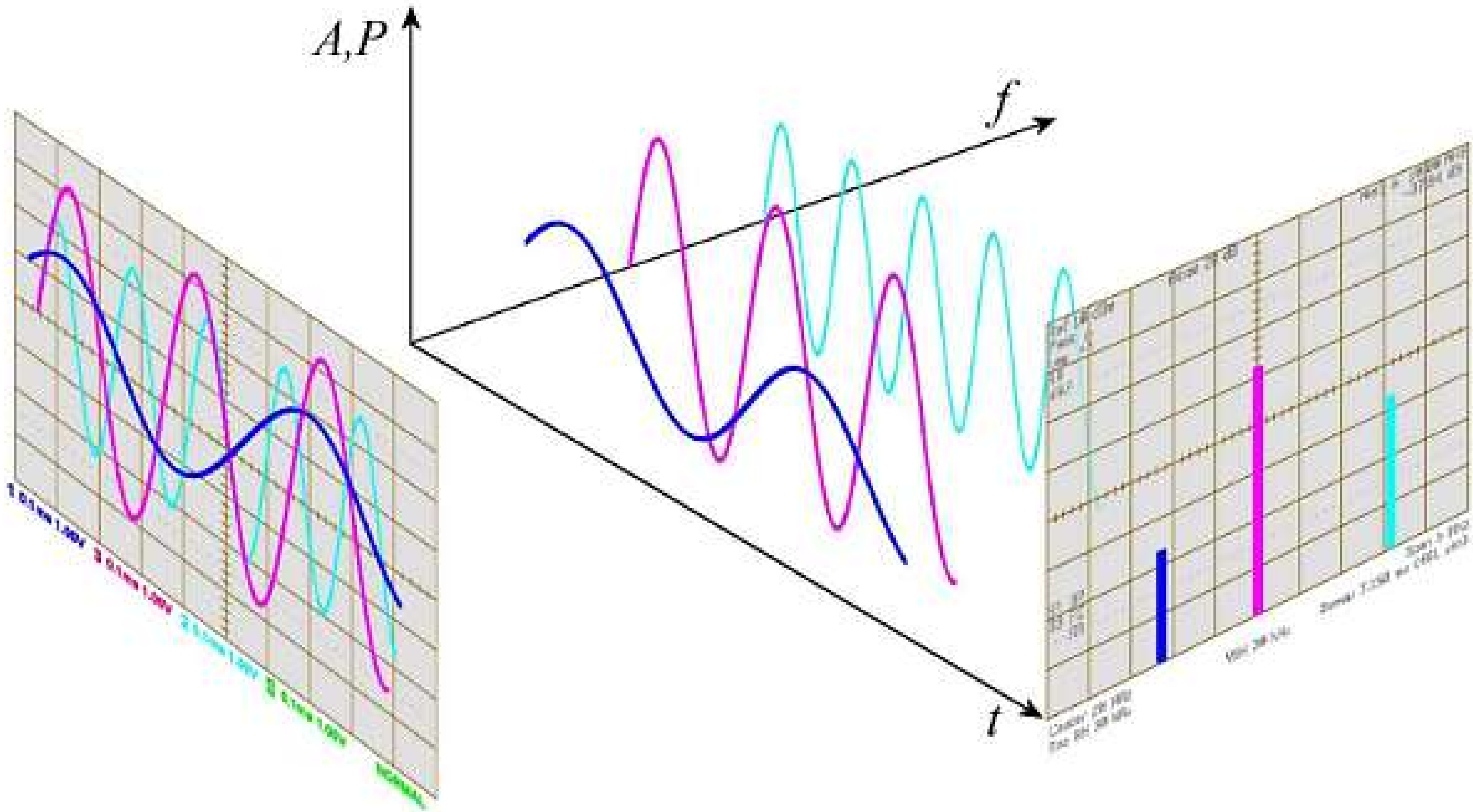
- For example, FT of electric current supply of $110\,V$ has one spike at $50\,Hz$, and nothing elsewhere, since that signal has only $50\,Hz$ frequency component.



- Although FT is probably the most popular transform being used (especially in electrical engineering), there are many other transforms that are used quite often by engineers and mathematicians: *Hilbert transform, short-time Fourier transform, Wigner distributions, the Radon transform, and of course, the wavelet transform*, constitute only a small portion of a huge list of transforms that are available.
- Every transformation technique has its own area of application, with advantages and disadvantages, and the wavelet transform (WT) is not exception

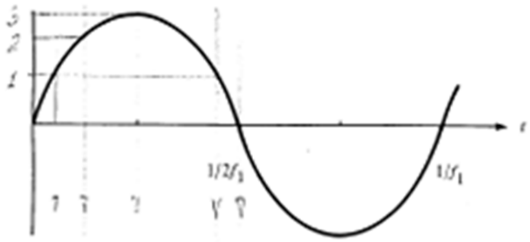
1.3 DATA TRANSMISSION FUNDAMENTALS

Time domain and Frequency Domain Concepts

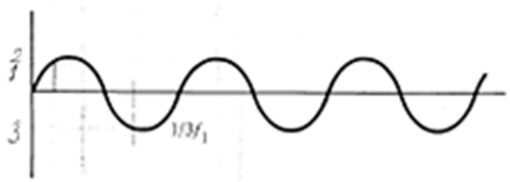


1.3 DATA TRANSMISSION FUNDAMENTALS

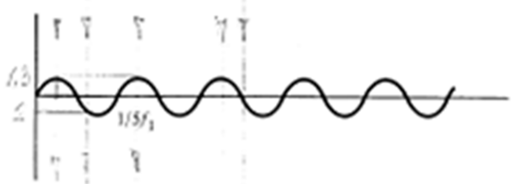
Time domain and Frequency Domain Concepts



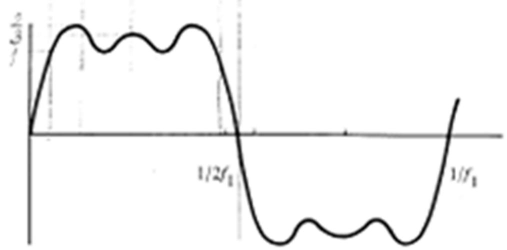
(a) $\sin 2\pi f_1 t$



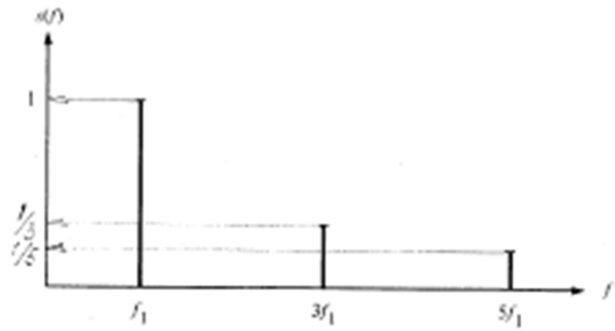
(b) $1/3 \sin 3 (2\pi f_1) t$



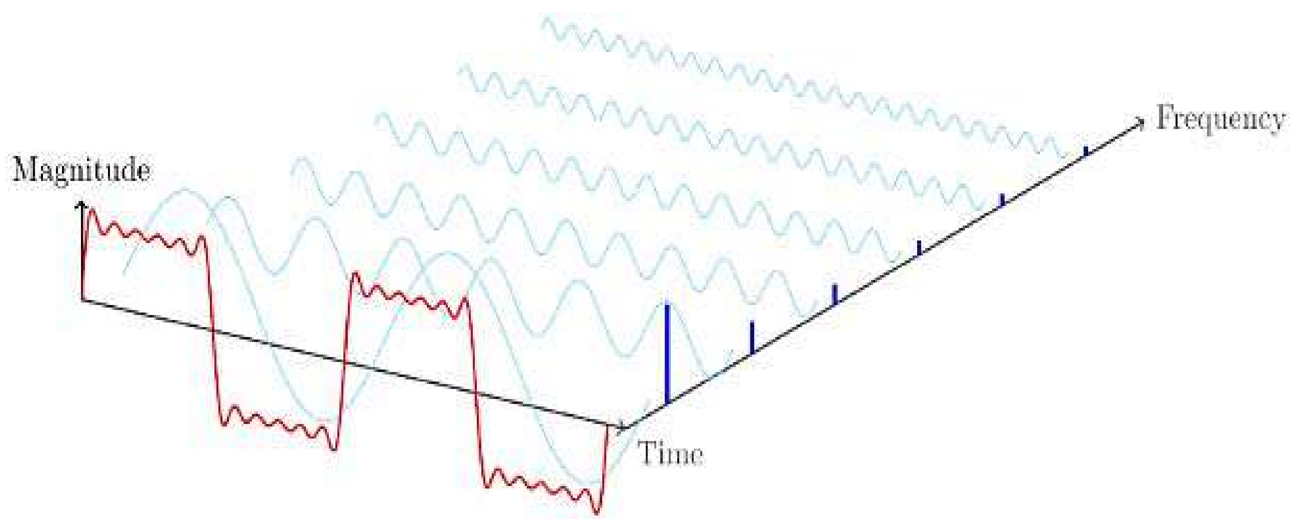
(c) $1/5 \sin 5 (2\pi f_1) t$



(d) $\sin 2\pi f_1 t + 1/3 \sin 3 (2\pi f_1) t + 1/5 \sin 5 (2\pi f_1) t$



(a) $s(t) = \sin 2\pi f_1 t + 1/3 \sin 3 (2\pi f_1) t + 1/5 \sin 5 (2\pi f_1) t$



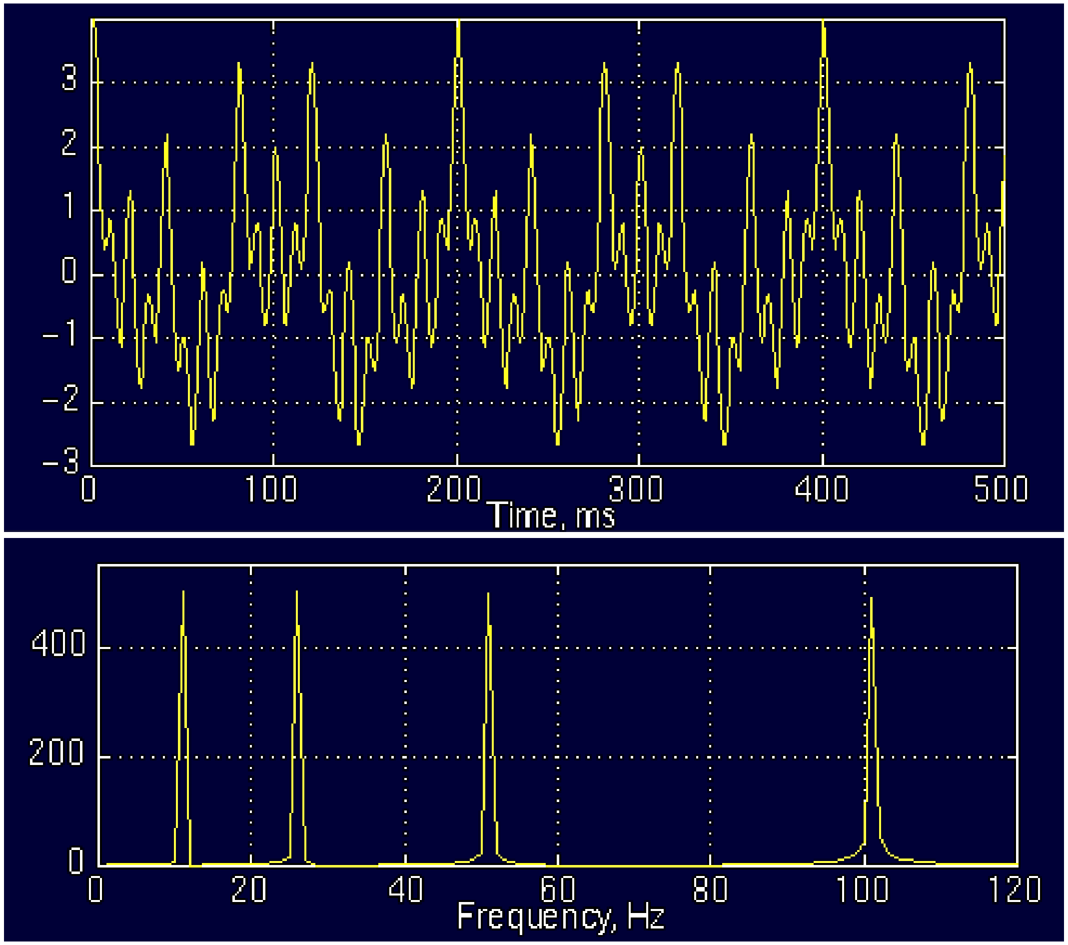
1.3 DATA TRANSMISSION FUNDAMENTALS

Time domain and Frequency Domain Concepts

- For *example* the following signal

$x(t) = \cos(2\pi 10t) + \cos(2\pi 25t) + \cos(2\pi 50t) + \cos(2\pi 100t)$

is a stationary signal, because it has frequencies of $10, 25, 50$ and 100 Hz at any given time instant.



- The time domain

and Fourier transform

of this signal is computed as:

$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}dt\ .$$

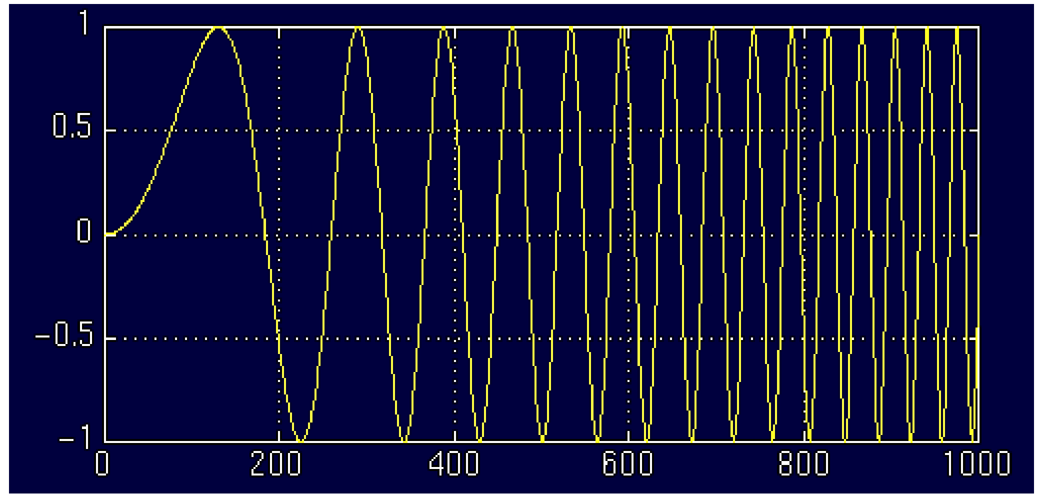
Note: inverse Fourier transform:

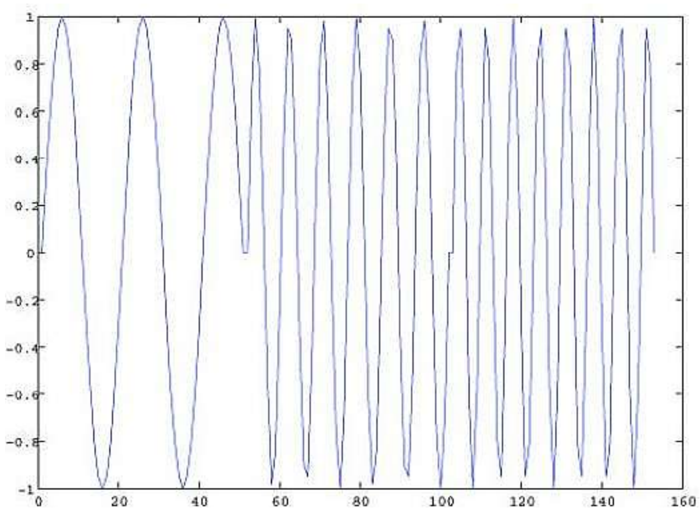
$$x(t) = \int_{-\infty}^{\infty} X(f)e^{j2\pi ft}df$$

1.3 DATA TRANSMISSION FUNDAMENTALS

Time domain and Frequency Domain Concepts

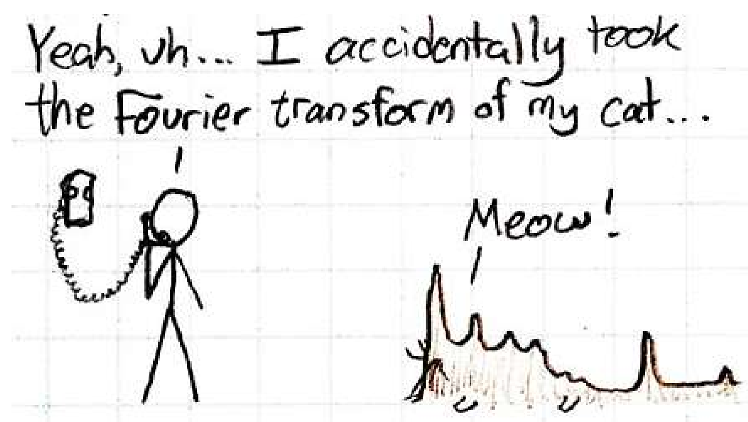
- Contrary to the previous signal, the following signal is not stationary because signal frequency constantly changes in time.





- Another *example* of non-stationary signal:

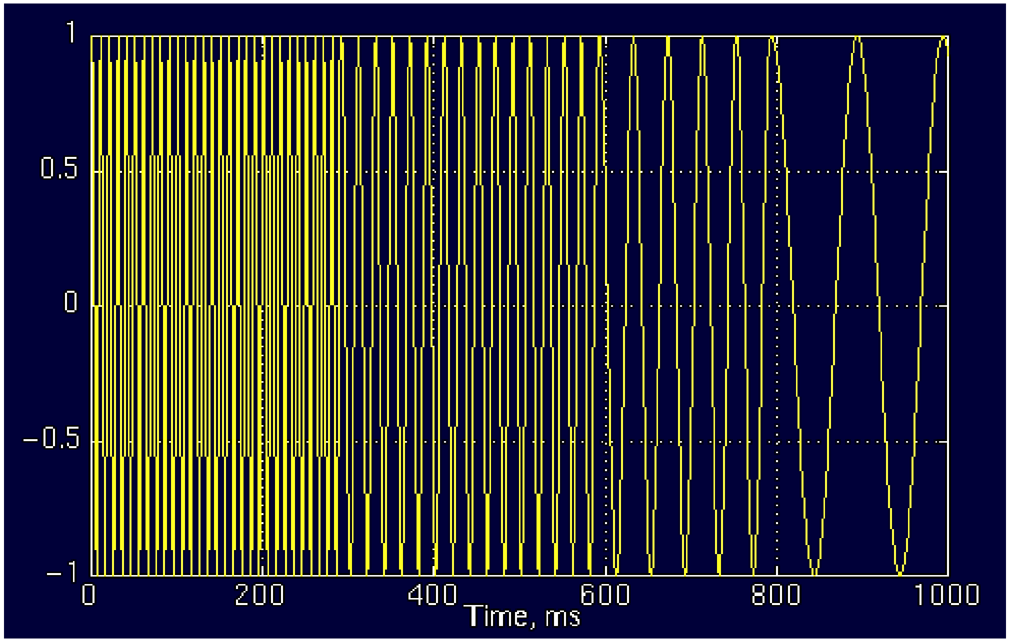
$$x(t) = \cos(2\pi 50t) * \cos(2\pi 120t) * \cos(2\pi 150t) * \cos(2\pi 100t)$$

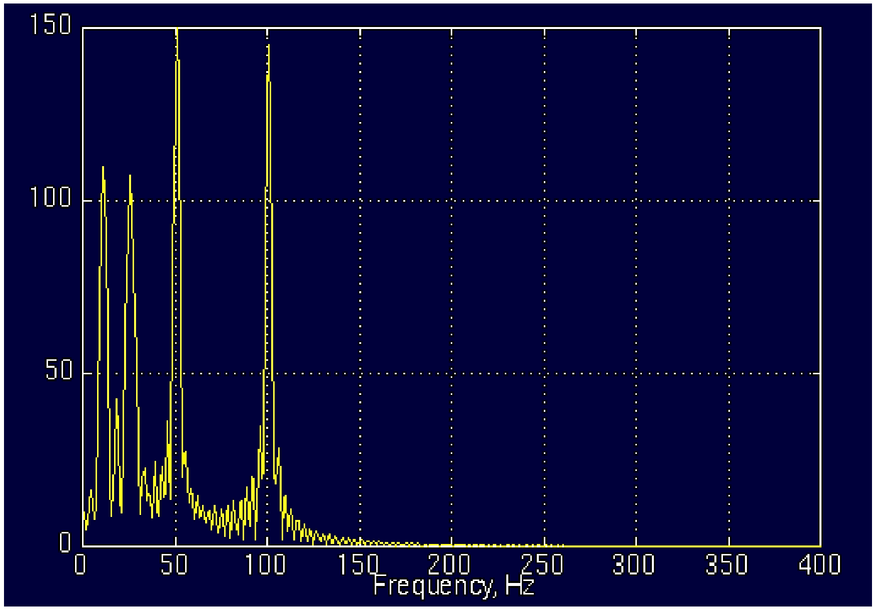


1.3 DATA TRANSMISSION FUNDAMENTALS

Another *example*: signal with *4* different frequency components at *4* different time intervals, hence, it is non-stationary signal.

The interval *0* to *300 ms* has *100 Hz* sinusoid, the interval *300* to *600 ms* has *50 Hz* sinusoid, the interval *600* to *800 ms* has *25 Hz* sinusoid, and finally the interval *800* to *1000 ms* has *10 Hz* sinusoid.



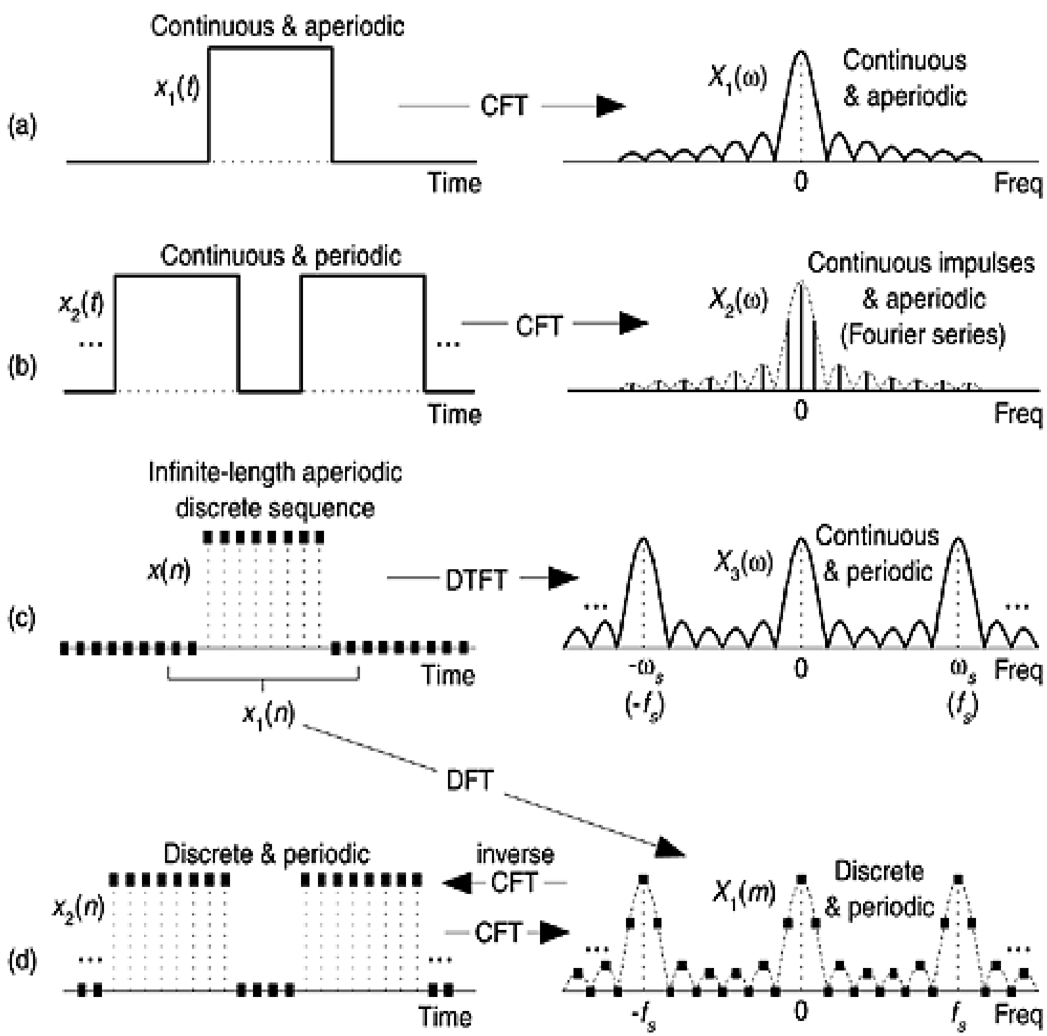


Little ripples are due to sudden changes from one frequency component to another in its spectrum. Amplitudes of higher frequency components are higher than those of lower frequency ones due to higher frequencies last longer (*300 ms* each) than lower frequency components (*200 ms* each) and exact value of amplitudes are not important).

1.3 DATA TRANSMISSION FUNDAMENTALS

Discrete Fourier transform

Time domain signals and sequences, and magnitudes of their transforms in frequency domain



Time Duration		
Finite	Infinite	
Discrete FT (DFT) $X(k) = \sum_{n=0}^{N-1} x(n)e^{-j\omega_k n}$ $k = 0, 1, \ldots, N-1$	Discrete Time FT (DTFT) $X(\omega) = \sum_{n=-\infty}^{+\infty} x(n)e^{-j\omega n}$ $\omega \in [-\pi, +\pi)$	discr. time n
Fourier Series (FS) $X(k) = \frac{1}{P}\int_0^P x(t)e^{-j\omega_k t}dt$ $k = -\infty, \ldots, +\infty$	Fourier Transform (FT) $X(\omega) = \int_{-\infty}^{+\infty} x(t)e^{-j\omega t}dt$ $\omega \in (-\infty, +\infty)$	cont. time t
discrete freq. k	continuous freq. ω	

a) magnitude of its CFT is the continuous frequency-domain function $X_1(\omega)$

b) result is infinite-length signal of periodic pulses represented by line spectra known as the Fourier series $X_2(\omega)$

c) Infinite-length discrete time signal $x(n)$, with some non-zero samples, has spectrum called discrete-time Fourier transform (DTFT) described by continuous function $X_3(\omega)$

d) Taking DFT of $x_2(n)$ that is finite-length portion of $x(n)$, discrete periodic $X_1(m)$ spectral samples are obtained as sampled version of continuous periodic $X_3(\omega)$

1.3 DATA TRANSMISSION FUNDAMENTALS
Disadvantages of Fourier transform

- Comparing frequency-domain representation of two signals from slide *31* and *33*, the similarity between these two spectrum should be apparent.
- Both of them show *4* spectral components at exactly the same frequencies, i.e., at *10, 25, 50* and *100Hz*.
- Despite of the ripples and the difference in amplitude (which can always be normalized), two spectrums are almost identical, although the corresponding time-domain signals are not even close to each other.
- Both of the signals involves the same frequency components, but the first one has these frequencies at all times, the second one has these frequencies at different intervals so, the spectrums of two entirely different signals look very much alike
- Recall that the FT gives the spectral content of the signal, but it gives no information regarding *where in time those spectral components appear*.
- Therefore, FT is not a suitable technique for non-stationary signal, with one exception: FT can be used for non-stationary signals, if we are only interested in what spectral components exist in the signal, but not interested when these occur.
- However, if this information is needed, i.e., if we want to know, what spectral component occur at what time (interval), then Fourier transform is not the correct transform to use.

1.3 DATA TRANSMISSION FUNDAMENTALS

- **Bandwidth** is a measurement of how much information (voice, data etc.) can be sent via given frequency band in the electromagnetic **spectrum**. So, absolute bandwidth is the width of the spectrum that defines a range of frequencies that it contains

- Visible light is familiar spectrum, ranging in frequencies from red to violet with each color being unique frequency.

- Frequencies are measured in Hertz(Hz), although older method of cycles per second is more intuitive.

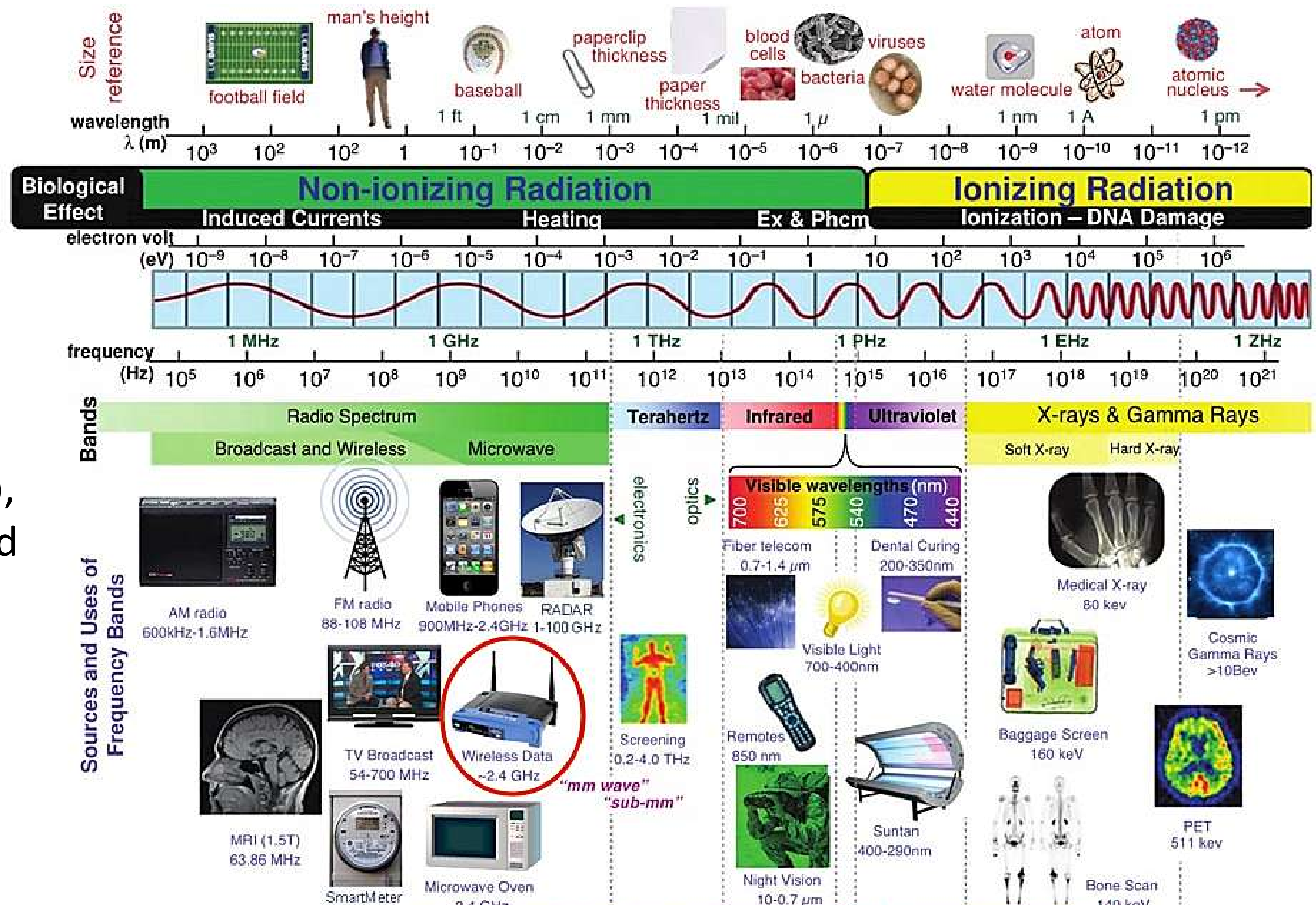
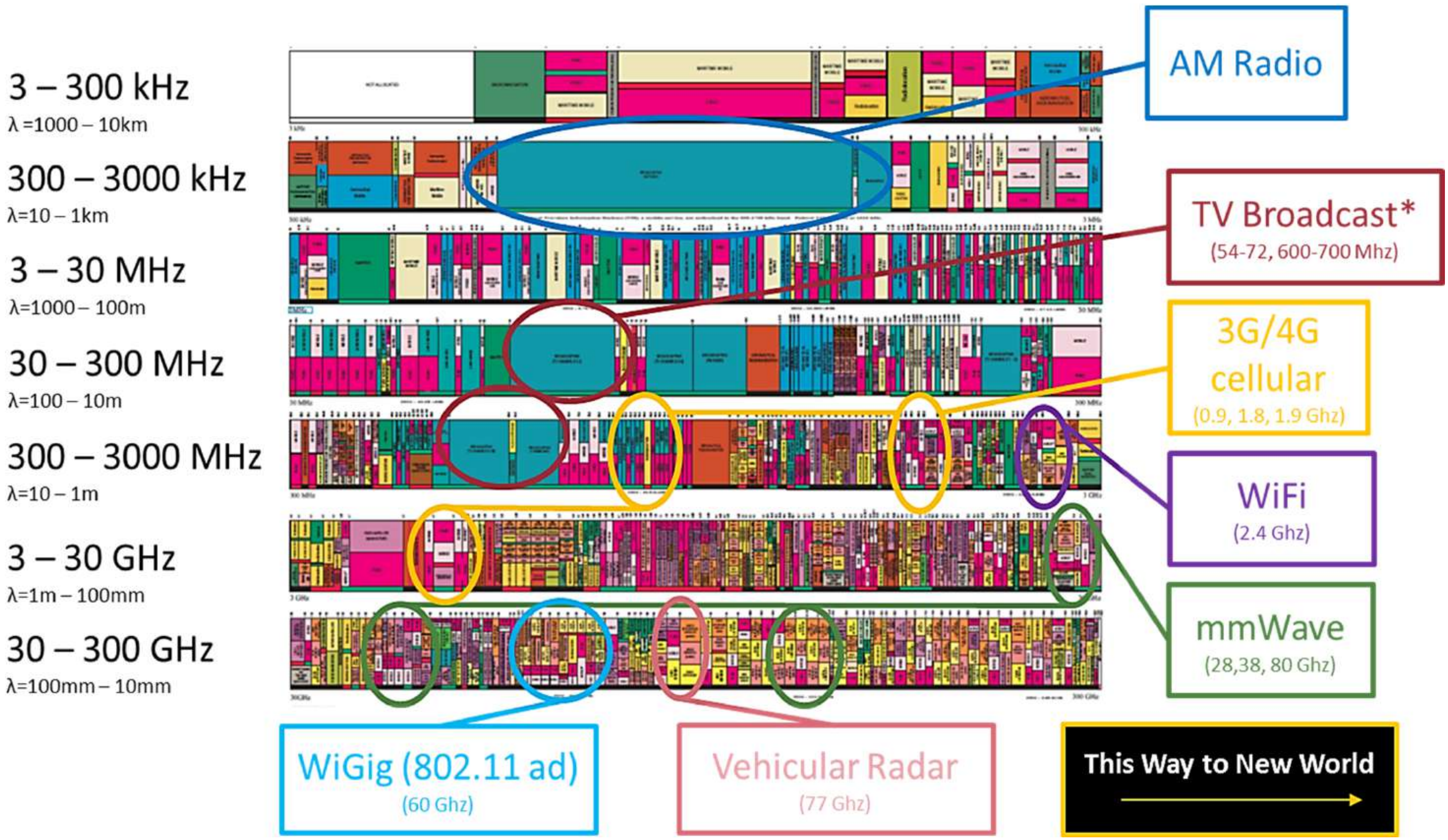


Image: http://www.andrewgeller.me/wp-content/uploads/2014/07/electromagnetic-spectrum.jpg

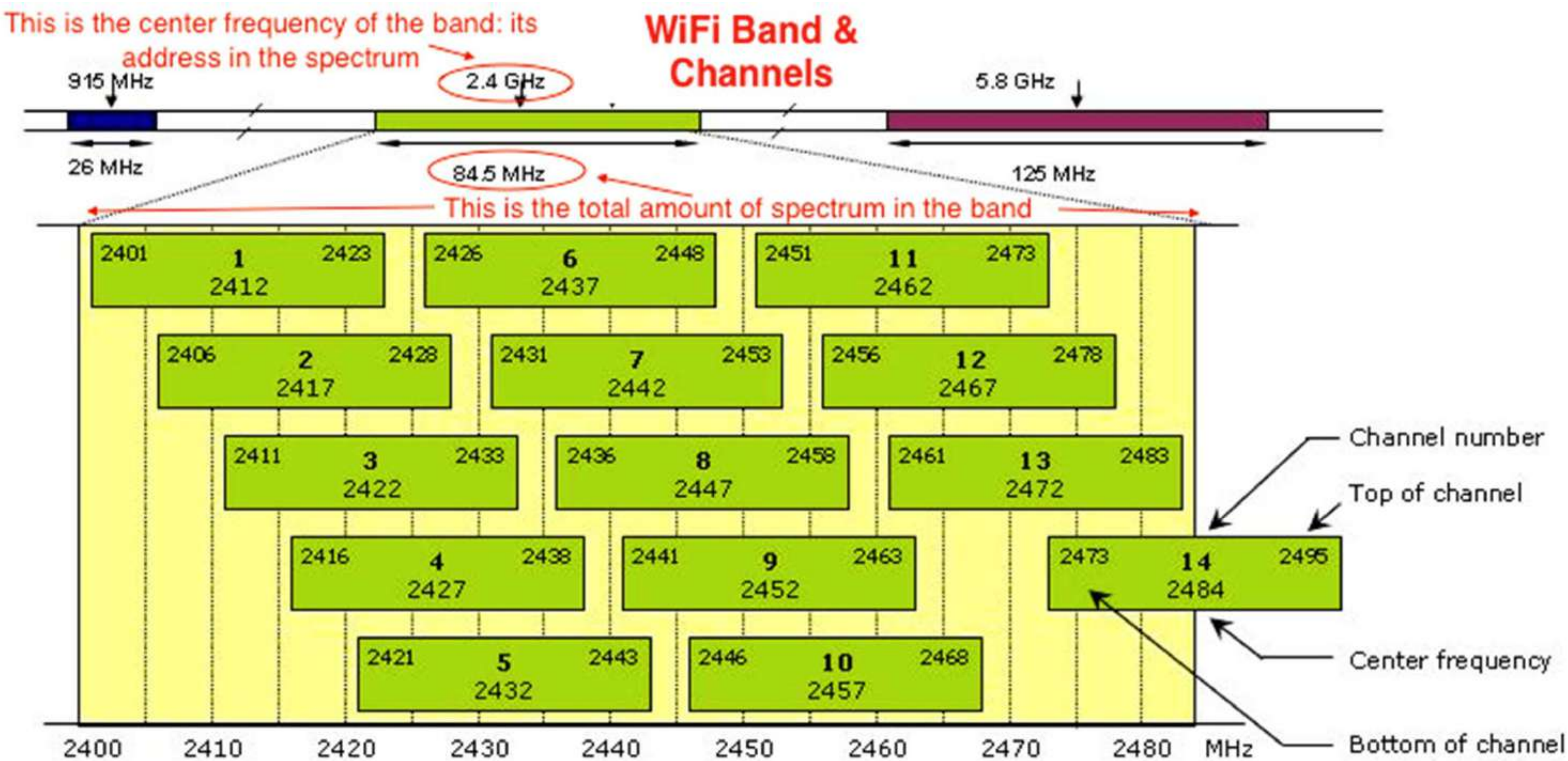
1.3 DATA TRANSMISSION FUNDAMENTALS

- **Radio waves** also have a spectrum of frequencies all of which are lower than **light**.
- The spectrum of common radio frequencies range from the radio AM (KHz) to broadcast television and FM radio (MHz) and WiFi at 2.4 GHz



1.3 DATA TRANSMISSION FUNDAMENTALS

- Within an assigned frequency WiFi band (such as 2.4 GHz), there are smaller slices of frequencies called channels, each of which can provide bandwidth to carry information without interfering with other channels, and all bands are known as wireless spectrum.
- The bands, and width of the channels needed to create bandwidth are measured in MHz.



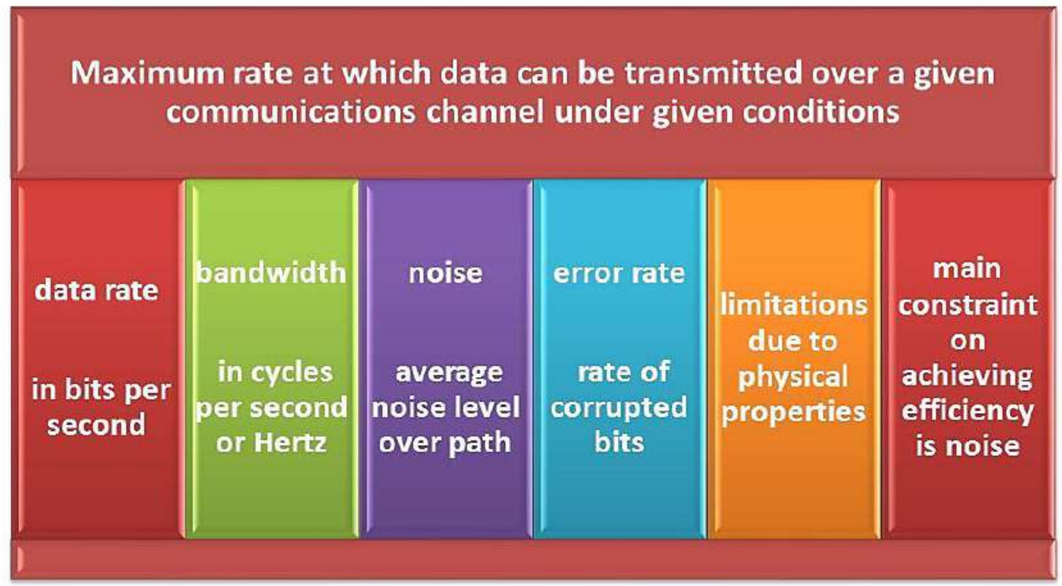
1.3 DATA TRANSMISSION FUNDAMENTALS

Relationship between **data rate** and **bandwidth:**

1. For **very good representation** of a signal a twice of data rate R is equal to bandwidth W

$$R(bps) = W/2(Hz)$$

2. **Cannel capacity** C (bps or bauds-cycles per sec) is defined as max rate at which data can be transmitted over a given communication path or channel under given conditions: data rate, bandwidth, noise level , error rate, signal power, etc.



3. **Nyquist bandwidth**: If there is no noise data rate is limited by bandwidth only. So, Nyquist states that if rate of signal $R(bps)$ is $2W(Hz)$ then signal with frequencies no greater than W is sufficient to carry the signal with $R = 2W$

For multilevel signals the data rate or channel capacity is computed as

$$R = C = 2W * log_2 M$$

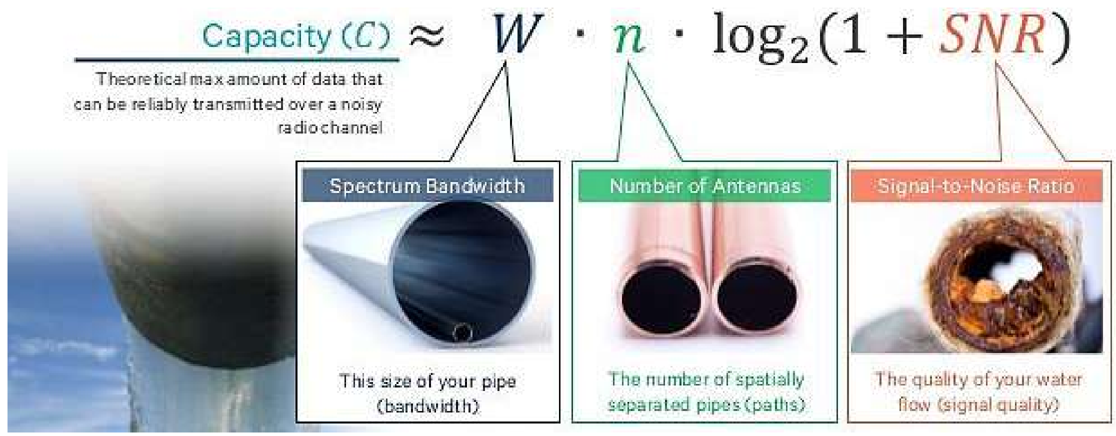
where M is the number of levels of signal

1.3 DATA TRANSMISSION FUNDAMENTALS

4. **Shannon Capacity** Formula: It considers the noise and error rate through Signal-to-Noise Ratio $SNR = \frac{signal\ power}{noise\ power}$ that represents power of signal to power of noise measured at receiver. In dB notation SNR is found as $SNR_{dB} = 10log_{10}(\frac{signal\ power}{noise\ power})$

- The Shannon equation defines channel capacity as $C(bps) = \mathrm{W} * log_2(1 + SNR)$

Using more than one antenna for generating electromagnetic field, the Shannon equation defines a radio channel finite capacity as:



example:

Suppose the channel spectrum is in range from $3MHz$ to $4MHz$ and $SNR_{dB}= 24dB$

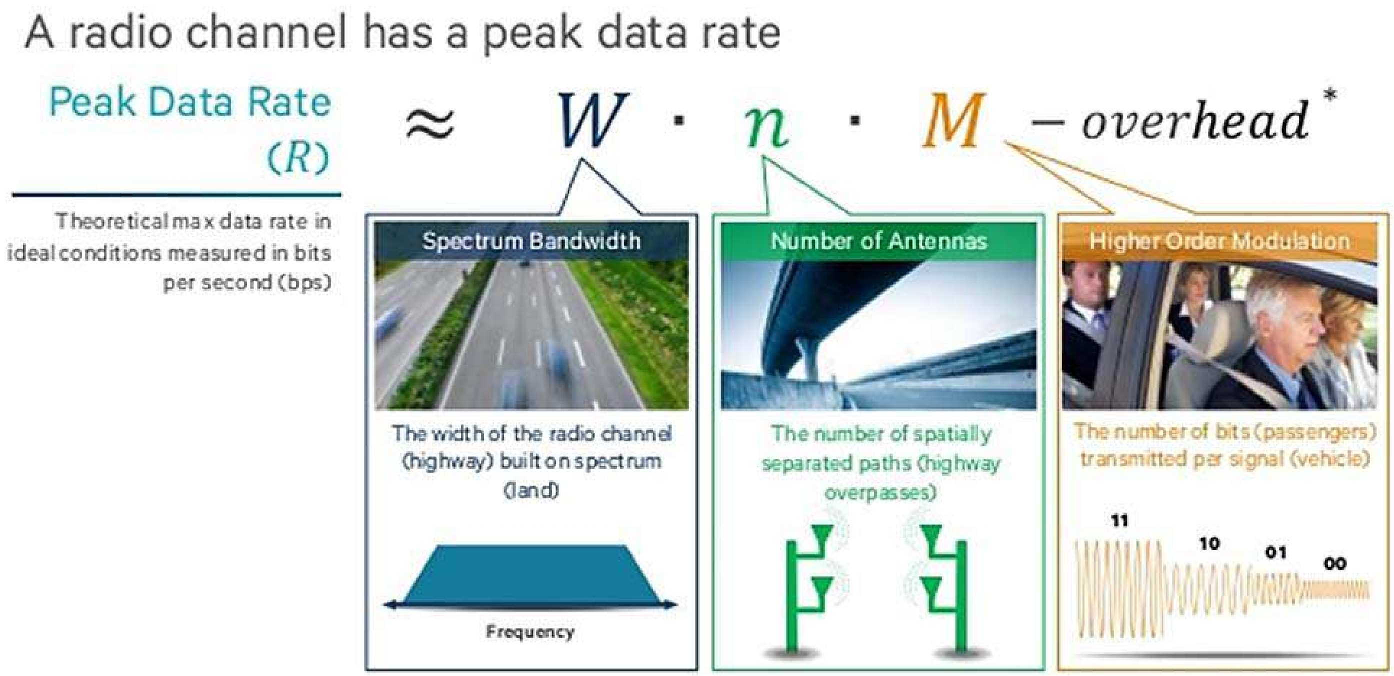
So, using system with one antenna, bandwidth is computed as $\mathrm{W} = 4 - 3 = 1MHz$ and

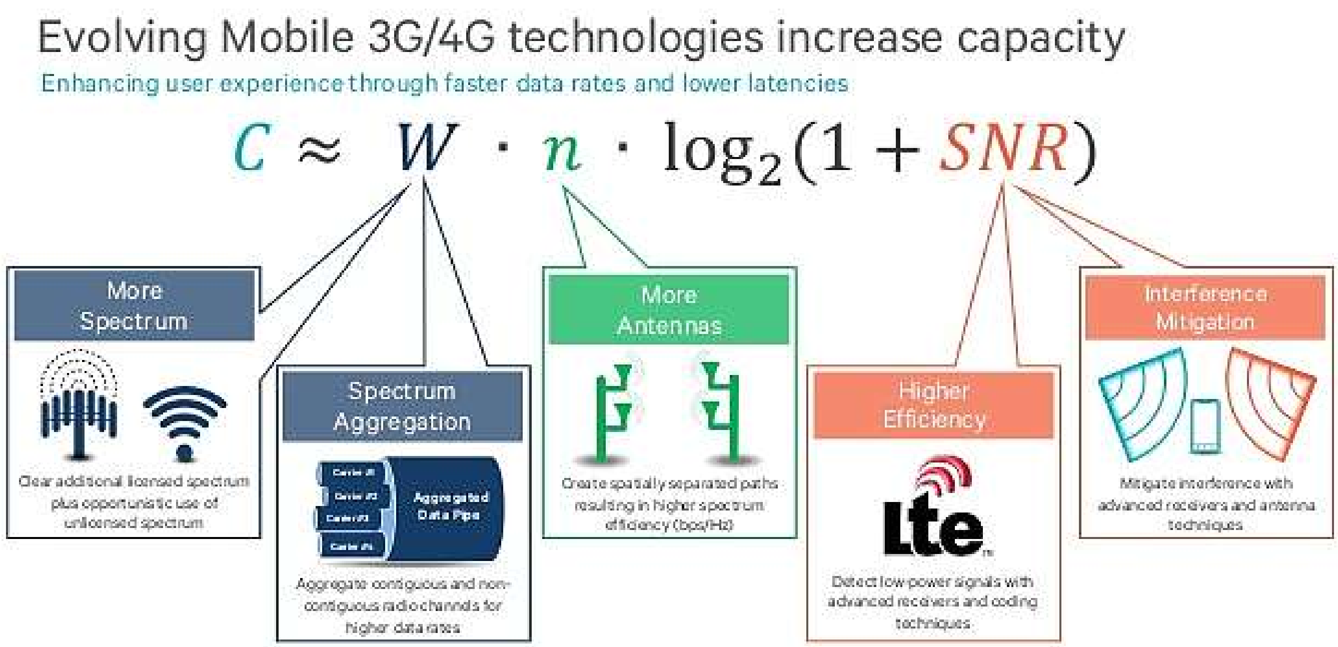
$$SNR_{dB} = 24dB = 10log_{10}(SNR) \text{ that gives } SNR = 251$$

For Shannon's formula theoretical max: $C(bps) = 10^6 * log_2(1 + 251) \approx 10^6 * 8 = 8Mbps$

Based on Nyquist's formula $C = 2W * log_2 M$ the number of necessary levels for this channel capacity is computed as $8 * 10^6 = 2 * 10^6 * log_2 M$ obtaining $M = 16$

1.3 DATA TRANSMISSION FUNDAMENTALS

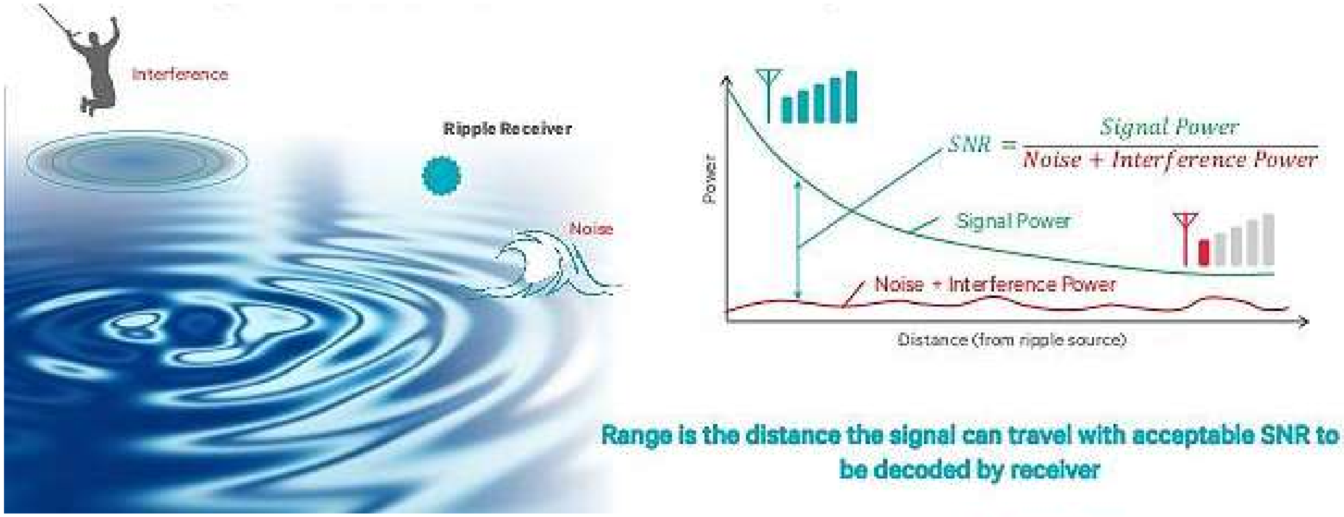




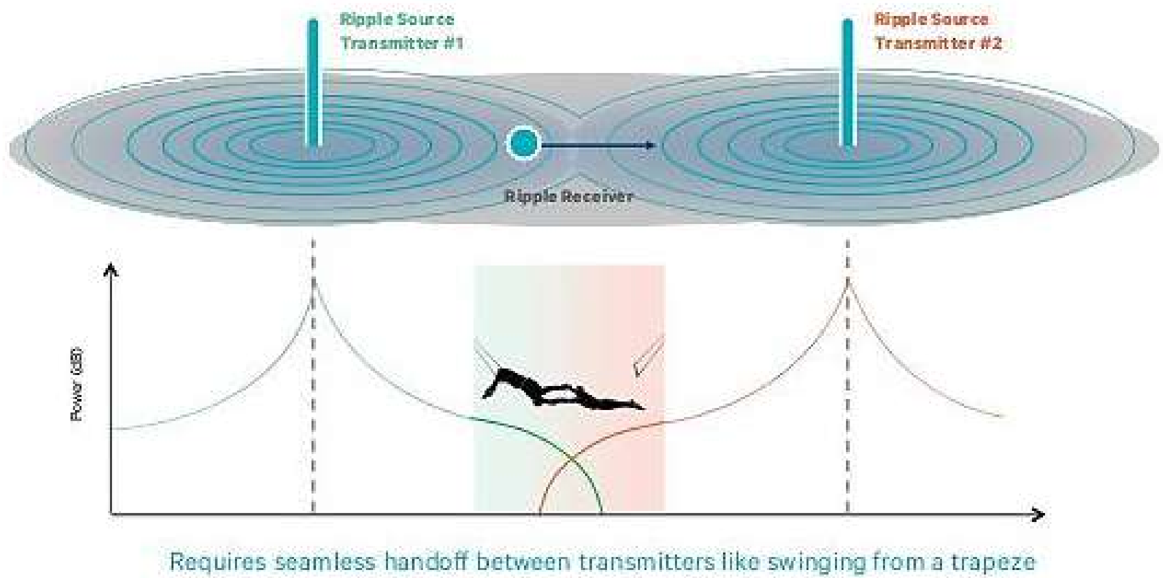
1.3 DATA TRANSMISSION FUNDAMENTALS

Signal strength and its measurement

- Signal strength, usually falls (loss or attenuation) or raises (gain or amplification) logarithmically, so it may be easy expressed in dB



- Mobile technologies provide signal quality despite hard wireless environment and provide coverage beyond the cell



1.3 DATA TRANSMISSION FUNDAMENTALS

Signal strength is evaluated quantitatively using following equations:

- for power comparison the number of decibels is:

$$N_{dB} = 10log_{10}(\frac{signal\ power_1}{signal\ power_2})$$

- for voltage or current comparison the number of decibels is:

$$N_{dB} = 10log_{10}\left(\frac{signal\ power_1}{signal\ power_2}\right) = 10log_{10}\left(\frac{{V_1}^2/R}{{V_2}^2/R}\right) = 10log_{10}\left(\frac{{I_1}^2 * R}{{I_2}^2 * R}\right) =$$

$$= 20log_{10}\left(\frac{V_1}{V_2}\right) = 20log_{10}\left(\frac{I_1}{I_2}\right)$$

- for absolute dB applications comparison with $1Watt$ or $1Volt$ or $1Amper$ is used

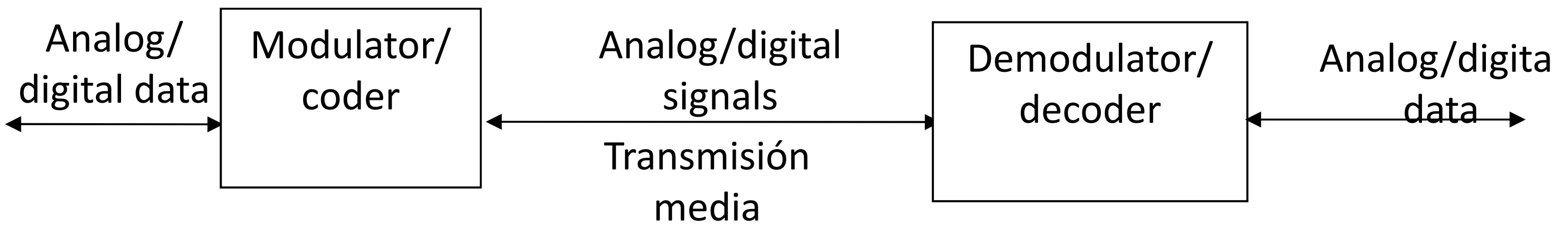
$$Power_{dBW} = 10log_{10}(\frac{signal\ power}{1W})$$

$$Voltage_{dBV} = 20log_{10}(\frac{signal\ voltage}{1V})$$

$$Current_{dBA} = 20log_{10}(\frac{signal\ current}{1A})$$

1.3 DATA TRANSMISSION FUNDAMENTALS

Analog and digital data transmission



	Analog Signal	Digital Signal
Analog data	Signal occupies the same spectrum as the analog data. Analog data are encoded to occupy a different portions of spectrum	Analog data are encoded using a code to produce a digital bit stream
Digital data	Digital data are encoded using a modem to produce analog signal	Signal consists of two voltage levels to represent two binary values. Digital data are encoded to produce a digital signal with desired properties

	Analog Transmission	Digital Transmission
Analog signal	It is propagated through amplifiers; same treatment if signal is used to represent analog or digital data	Analog signal represents digital data. Signal is propagated through repeaters to recover from inbound signal generating new analog outbound signal
Digital signal	Not used	Digital signal represents a stream of 1s and 0s encoding the analog data. Propagation via repeaters. Stream of 1s and 0s is recovered from inbound signal and new digital outbound is generated

1.3 DATA TRANSMISSION FUNDAMENTALS

Analog and digital data transmission

1. Digital data-digital signal:

NRZ-L, Bipolar AMI, Pseudo-ternary, Manchester, Differential Manchester, Bipolar 3, 6, 8 zero substitutions BNZS, high density 4 Zeros substitution HDB3

2. Digital data-analog signal:

ASK, FSK (or binary BFSK) and PSK (or binary BPSK, QPSK-four level used 90^0 phase shift)

Multiple FSK (MFSK) is a technique when more than two frequencies are used

The transmitted MFSK signal for one data element time can be defined as follows:

$s_i(t) = \mathrm{A} * \cos(2\pi f_i t), \quad 1 \le i \le M$ where $f_i = f_c + (2i - 1 - M) f_d$

$f_c -$ carrier frequency; $f_d -$difference frequency;

$M -$ number of different signal elements $= 2^L$; $L -$number of bits per signal element

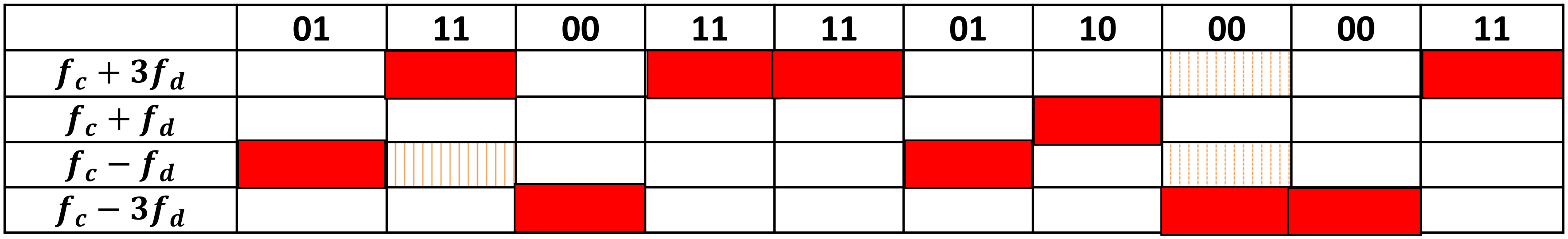
If T is the time for one bit, the $T_s = LT -$ time for sequence of bits representing the combination

Total bandwidth required is $W_d = 2Mf_d$ or M/T_s due to $2f_d = 1/T_s$

Analog and digital data transmission

2. Digital data-analog signal:

example: MFSK with $M = 2^L = 4$ (4 combinations for two bits $T_s = LT$, $L = 2$)



3. Analog data-digital signal:

- pulse code modulation PCM,
- analog-to-digit conversion ADC,
- delta modulation DM

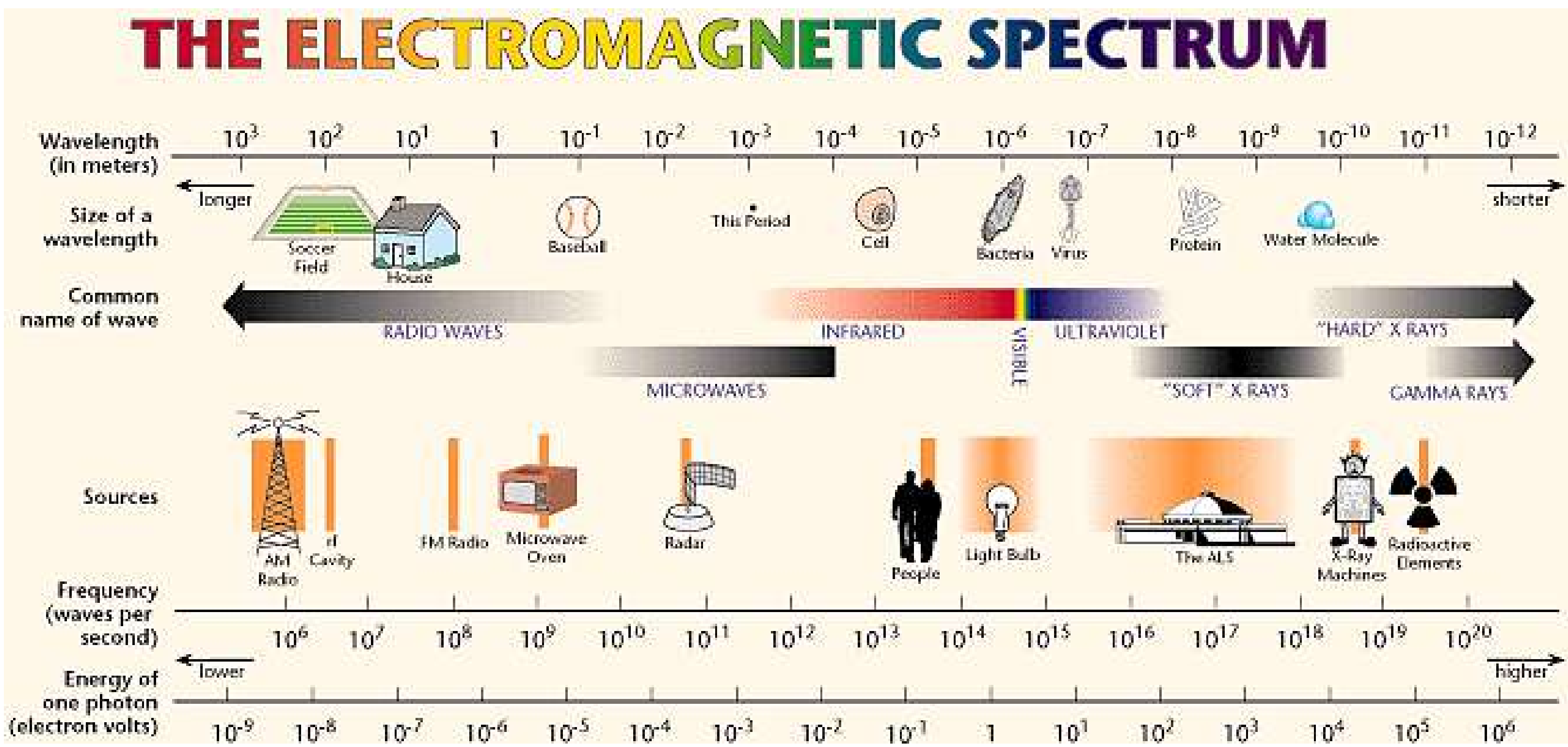
4. Analog data analog signals

- amplitude modulation AM
- frequency modulation FM
- phase modulation PM

1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

- Wireless communications are provided via unguided transmission media, usually using omnidirectional antenna on low frequencies and directional antenna on high frequencies
- Three general ranges of frequencies are of interest for wireless communications:

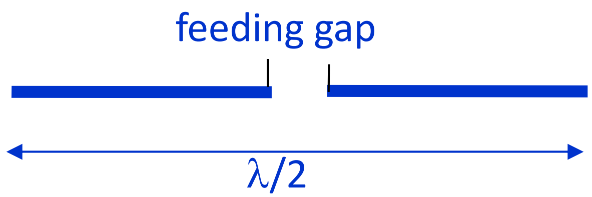
1. $f = 30MHz - 1GHz$ are suitable for omnidirectional applications – **radio range**
2. $f = \ 1GHz\_40\mathrm{GHz}$ **microwave frequencies** for point-to-point using directional beams
3. $f = \ 13 * 10^{11}Hz$ to $2 * 10^{14}Hz$ is **infrared portion** of spectrum suitable for point-to-point and multipoint applications within confined area (room)



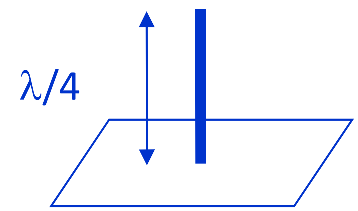
1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

Antennas and Propagation

- Antenna is used for irradiating the electromagnetic energy to/from space (omnidirectional (isotropic-hypothetical) or directional applications)
- Two of the simplest and most basic practical antennas are:

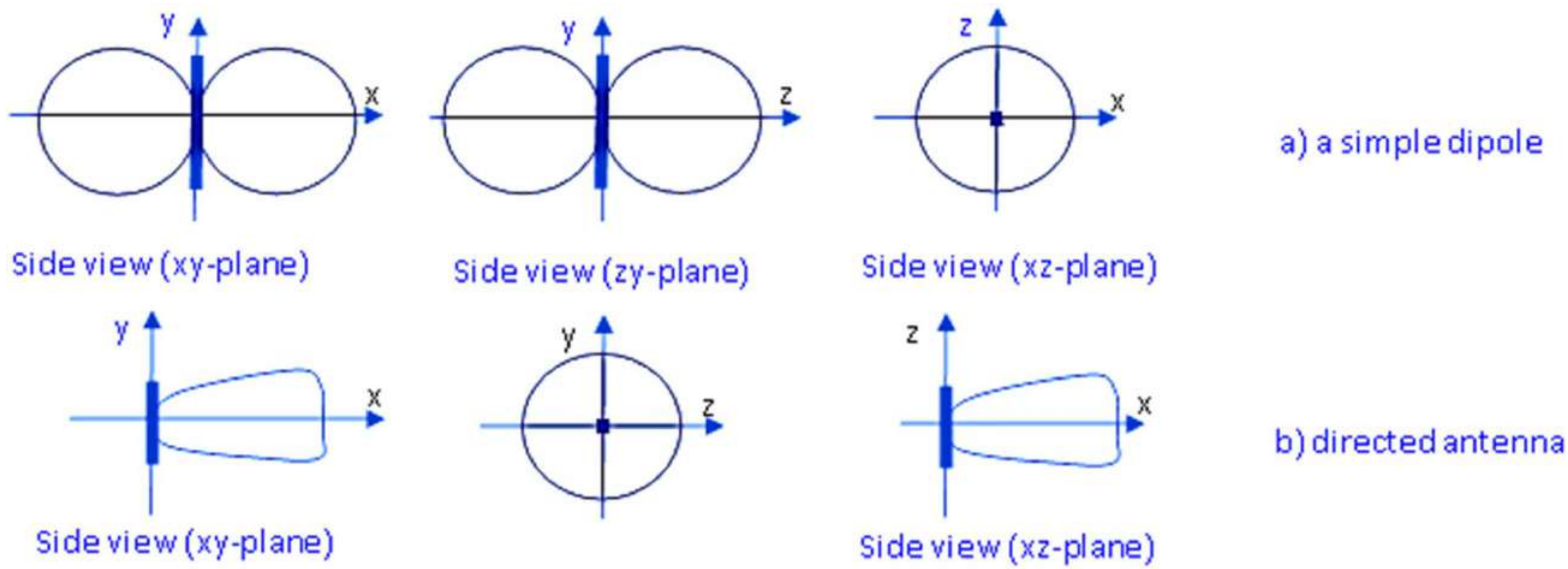


half-wave dipole or Hertz antenna



vertical quarter-wave or Marconi (Hertz) antenna

- Hertz antenna has uniform or omnidirectional radiation pattern in one dimension other patterns in next two dimensions *a).* A typical directional radiation patterns are in *b)*

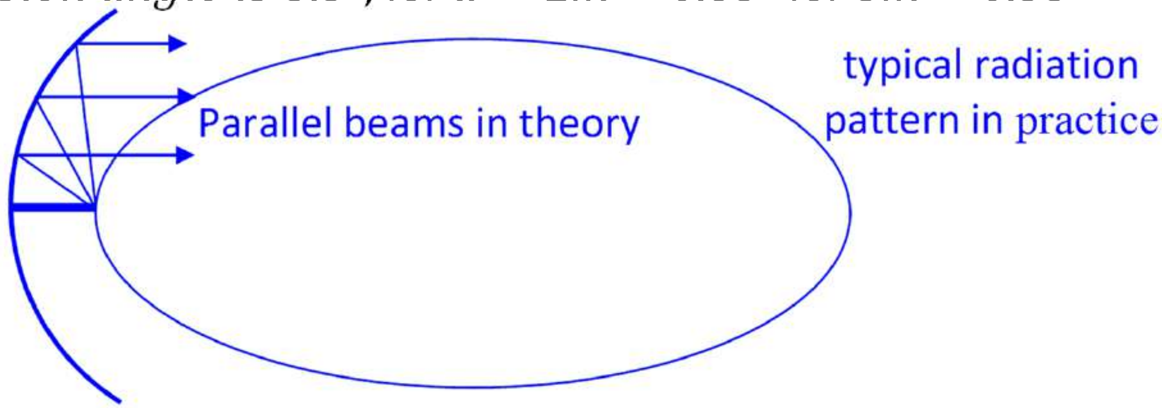


1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

Antennas and Propagation

- Parabolic reflective antenna is used in terrestrial microwave and satellite applications
- The parallel lines generates a beam but in practice there is dispersion.
- More diameter of antenna tightly directional is a beam

example: for $d = 0.5\ beam\ dispersion\ angle\ is\ 3.5°$, for $d = 2m - 0.85°$ for $5m - 0.35°$



The measures of antenna gain is defined by effective area of antenna:

$$G = \frac{4\pi * A_e}{\lambda^2} = \frac{4\pi * f^2 * A_e}{c^2}$$

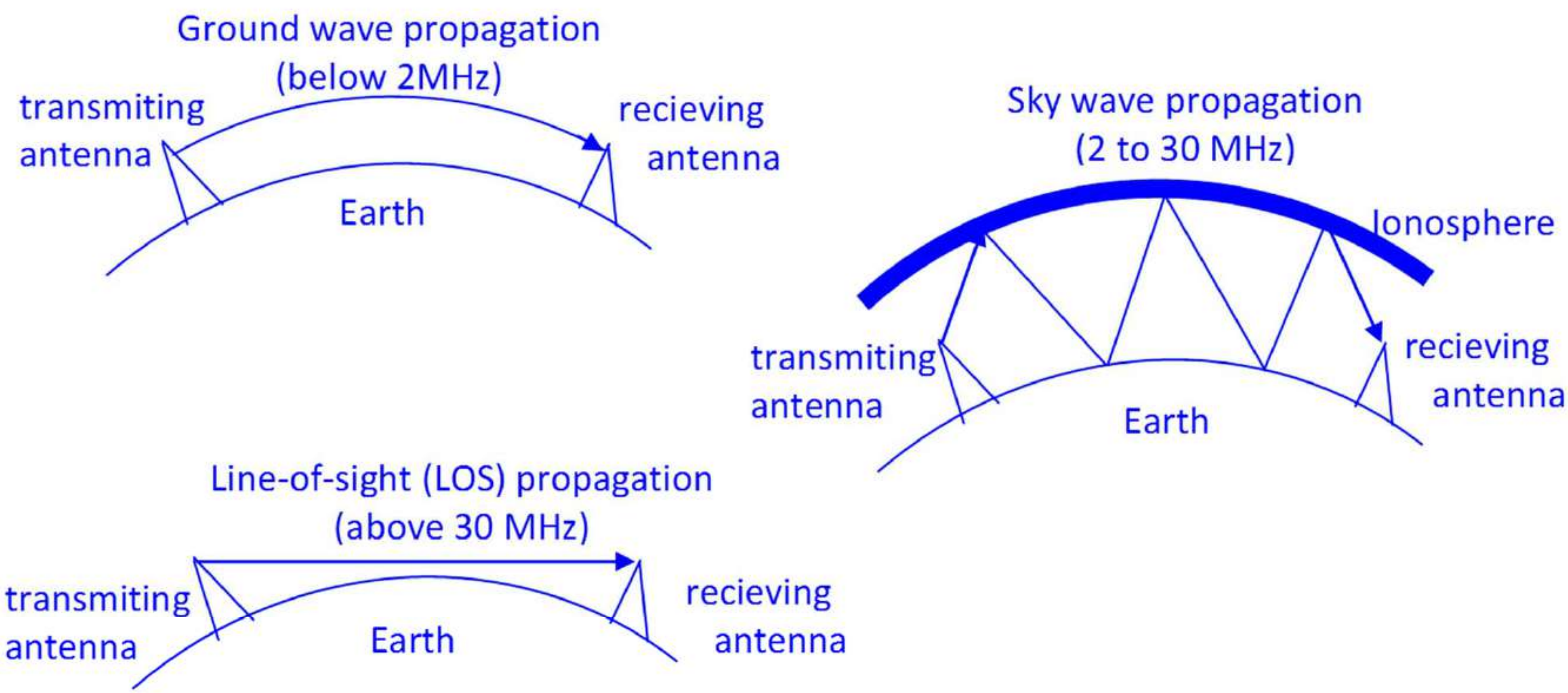
- where G - is the gain , A_e - effective area, f – carrier frequency, c – speed of light $(3 * 10^8 m/s)$, λ - carrier wavelength

Type of antenna	Effective area A_e (m^2)	Power gain(relative to isotropic)
Isotropic	$\lambda^2/4\pi$	1
Half-wave dipole	$1.64\ \lambda^2/4\pi$	1.64
Parabolic face area A	0.56 A	$7\ A/\lambda^2$

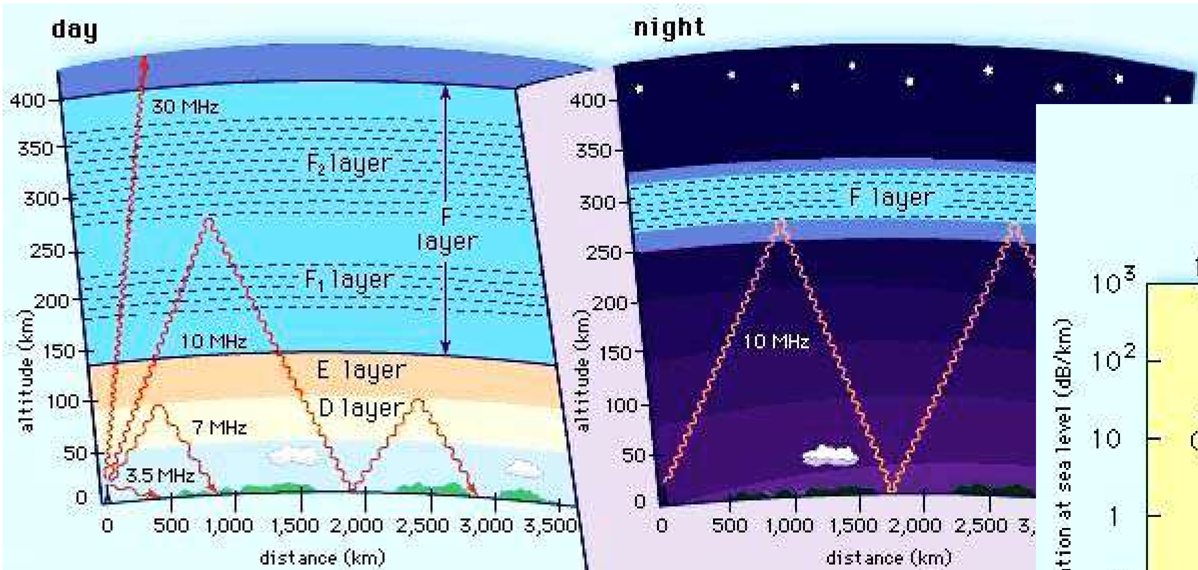
1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

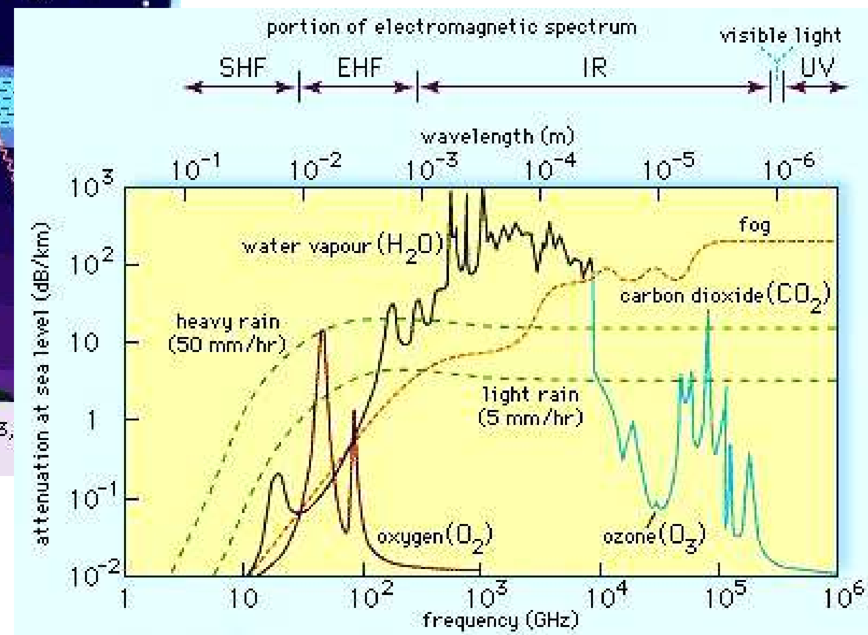
Antennas and Propagation

- There are 3 propagation modes for wireless communications when signals from antenna travel along:

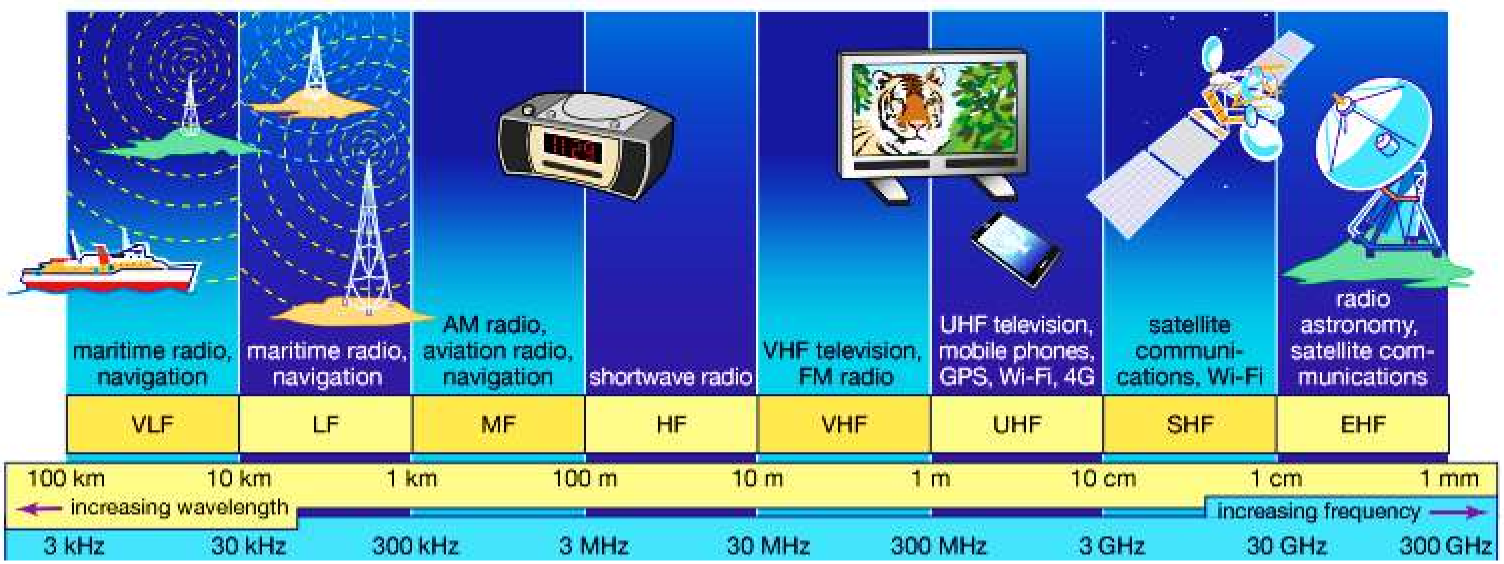


1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

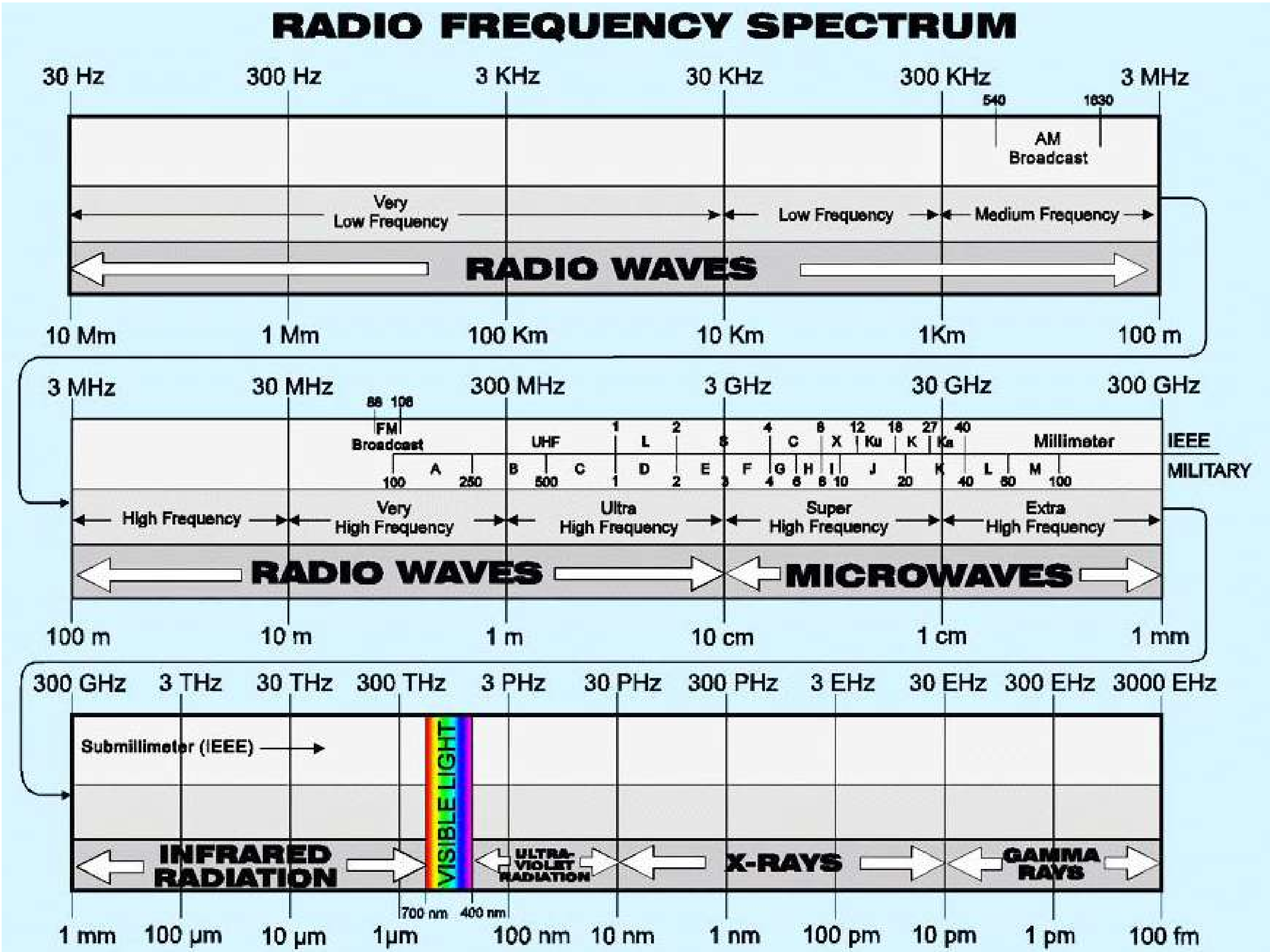




- The frequency bands classification and wireless applications



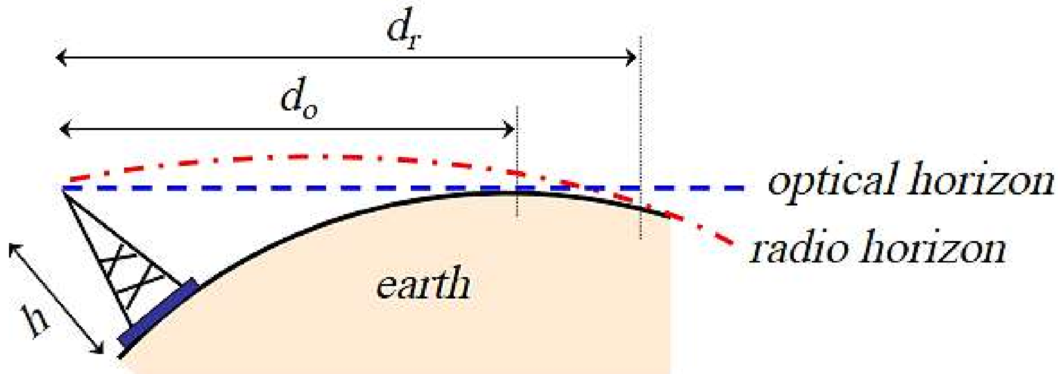
1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES



1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

Antennas and Propagation

- **Refraction** is another propagation mode of electromagnetic waves that depends on the density of medium (changing the velocity of propagation comparing with vacuum).
- So, the speed of radio waves is more slowly near the ground than at higher altitudes.



- Relationship between antenna height $h(m)$ and distance between antenna and horizon $d(km)$:

- for optical horizon: $d_o = 3.57\sqrt{h}$

- for effective or radio horizon:

$$d_r = 3.57\sqrt{Kh} \text{ where } K \text{ is an adjustment factor for refraction, } K = 4/3$$

- for maximum distance d between two antennas for radio horizon propagation:

$$d = 3.57\left(\sqrt{Kh_1} + \sqrt{Kh_2}\right)$$

1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

Attenuation and attenuation distortion

- Strength of signal falls down in unguided medium due to factors such as:
  - received signal must have sufficient strength so that receiver can interpret the signal
  - signal must maintain a level sufficiently higher than noise to be received without error
  - attenuation is greater at higher frequencies causing distortions (atmospheric absorption: due to water vapor on 22GHz, oxygen on 60 GHz).

Free Space Loss is measure for ideal omnidirectional antenna (signal dispersion vs distance)

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

P_t- transmitting antenna signal power; P_r- receiving antenna signal power; $\lambda(m)$ – carrier wavelength; $d(m)$– propagation distance between antennas, $c(m/s)$–speed of light

Free space loss is better to express in dB as

$$L_{dB} = 10\log_{10}\frac{P_t}{P_r} = 20\log_{10}\frac{4\pi d}{\lambda} = -20\log_{10}(\lambda) + 20\log_{10}(d) + 21.98dB =$$
$$= 20\log_{10}\left(\frac{4\pi f d}{c}\right) = 20\log_{10}(f) + 20\log_{10}(d) - 147.56dB$$

- L_{dB} of other antennas is computed taking into account their effective areas A_t and A_r

$$L_{dB} = 20\log_{10}(\lambda) + 20\log_{10}(d) - 10\log_{10}(A_t A_r) =$$
$$= -20\log_{10}(f) + 20\log_{10}(d) - 10\log_{10}(A_t A_r) + 169.546dB$$

1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

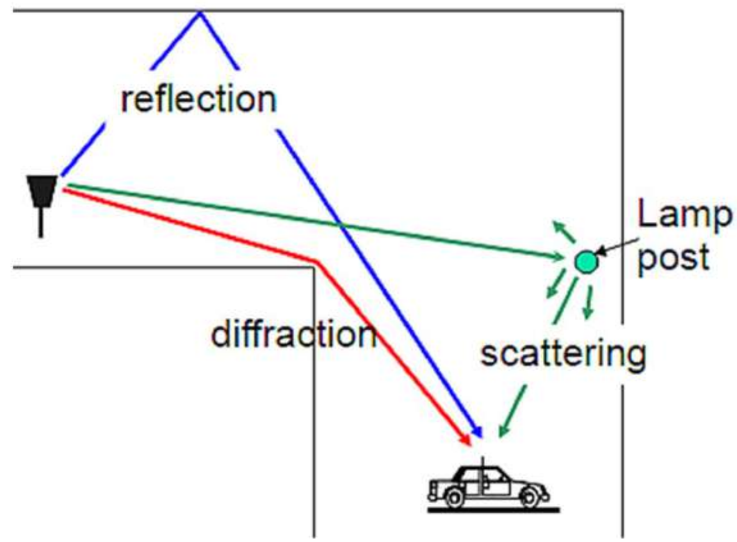
Wireless propagation mechanisms

- On contrast to line-of-sight propagation the presence of obstacles results multipath propagation when receiver may receive multiple copies of signal with delay due to:

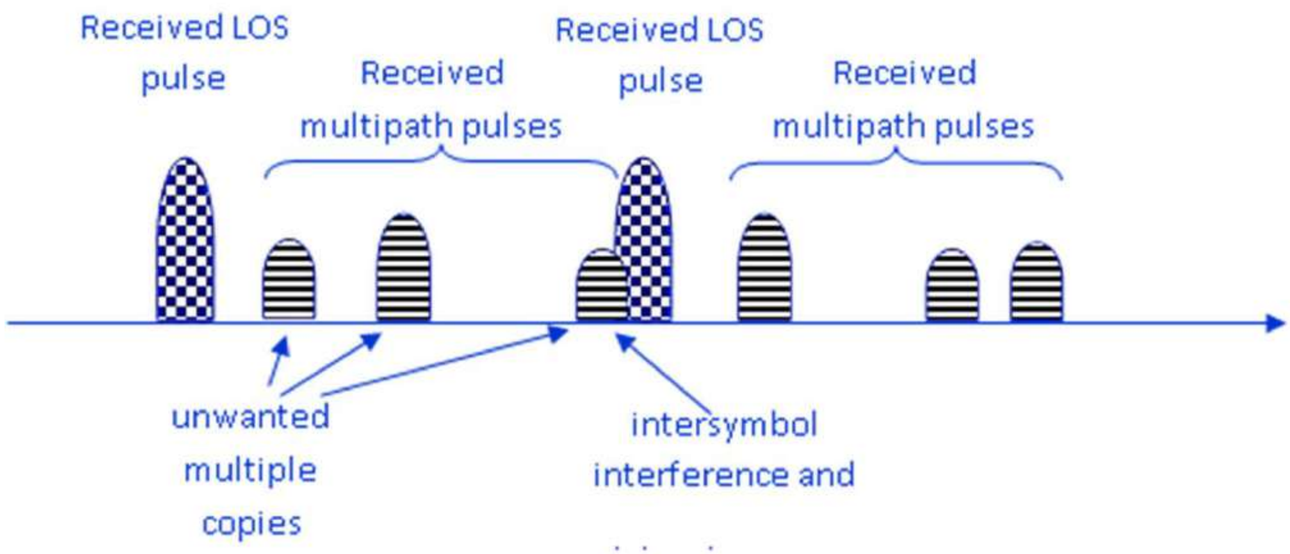
- reflection when there is a surface that is large relative to the wavelength of the signal

- diffraction is due to changing the direction in corners of impenetrable obstacle that is larger than signal wavelength

- scattering when incoming signal hits an object whose size is of the order or less of the wavelength of signal



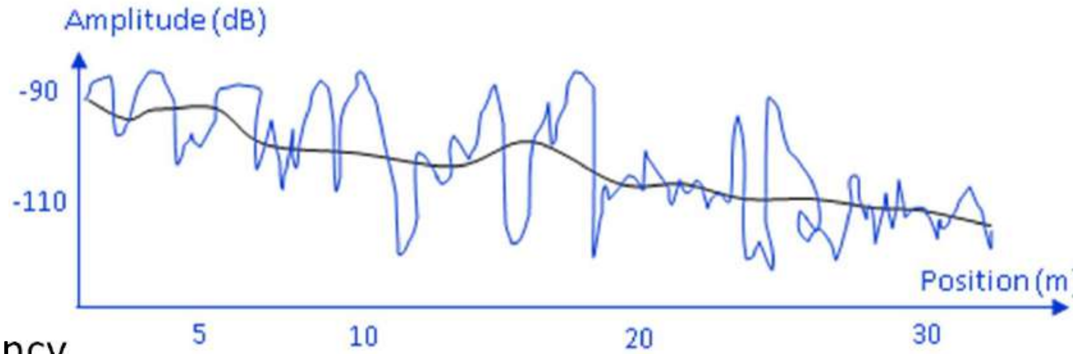
- Effect of multipath propagation



1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

Wireless propagation mechanisms

- **Fading** refers to the time variation of received signal power caused by changes in the transmission medium or path.
- In fixed environment fading is due to changing the atmospheric conditions, in mobile – the relative location of various obstacles that are changed over time creating complex transmission effects



- Fading classification:

- fast fading – rapid variations in signal strength (20-30dB) over distances of about one-half a wave-length (at frequency of cell applications 900MHz the wavelength is about 0.33 m)

- slow fading – on the longer well covered by waves distances there is changes in average received power level about which the rapid fluctuation occur.

- flat fading – (non-selective fading) **–** frequency components of the received signal fluctuate in the same proportion simultaneously

-selective fading – affects unequally the different spectral components of signal

- **Rayleigh fading** – there are multiple indirect paths between transmitter and receiver and no distinct dominant path, such as LOS path

- **Rician fading** – there is direct LOS path in additional to number of indirect multipath signals

1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

Wireless propagation mechanisms

- For designing of communication system the effects of fading must be estimated according some channels models:

- The simplest is additive white Gaussian noise (AWGN) channel assumes only thermal noise in physical channel of transmitter and receiver (it is not good for wireless communications)

- Another is Rayleigh fading which take into account complex paths between transmitter and receiver without distinction dominant LOS path (good but not real for wireless with dominant LOS paths)

- Last one is Rician fading – the best where the direct LOS path with addition to some of indirect multipaths are analyzed . The channel is characterized by parameter K that is

$$K = \frac{power\ in\ dominant\ path}{power\ in\ scattered\ paths}$$

if $K = 0$ the channel is Rayleigh and if $K = \infty$ the channel is AWGN

1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

Error and distortions compensation mechanisms

- The compensation mechanisms are classified as: forward error correction, adaptive equalization and diversity techniques

- forward error correction used for digital transmission when the receiver correct errors using only incoming sequence of bits (forward).

In contrast to **backward correction** when receiver detects the presence of errors and sends NAK to transmitter for retransmission – is not practical in mobile communications.

Operations are based on additional bits in error correction codes VLRC, CRC, Hamming…

In the wireless applications the ratio of all sent data to error correction bits is 2 or 3 (a lot of additional bits – overhead but it is useful)

- adaptive equalization is used for analog or digital data to resolve the intersymbol interference.

It is based on gathering dispersed symbol energy back to the original interval on base of so-called lumped analog signals and sophisticated digital signals processing algorithms.

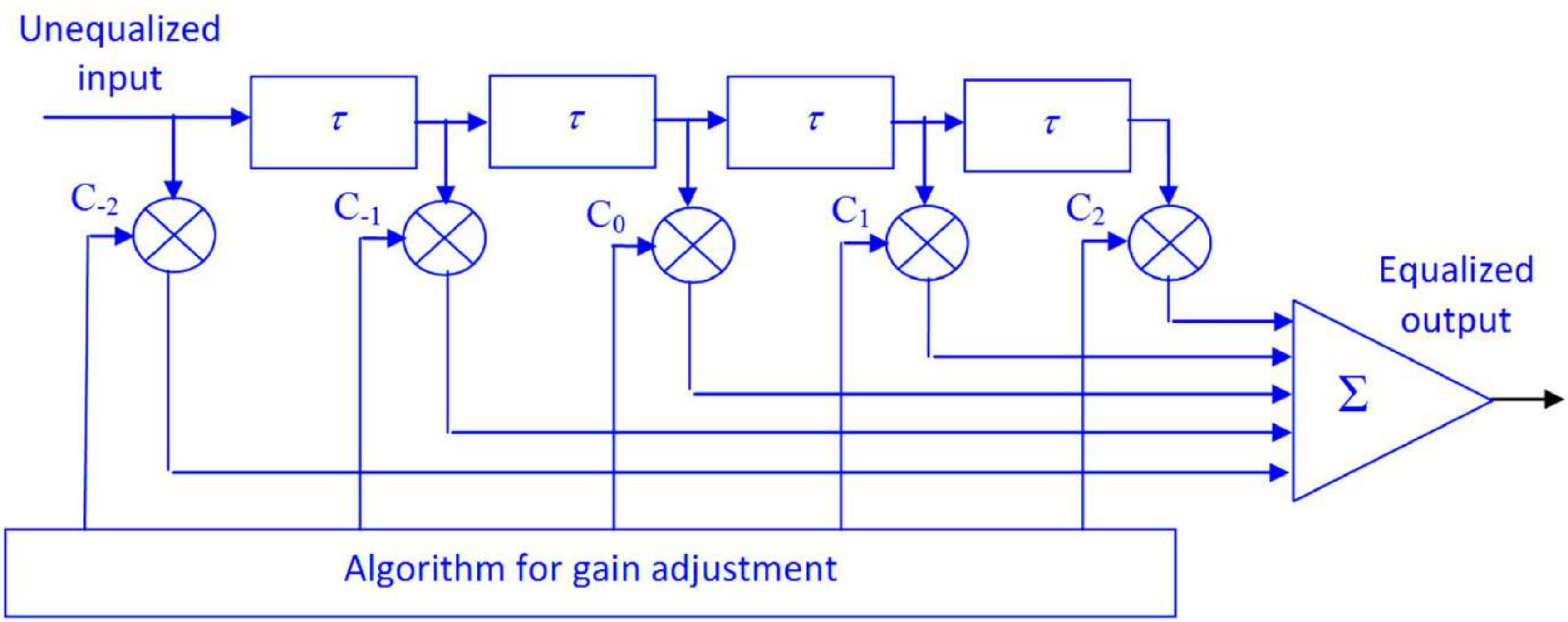
1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

Error and distortions compensation mechanisms

example: Linear equalized circuit where signal is sampled at *5* spaced intervals of time separated by delay τ.

These samples are individually weighted by the coefficient C_i and then all are summed.

The process is adaptive due to coefficients are dynamically updated and sent periodically to receiver which compares this *training sequence* with expected one and calculates its proper coefficients.



1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

Error and distortions compensation mechanisms

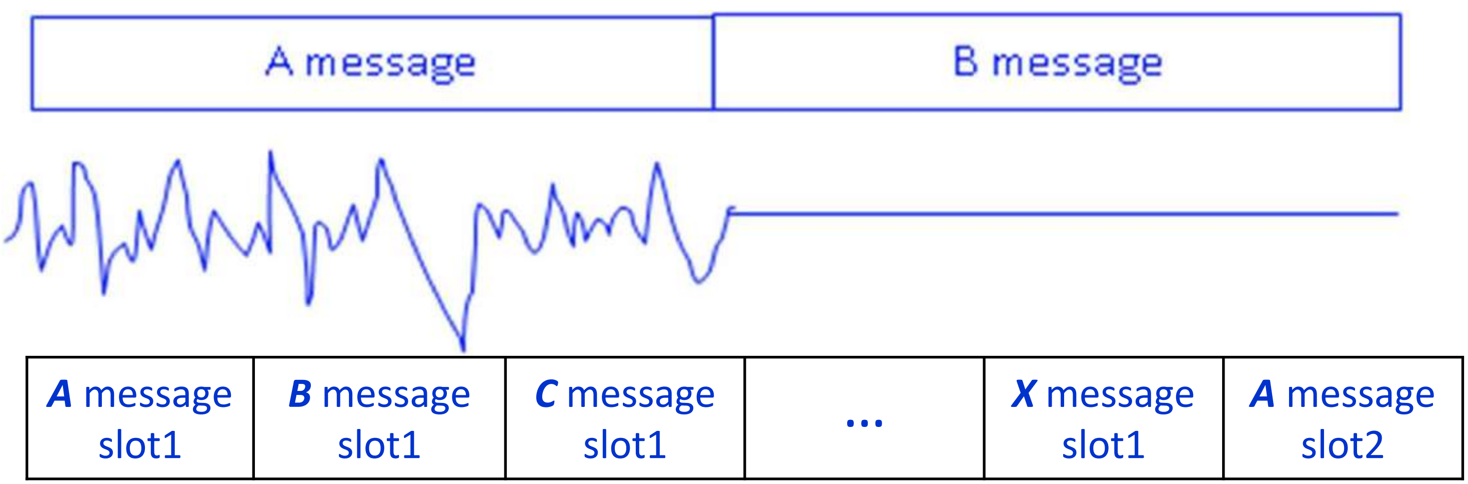
- diversity techniques – compensate the errors by providing the multiple channels and sending the portions of information over each channel

There are **space diversity** (nearby antennas), **frequency diversity** (using wider bandwidth or multiple frequency carriers (spread spectrum) and **time diversity** – using the portion of different frames as it made in TDM.

The idea is reduce the number of bits in slot for more effective forward correction

example: 1. suppose that fading is applied to whole *A* message that produce significant errors

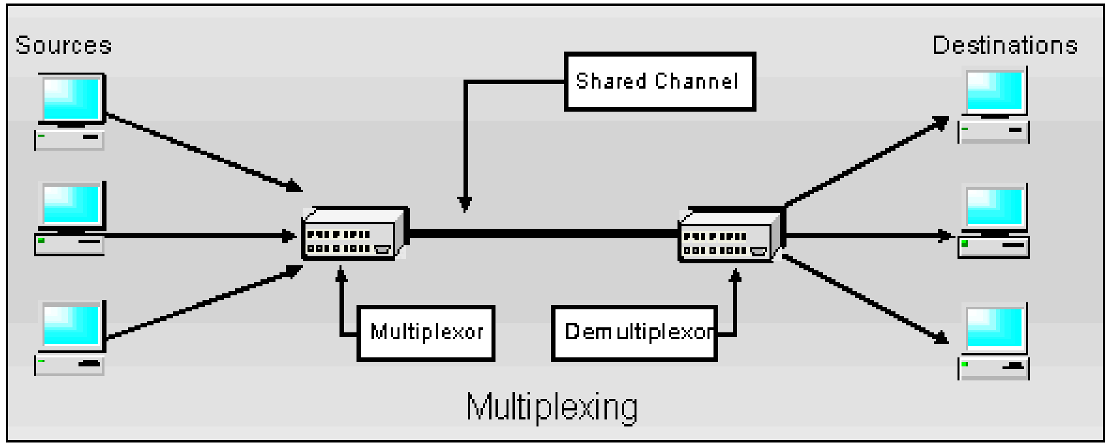
2. using TDM the fading affects less number of bits of *A* and error rate may be reduced by more efficient forward correction because it is applied to small number of bits



1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

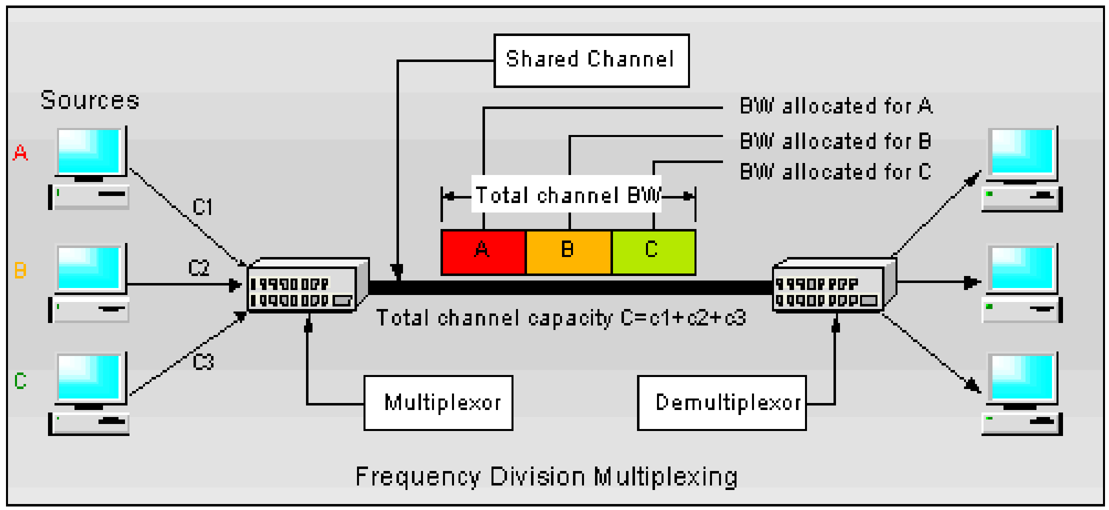
Multiplexing

- Multiplexing is used for transmission of data from multiple sources via unique line or media with limited bandwidth.



Individual stations at source generate their signals and each sends its signal to a multiplexor.

The multiplexor multiplexes, i.e. aggregates, signals from different stations into a different frequency channels (FDM)or into single stream that contains portions of input signals (TDM)



- Frequency division multiplexing

The frequency bandwidth known as capacity, of transmission medium is divided into segments of smaller bandwidths (bands, sub-channels)

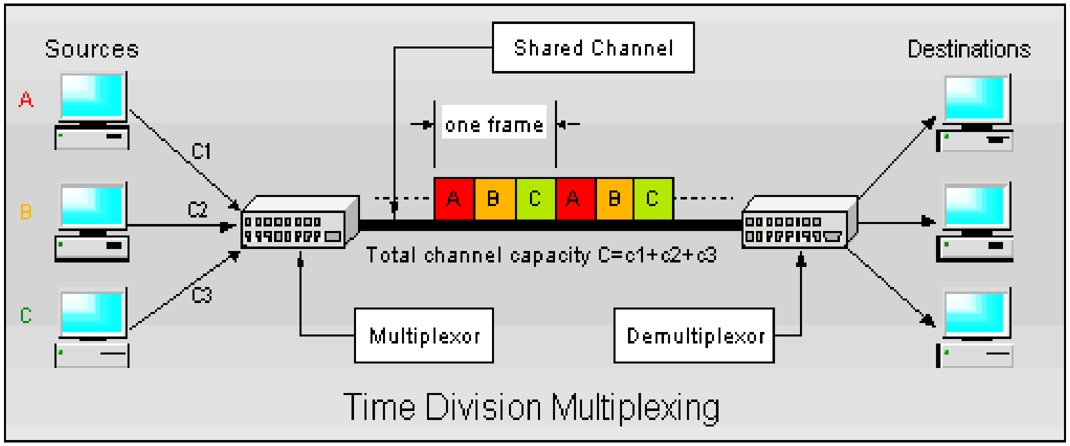
1.4 TRANSMISSION MEDIA ACCESS TECHNIQUES

Multiplexing

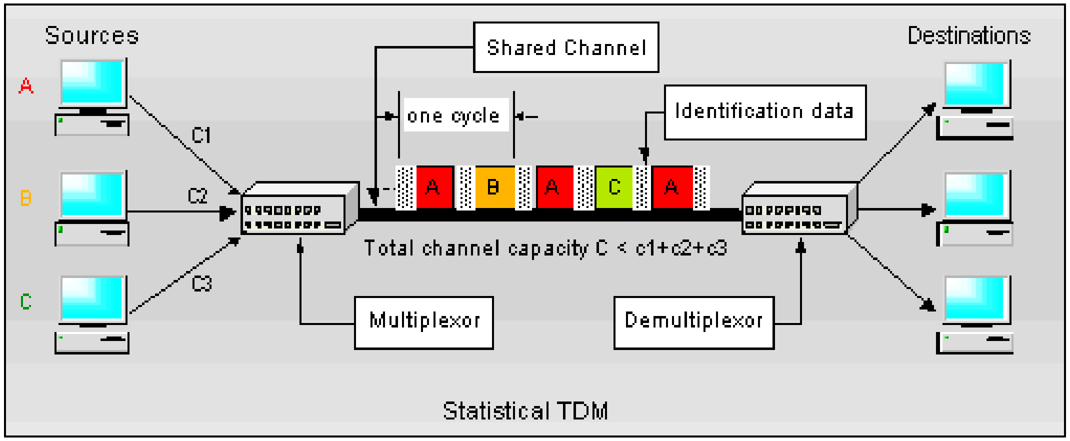
- Time division multiplexing

Digital bandwidth (in bps), also known as capacity, is divided into equal sized time frames.

Each frame consists of equally sized slots Slots at the same chronological location in the frames are designated as channel and are assigned to one specific pair of users (**synchronous TDM**)



Using **statistical TDM** slots are assigned to channels if they have data to transmit removing empty time slots



- However,
  for wireless communication is not always possible to use these types of multiplexing