COMMUNICATING BY ELECTROMAGNETIC WAVES TO 7G

From book WRITINGS II by Irina Rodica Rabeja

The communication is an intrinsic feature of the human society, communicating between entities or groups of people has been always important in the everyday life of humans.
Communication is the activity or process of giving messages or information to others using signals such as speech, body movements or radio signals.
The goal of any communication is to connect and to transmit information.
The word “communicate” comes from the Latin word “communicare” meaning “to share”.
The human communication was revolutionized with speech approximately 200,000 years ago, the symbols were developed about 30,000 years ago and the writing appeared about 7,000 years ago.
The communication over a distance, called *telecommunication* - a compound word with the Greek prefix “tele” meaning "far off" - began thousands of years ago with the use of *fire/smoke signals* and *drums/horns* in Africa, America and parts of Asia. Later appeared *mail* in 6th century BC, *pigeon post* in 5th century BC, *hydraulic semaphores* in 4th century BC, *heliographs* in 490 BC, chains of *beacons* in Middle Ages, *maritime flags* in 15th century.
The French inventor **Claude Chappe** (1763-1805) designed the *visual telegraphy system* or *semaphore* between Lille and Paris in 1792 year, which was the first telecommunication system of the industrial age.
The American painter and inventor **Samuel Finley Breese Morse** (1791-1872) developed and patented a *recording electric telegraph* in 1837 year and co-invented with the American machinist and inventor **Alfred Lewis Vail** (1807-1859) the Morse code signalling the alphabet in 1838 year. The first telegrams were sent by Morse on 11 January 1838 across 3 km of wire at Speedwell Ironworks near Morristown New Jersey USA and in 1844 over 71 km of wire from the Capitol in Washington to the old Mt. Clare Depot in Baltimore USA, the latter messaging: WHAT HATH GOD WROUGHT? (Archaic from Bible for "what has God done?")
From then on, commercial telegraphy became successful and popular in America with lines linking in the next decade all the major metropolitan centres on the East Coast.
The *first successful telegraph cable across the Atlantic Ocean* was laid in 1866 year.
Australia was first linked to the rest of the world in October 1872 by a submarine telegraph cable at Darwin.

The American electrical engineer **Elisha Gray** (1835-1901) and the Scottish-American scientist, engineer, inventor **Alexander Graham Bell** (1847-1922) invented the *telephone* same year 1876.
Elisha Gray and Alexander Graham Bell controversy concerns the question of whether Gray and Bell invented the telephone independently.
The first *commercial telephone services* started between New Haven USA and London UK in years 1878-1879.
The *first telegraph cable across the Pacific Ocean* was completed in 1903 year when finally, the telegraph encircled the world. The cable carried the first message to ever travel around the globe, from USA President Theodore Roosevelt on July 4, 1903. He wished "a happy Independence Day to the USA, its territories and properties". The message took nine minutes to travel worldwide.
"Telegraph" and "telephone" are words with Greek language roots: "graph" meaning "written symbol" and "phone" meaning "sound" beside the prefix "tele" meaning "far off".
The telegraph and the telephone were electrical devices connected by wires or cables.
After them, appeared a variety of experimental techniques for communicating telegraphically "without wires" such as photoelectric and induction telegraphy.
They preceded the "wireless" telegraphy systems, which communicated by "radio waves" and were developed by the Italian inventor **Guglielmo Marconi** beginning in1895 year.
The term "wireless" is derived from the fact that communication may be effected between two points without the aid of wires connecting the points. The term "radio" is derived from the fact that the electromagnetic energy released into space is radiated in all directions.
By 1910 year, the term wireless telegraphy has been largely replaced by the more modern term "radiotelegraphy". In 1912 year, US Navy adopted the term "radio-communication".
The transmission of sound by radio waves or "radiotelephony" began by the 1920s, further making possible radio broadcasting.
"Wireless communication" is the transfer of information between two or more points that are not connected by physical link (an electrical conductor/wire).
The communication by radio waves has been most commonly form of wireless communication.
Non-common methods of achieving wireless communications had been considered the light, the magnetic or electric fields or the sound.
The distances encompassed by electromagnetic waves can be short, few meters for television remote control, or very long, millions of kilometres for deep-space radio communications.
The communication by electromagnetic waves encompasses various types of fixed, mobile or portable applications, including two-way radios, cellular telephones, personal digital assistants PDAs - handheld devices that combines computing, telephone/fax, Internet and networking

features. Also includes cordless telephones, garage door openers, wireless computer mice, keyboards and headsets, headphones, radio receivers, satellite television, broadcast television and GPS units.

Wireless communications is a broad and dynamic field that has generated great interest and technological awareness over the last few decades.

The use of wireless technology has grown dramatically over the past two decades.

Wireless icon/sign/symbol

The number of wireless devices worldwide has increased exponentially over the past decade, with consumer requirements for faster data rates and longer life devices. The former led to considering for wireless applications electromagnetic waves with frequency above 24 GHz.

More, the Mobile Communications Industry is on the way to connect the World with devices such as smartphones, tablets, wearables and everyday objects, a device revolution that is impacting lifestyles, businesses and institutions. These devices are gaining the ability to communicate wirelessly with each other and with remote locations via sensors, beacons and other data gathering and broadcasting technologies.

That represents the evolutionary role of the device toward becoming a network or relay node.

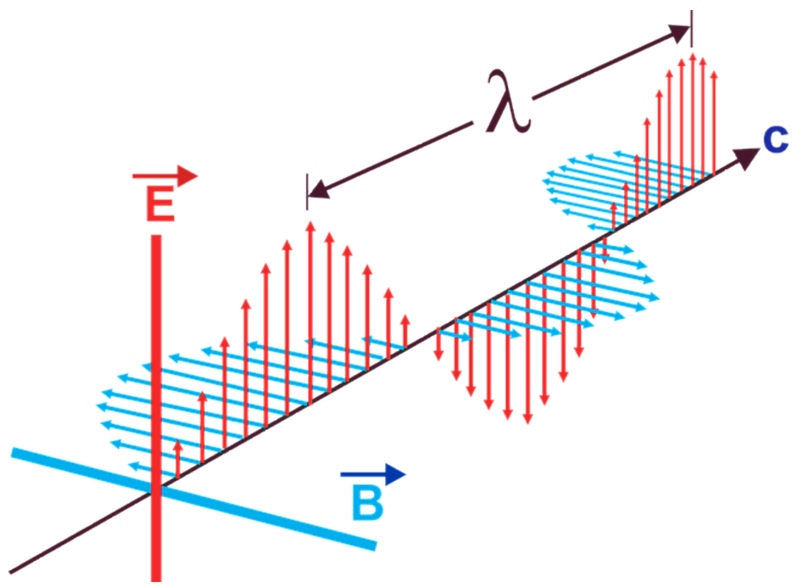
Technologies for communicating, storing, distributing data such as cloud, mesh, device-to-device D2D, peer-to-peer P2P are the key enablers of such a trend.

Inside those devices there are large numbers of sophisticated components such as processors, modems, sensors, chipsets, radios and battery growing in complexity and numbers; driven by cost and performance improvements in digital technologies, their prices lower making easier to incorporate sophisticated multiple functionalities into devices. Consumer demand for mobile data is exponential and shows no signs of slowing, the consumed mobile data of over 10 Exabytes per month in 2014 year is projected to increase over 70 Exabytes per month by 2020 year.

The Internet of Things IoT is the next big thing in the wireless revolution. It is a natural evolution of the Internet and, as the name suggests, goes beyond the connection of people to the Internet by connecting 'things' such as machines and sensors.
And the use of Low Power Wide Area Networks LPWANs as the communications medium will be the "killer application" that will invade the world creating other millions of applications and implementations over the next decade.

ELECTROMAGNETIC WAVES

The stationary electric charged objects produce an electric field E and the moving electric charged objects produce a magnetic field B.
The combination of the electric field and the magnetic field is the electromagnetic field EMF.
The electric and magnetic fields have around two types of actions:
- non-radiative (near field) action - power is transferred by inductive coupling between coils of wire (most widely used) or by capacitive coupling between metal electrodes.
- radiative (far-field) action - power is transferred by electromagnetic radiation between antennas.
In Physics the electromagnetic radiation EMR refers to the electromagnetic waves EMW of EMF.
The EM waves propagate through space, carrying electromagnetic radiant energy.



This diagram shows a linearly plane polarized EM wave propagating.
The electric field **E** is in a vertical plane and the magnetic field **B** is in a horizontal plane.
The electric and magnetic fields in EM waves are always in phase and at 90 degrees to each other.
EM waves travel in space at the speed of light **c** = 299,792,458 m/s.
"Plane polarization" of electromagnetic radiation is called the confinement of the electric field vector **E** or the magnetic field vector **B** to a given plane along the direction of propagation. Orientation of "linearly" polarized electromagnetic wave is defined by the direction of **E**. Above EM wave is vertically polarized.

The electromagnetic radiant energy exists everywhere in the universe, it is invisible and works in ways that are still something of a mystery to scientists. In historical terms, the humans harnessed it only some over 100 years ago for communication, which is the transmission of human intelligence and yet the social impact of this new means of communication has been nothing less than phenomenal.

Some say that the historical impact of wireless communications seems as revolutionary for the world as Gutenberg's moveable-type printing press was in the 15^{th} century.

Printing was introduced to Europe by the German blacksmith, goldsmith, engraver, printer, publisher and inventor **Johannes Gensfleisch zur Laden zum Gutenberg** (1400-1468).

His mechanical movable-type printing press started the "printing revolution" and is widely regarded as the most important invention of the second millennium.

Electromagnetic waves are synchronized, self-sustaining double oscillations, one of the electric field **E** and the other of the magnetic field **B**, that propagate perpendicular to the direction of propagation and perpendicular to each other.

The electromagnetic waves travel in space at the speed of light c = 299,792,458 metres/second.

When travel in an object, the waves are slowed according to that object's magnetic permeability μ and electric permittivity ε.

An electric or magnetic wave is characterized by amplitude, wavelength, frequency and phase.

Amplitude of wave is basically the height of the wave, marked E for electric wave and B for magnetic wave. Between E and B there is the relation $E = cB$.

Wavelength of wave, denoted by Greek letter **λ**, is the distance from one 'peak of wave' to next.

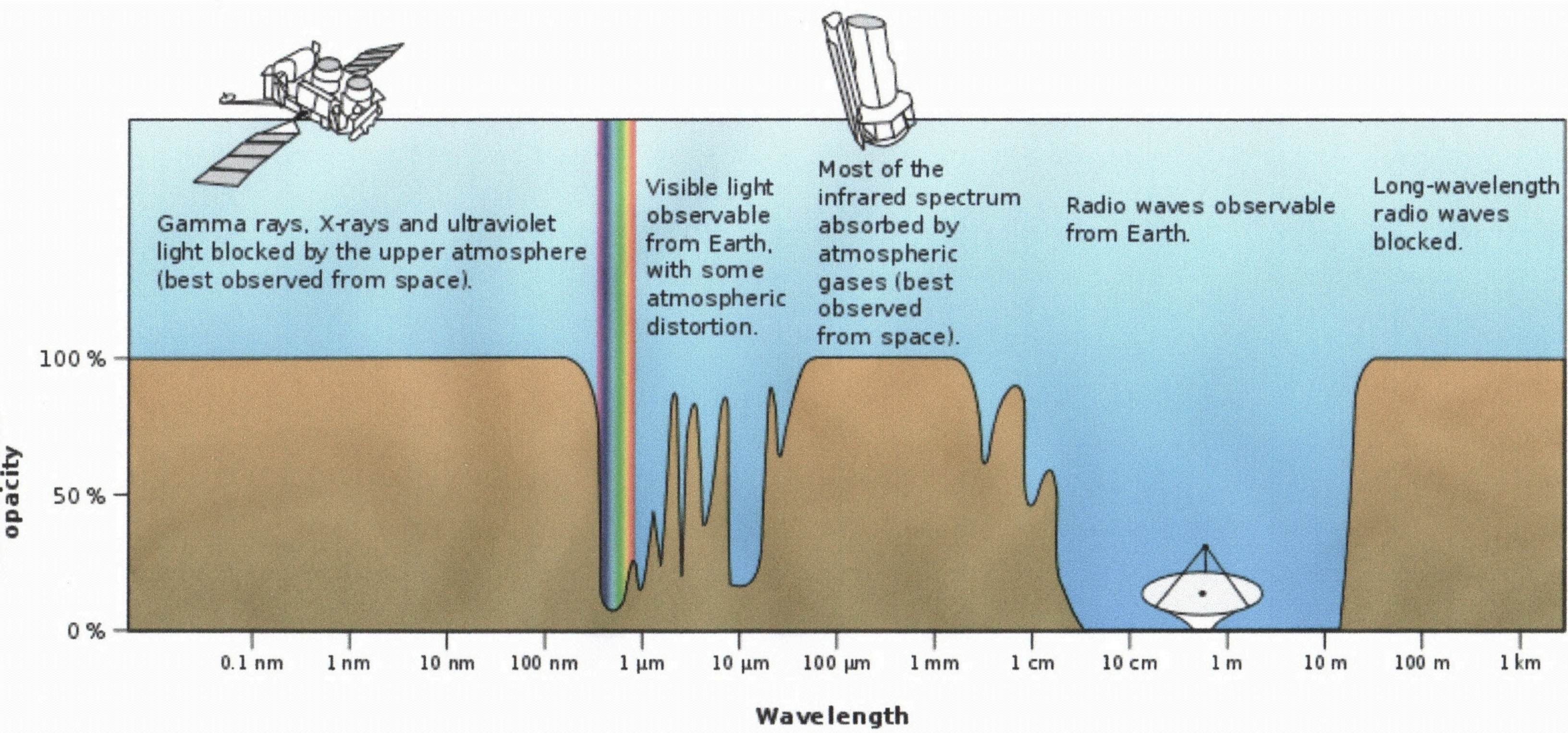
Frequency of wave, denoted by letter f, is the number of 'peaks' per second. Between λ and f there is the relation $f = c/\lambda$.

Phase of wave, denoted by Greek letter φ, is the position of a point on the wave.

The manifestation of the electromagnetic field is the *electromagnetic interaction*, one of the four fundamental interactions of Nature, beside gravitation, weak interaction and strong interaction.

In Quantum Physics the electromagnetic radiation EMR consists of photons, the elementary particles responsible for all electromagnetic interactions. Quantum effects give additional sources of EMR, such as the black-body radiation and the transition of electrons in an atom from high to lower energy levels.

The energy of an individual photon is quantized and is greater for photons of higher frequency in conformity to Planck's equation $E = h\nu$, where E is energy per photon, ν is frequency of photon and h is Planck's constant. As example, a single gamma ray photon could carry over 1 million times the energy of a single photon of visible light.



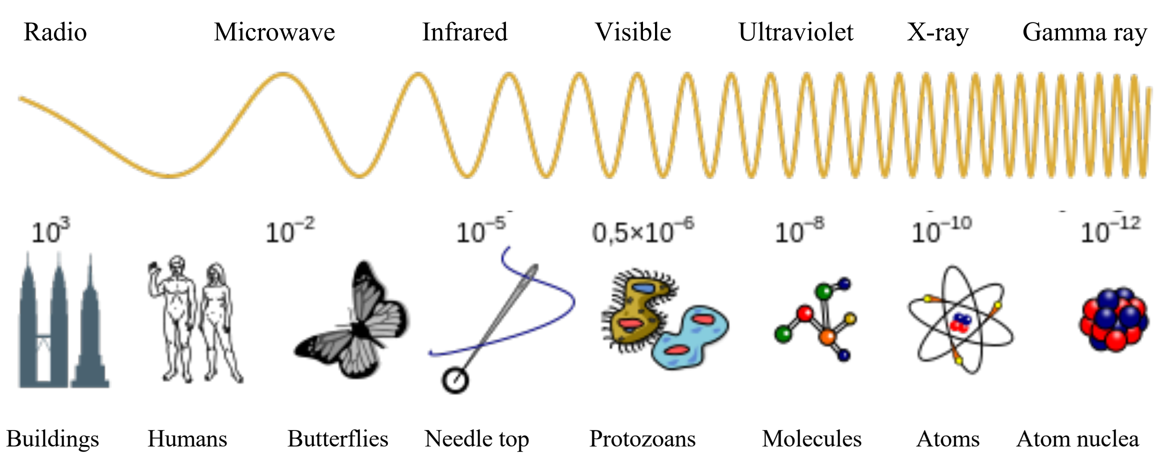
EARTH ATMOSPHERE ELECTROMAGNETIC OPACITY

In Nature the electromagnetic waves are created by lightning or by celestial bodies.
The regions of the electromagnetic spectrum that pass largely un-attenuated from space through the Earth atmosphere are called “windows”. The Earth atmospheric electromagnetic transmittance or opacity is illustrated in the previous image.
The range of all possible electromagnetic waves of the electromagnetic radiation, in all their possible lengths or frequencies, is called the *electromagnetic spectrum*.
Across its spectrum, the electromagnetic radiation interacts with the matter in different ways like would be more types of radiation. The spectrum is divided related to these qualitative interaction differences, but the reason invoked is the wavelength, respective the frequency of the electromagnetic waves. So, function of their wavelengths the range of electromagnetic waves is divided in 7 main groups: Radio, Microwave, Infrared, Visible, Ultraviolet, X and Gamma.
The boundaries between some could vary arbitrary in their use for different human activities.

Electromagnetic waves

Name	*Wavelength*	*Frequency*
Radio	100,000 km - 0.1 mm	3 Hz - 3 THz
Microwave	1 m - 1 mm	300 MHz - 300 GHz
Infrared	1 mm - 750 nm	300 GHz - 430 THz
Visible	750 nm - 390 nm	430 THz - 770 THz
Ultraviolet	390 nm - 10 nm	770 THz - 30 PHz
X	10 nm - 10 pm	30 PHz - 30 EHz
Gamma	< 10pm	> 30 EHz

Electromagnetic waves of different wavelengths (m) and their scales



Electromagnetic waves of different frequencies experience differences in reflection, refraction, polarization, diffraction, absorption and how move in free space and over the surface of Earth.
The electromagnetic waves are used by humans for different purposes, function of their different frequencies. They are used in communication, radar, radio astronomy, navigation, heating and power application, spectroscopy (interaction between matter and electromagnetic radiation), atomic absorption spectroscopy AAS (determination of around 70 elements), high-resolution imaging, medicine.
The communication by electromagnetic waves is also called "wireless communication" using mainly the radio waves and the microwaves.

Radio waves RW are the electromagnetic waves in the range of 0.1 mm-100,000 km for wavelength and in the range of 3 Hz-3 THz for frequency, including waves used for communication or radar signals.
Their main interaction with the matter is the collective oscillation of charge carriers in bulk material (plasma oscillation). An example is the oscillatory travels of the electrons in an antenna.
International Telecommunication Union ITU is a specialized agency of UN responsible for issues concerning information/communication technologies. Radio Regulations RR of ITU regulates on law of nations scale radio-communication services and utilisation of radio frequencies.
ITU divides the radio waves spectrum in 12 bands, denoted by symbols, each beginning at a wavelength that is a power of 10 and covering a decade of wavelengths (or frequencies).
That originated with a recommendation of the fourth meeting of the Consultative Committee on International Radio CCIR held in Bucharest, Romania in 1937 year and was approved by the International Radio Conference held in Atlantic City, New Jersey, USA in 1947 year.
B.C. Fleming-Williams in 1942 year suggested to give each band also a number, which is the logarithm of the approximate geometric mean of the upper and lower band limits in Hz, for example the approximate geometric mean of Band 6 is 10^6Hz.

ITU Radio Bands Symbols	ELF	SLF	ULF	VLF	LF	MF	HF	VHF	UHF	SHF	EHF	THF
ITU Radio Bands Numbers	1	2	3	4	5	6	7	8	9	10	11	12

Function of their frequency, the radio waves have different propagation characteristics in the Earth's atmosphere: the very high frequency ones travel on the line of sight, bend and reflect very little, the high frequency ones called sky waves can reflect on ionosphere and return to earth beyond horizon and the low frequency ones called ground waves have low attenuation, suitable for long distance communication because diffract around obstacles.

Radio waves created by men are generated by different devices and are used for fixed and mobile radio communication, broadcasting, radar, navigation systems, communications satellites, computer networks and others.
Like all other electromagnetic waves, the radio waves travel through space at the speed of light.

Radio waves

Band Number	*Band Symbol*	*Frequency Range*	*Wavelength Range*
1	ELF	3-30 Hz	10000-100000 km
2	SLF	30-300 Hz	1000-10000 km
3	ULF	300-3000 Hz	100-1000 km
4	VLF	3-30 kHz	10-100km
5	LF	30-300 kHz	1-10km
6	MF	300-3 MHz	100-1000m
7	HF	3-30 MHz	10-100m
8	VHF	30-300 MHz	1-10m
9	UHF	300-3000 MHz	10-100cm
10	SHF	3-30 GHz	1-10cm
11	EHF	30-300 GHz	1-10mm
12	THF	300 -3000 GHz	0.1-1mm

THF = Tera frequencies (far-infrared waves)

EHF = Extremely high frequency (microwaves)

SHF = Super-high frequency (microwaves)

UHF = Ultra-high frequency (radio waves)

VHF = Very high frequency (radio waves)

HF = High frequency (radio waves)

MF = Medium frequency (radio waves)

LF = Low frequency (radio waves)

VLF = Very low frequency (radio waves)

ULF = Ultra-low frequency (radio waves)

SLF = Super-low frequency (radio waves)

ELF = Extremely low frequency (radio waves)

Millimeter-wave mmW and *submillimeter-wavs* sub-mmW are radio spectrum bands in the range 0.3-3 mm / 100-1000 GHz and *terahertz wave* THz is radio spectrum band in the range 0.1-1mm / 300-3000 GHz. They are receiving increasing attention bringing distinct benefits, such as wider bandwidth, higher spatial and temporal resolution, more compact antennas and reusability of frequencies.

The sparsely used electromagnetic spectrum between 100 GHz and 1000 GHz commonly known as millimetre-wave and sub-mmW regions, can be conquered by the current rapid development of electronic circuits and subsystems beyond 100 GHz enabled by improvements in high-frequency semiconductor technology (using gallium nitride GaN and indium phosphide InP and new packaging techniques).

In recent years mmW and THz applications for spectroscopy and imaging, astronomy and environmental/atmospheric study and monitoring have grown more and more rapid as push forward techniques. The mmW/THz imaging is viewed as a safe, low-cost alternative to usual techniques for biological, security and health-sciences applications.

Close, applications in areas of high-speed wireless communication using carriers at 38 GHz, 68 GHz, 81-86 GHz and 92-95 GHz for defence, security and space science have been increasing rapidly.

Microwaves MW are defined as the electromagnetic waves with wavelength in the range 1 mm-1 m and frequency in the range 300 MHz-300 GHz.

Their main interactions with the matter are plasma oscillation and molecular rotation.

They belong to upper frequencies range of radio waves including UHF, SHF, EHF but are defined separately because of their special applications. Most common applications of microwaves are in the 1- 40 GHz range.

The prefix “micro-“ is not for micro- range, it indicates that they have shorter wavelengths than the waves used in radio broadcasting, which is the unidirectional wireless transmission of radio waves for large audience.

Different sources define different frequency ranges for microwaves. In general, the boundaries between ultra-high frequency radio waves, microwaves, terahertz radiation and far infrared light vary arbitrary in their use for different activities.

All warm objects emit microwave radiation function of their temperature, so microwave radiometers can be used to measure the temperature.

The galaxies, their stars emit microwave radiation, which is studied by radio astronomers using cosmic microwaves receivers called radio telescopes.

The **c**osmic **m**icrowave **b**ackground **r**adiation CMBR is considered "relic radiation" from the inception of the universe. Due to expansion followed by cooling of the universe, the originally high-frequency electromagnetic radiation has been shifted to microwave-frequency radiation. Sensitive radio telescopes can detect the faint, omnidirectional, background glow CMBR, which is not associated with any star, galaxy or other celestial body.

Man-made sources of microwaves use specialized vacuum tubes and field effect transistors and tunnel, Gunn, IMPATT diodes.

Maser (acronym for **m**icrowave **a**mplification by **s**timulated **e**mission of **r**adiation) is the device that produces and amplifies coherent microwaves.

Microwaves travel by line-of-sight paths. Therefore, on the surface of the Earth microwave communication links are limited by the visual horizon to about 48-64 km.

Microwaves are easily focused in narrow beams, allow broad bandwidth, need small antenna size for transmitters, receivers or transceivers.

Microwaves are the principal means that transmit data, TV and telephone speech between ground stations and satellites. They are used extensively for point-to-point telecommunications, in radar technology and microwave ovens.

The microwaves spectrum is divided in 13 bands: L, S, C, X, Ku ,K, Ka, Q, V, E, W, F, D

Microwaves

Band Symbol	*Frequency Range*	*Wavelength Range*
L	1-2 GHz	15-30 cm
S	2-4 GHz	7.5-15 cm
C	4-8 GHz	3.75-7.5 cm
X	8-12 GHz	25-37.5 mm
Ku	12-18 GHz	16.7-25 mm
K	18-26.5 GHz	11.3-16.7 mm
Ka	26.5-40 GHz	5.0-11.3 mm
Q	33-50 GHz	6.0-9.0 mm
V	50-75 GHz	4.0-6.0 mm
E	60-90 GHz	3.3-5 mm
W	75-110 GHz	2.7-4.0 mm
F	90-140 GHz	2.1-3.3 mm
D	110-170 GHz	1.8-2.7 mm

L is used for military telemetry, GPS,

mobile phones GSM, amateur radio

S is used for weather radar, surface ship radar,

some communication satellites

C is used for long distance radio

telecommunications

X is used for satellite communications,

radar, terrestrial broadband, space

communications, amateur radio

Ku is used for satellite communications

K is used for radar, satellite communications,

astronomical observations

Ka is used for satellite communications

Q is used for satellite communications,

terrestrial microwave communications, radio

astronomy, automotive radar

V is used for millimetre wave radar research

and other scientific research

E is used for UHF transmissions,

W is used for satellite communications,

millimetre wave radar research, military radar

targeting and tracking applications,

non-military applications, automotive radar

F is used for SHF transmissions: radio

astronomy,

microwave devices/communications,

wireless LAN, most modern radars,

communication satellites, satellite direct

broadcasting television DBSTV, amateur radio

D is used for EHF transmissions: radio

astronomy,

high frequency microwave radio relay,

microwave remote sensing, amateur radio,

directed-energy weapon, millimetre wave

scanner

Infrared waves IRW are electromagnetic waves with wavelength in the range 750 nm-1 mm and frequency in the range 300 GHz-430 THz.
Their main interactions with matter are molecular vibration and plasma oscillation (only metals).
Everything with a temperature above 5 degrees Kelvin [or -450 °F or -268 °C] emits IR radiation.
It is, beside convection and conduction, the way heat is transferred from one place to another.
The infrared electromagnetic radiation has industrial, scientific, medical and short-ranged wireless communication applications, is important in remote sensing, spectroscopy and weather forecasting.

Visible waves VW or *Light* are the part of the electromagnetic spectrum that is visible to the human eye. A typical human eye will respond to electromagnetic waves with wavelength in the range of 390-750 nm and corresponding frequency in the range of 430-770 THz.
Their main interactions with matter are molecular electron excitation (including pigment molecules found in the human retina) and plasma oscillations (in metals only).
The visible spectrum does not contain all the colours that the human eye can distinguish; un-saturated colours such as pink or magenta are not present since they are a mix of electromagnetic waves of different frequencies. The colours containing electromagnetic waves of only one frequency or wavelength are called "pure" colours or "spectral" colours.
The future promises a green technology where office lighting will have a double-duty, will be a source of light and a wireless transmission source. The idea is that a Light Emitted Diode LED can vary its intensity so quickly that a human eye cannot see it, but a photo detector can detect it. That is the Visible Light Communication VLC or Light Fidelity LiFi, which is one of the solutions to the problem about the lack of radio spectrum.
LiFi refers to the high-speed, bidirectional and networked wireless communications using light to provide a seamless wireless user experience much like traditional mobile communications.
It advances the visible light communication VLC, which was first introduced by the Japanese professor **Nakagawa** of Keio University. At Keio Techno-Mall in December 2009, there were demos of visible light communication and the latest research results were presented.
LiFi offers secure and safe wireless communications in a globally unlicensed spectrum that repurposes the energy used for lighting to provide wireless data. LiFi is a complete mobile communication solution to augment the fifth generation of cellular phone called 5G and beyond.
LiFi technology is expected to be a key part of the future 5G Systems.
How to integrate LiFi into existing WiFi connections is a compelling problem but its solution will promise more data to customers. How to modulate, multiplex and handover LiFi data is under debate in engineering circles, possibly an **o**rthogonal **f**requency **d**ivision **m**ultiplexing OFDM.
Radio is the very utilised part of the electromagnetic spectrum but visible/light and infrared have been underutilised parts of spectrum and both are unlicensed.
The visible/light spectrum alone stretches from approximately 430 THz to 770 THz that is over hundred times the bandwidth of the radio electromagnetic spectrum.

Ultraviolet waves UVW have shorter wavelength and higher frequency than the visible waves/light. Their wavelength is in the range of 10 nm-390 nm and their frequency is in the range of 770 THz-30 PHz.

Their main interaction with matter is the excitation of molecular and atomic valence electrons, including ejection of the electrons (photoelectric effect).
They are produced by Sun or artificial sources.
They are invisible to humans but near UV radiation is visible to some insects and birds.
UV lamps sterilise the air in operating theatres, surgical equipment, drugs, food and in suitable doses cause the human body to produce vitamin D, treat vitamin D deficiency or skin disorders.

X waves XW or *X rays* are called the waves of the electromagnetic radiation with the wavelength ranging in 10pm-10 nm and frequency in the range 30 PHz-30 EHz.
Their main interaction with matter is the excitation and ejection of core atomic electrons called Compton scattering for elements of low atomic numbers.
X rays are produced when the electrons strike a metal target.
They are the kind of rays that could travel through solid wood or flesh and, because they impressed photographic plates as light, they can yield photographs of people's bones and are used in diagnostic radiology.

Gamma waves GW or *Gamma rays* or ***γ** rays* denoted by Greek letter gamma **γ**, are called the waves of the electromagnetic radiation with wavelength less than 10 pm (10×10^{-12} m) and frequency above 30 EHz (30×10^{18} Hz) and therefore are composed of high energy photons.
Their main interactions with matter are the energetic ejection of core electrons in heavy elements called Compton scattering for all atomic numbers, the excitation of atomic nuclei including dissociation of nuclei and for high-energy rays the creation of particle-antiparticle pairs or a shower of high-energy particles-antiparticles.
Gamma rays are ionizing radiation, therefore dangerous to the people’s health.
Gamma radiation is generated by gamma decay of radionuclides/radioisotopes (unstable atoms), atmospheric interaction with cosmic ray particles, lightning strikes, terrestrial gamma-ray flashes TGF caused by intense electric fields above or inside thunderstorms (last 0.2-3.5 ms with energy up to 20 MeV), astronomical processes producing high-energy electrons causing deceleration radiation, nuclear fusion in stars, collapse of hyper-novae stars (give the most powerful bursts of gamma rays).
Gamma rays are used in medicine in radioactive tracers, to sterilise medical equipment, to treat internal organs, to kill cancer cells.

Electromagnetic spectrum is the range of all possible electromagnetic waves of the electromagnetic radiation, in all their possible wavelengths or frequencies. It is a naturally occurring resource much like air or water.

The word “spectrum” was introduced in the year 1666 by the genial English mathematician and Nature scientist **Isaac Newton** (1643-1727) when he directed a ray from Sun through a prism and saw that on the wall of his room appeared the colours of the rainbow. The prism decomposed the light in a row of colours entering lightly one in another from red, through orange, yellow, green, blue, indigo to violet. To name the multicolour band that appeared like by magic on the wall of room, Newton took from the Latin language the word “spectrum” meaning “ghost appearance” or “phantom” (plural “spectra” or “spectrums”).

In general “spectrum” defines a condition that can vary continuously, is not limited to a set of values.

The range of all possible electromagnetic waves of the electromagnetic radiation are presented further by their wavelength λ on a decimal logarithmic scale and the corresponding frequency f, resulted in conformity with the formula $f = c/\lambda$, also on a decimal logarithmic scale.

Communicating by electromagnetic waves implies the use of the electromagnetic spectrum and it is here where the possibilities for radio communications begin and end.

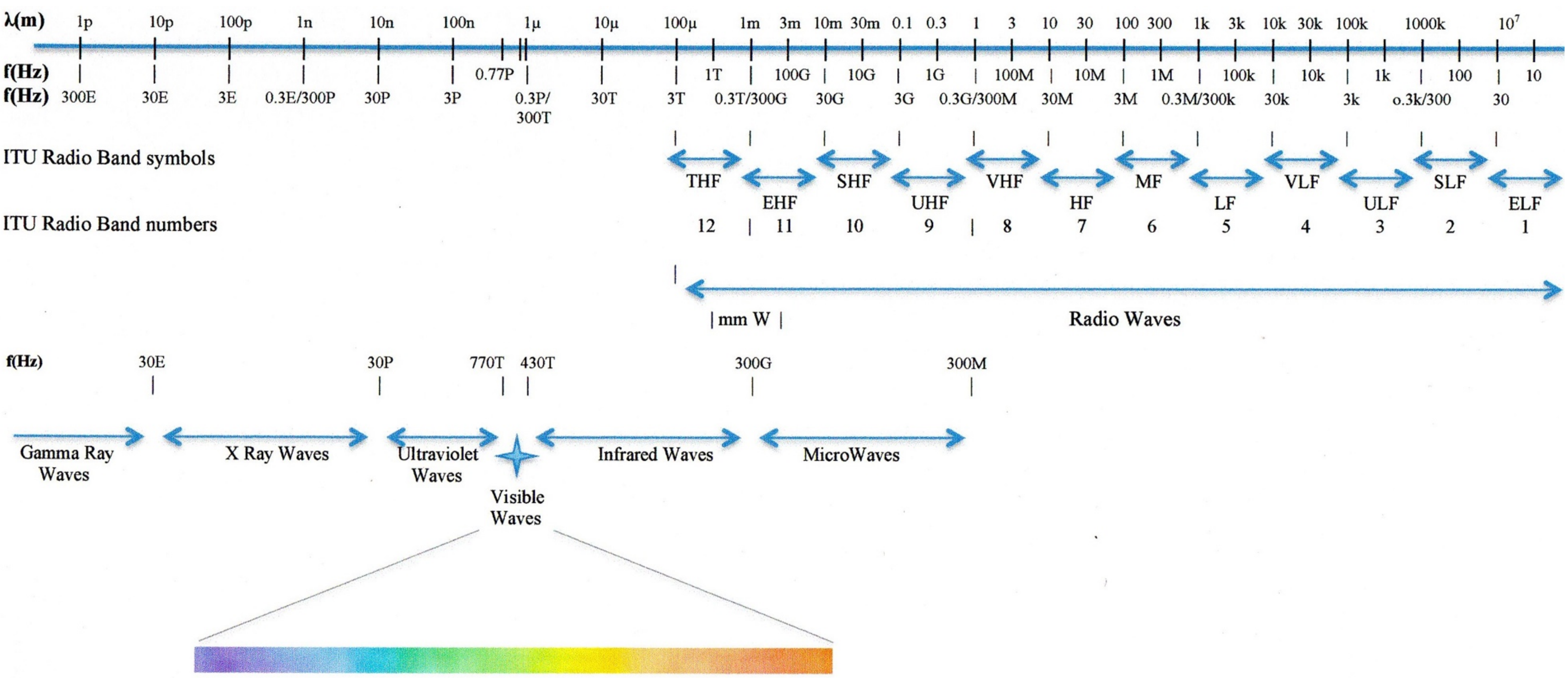
With the exploding popularity of all things wireless, the radio spectrum has become a scarce commodity in many countries.

Radio spectrum, which is finite, must accommodate mobile phone calls and data traffic that are increasing at an unprecedented rate. Globally, the traffic on mobile broadband systems has grown so fast that current levels already exceed predictions made in the 2010 year for the 2020 year according to Huawei, a global information and communications technology provider in China.

The efficient use of spectrum required the coordinated development of standards, which in turn contributed to the development of technologies that relied on spectrum use.

Spectrum management is the process of regulating the use of radio frequencies to promote efficient use because of the increasing number of spectrum uses in air-broadcasting, commercial services to the public, government, industrial, scientific, medical services.

Cognitive radio CR is one technology under development that could allow spectrum to be used more efficiently. A CR transceiver scans for unused spectrum bands and changes its transmission and reception parameters to different frequencies during heavy data loads without interruption. It also can listen for interference on busy channels and calculate a way to reduce it.



ELECTROMAGNETIC SPECTRUM

For wireless communication to be effective was necessary driving government intervention and international coordination.
International Telecommunication Union ITU coordinates internationally the use of radio electromagnetic spectrum, managing interference and setting global standards.
ITU was formed in 1865 year in Paris, at the International Telegraph Convention. Its first regulations were put in place at the 1906 Berlin International Radiotelegraph Conference.
In 1947 year, ITU became a United Nations specialized agency for information and communication technologies ICTs. It is based on public-private partnership and currently has a membership of 193 countries and almost 800 private-sector entities and academic institutions.
ITU has headquarters in Geneva, Switzerland and 12 regional and area offices around the world.
ITU coordinates the shared global use of the radio spectrum (used in modern technology, particularly in telecommunication), promotes international cooperation in assigning satellite orbits, works to improve telecommunication infrastructure in the developing world, assists in the development and coordination of worldwide technical standards.
ITU deals with interference by requiring member countries to respect notification and registration procedures whenever they plan to assign an electromagnetic wave of a particular frequency to a certain use like a radio station or a new satellite. Spectrum users are divided into primary and secondary, with primary users protected from interference from secondary users but not vice versa.

DISCOVERY OF ELECTROMAGNETIC WAVES

Apart from the discoveries and inventions associated with electricity generation, the discovery of electromagnetic waves and the inventions that followed have been responsible for major changes in the world. Without the communications by electromagnetic waves many of those changes would not have happened.

The light or the visible electromagnetic radiation is the only part of the electromagnetic spectrum known by humans for most of the history.
The study of light began in ancient Greece, regarding light reflection and light refraction.
In the16th century appeared conflicting light theories considering light either wave or particle.

The British-German astronomer and composer **Sir William Hershel** (1738-1822) in 1800 year discovered the “infrared radiation” when studying the temperature of different colours and observing that the highest temperature was beyond red.

The German chemist, physicist and philosopher **Johann Wilhelm Ritter** (1776-1810) in 1801 year discovered beyond the violet light rays the “chemical rays”, invisible rays inducing chemical reactions. They were renamed later “ultraviolet c radiation”.

The English scientist **Michael Faraday** (1791–1867) introduced the concept of *field* in physics to describe his discovery of electromagnetic induction in 1821 year.
Michael Faraday had little formal education, but was one of the most influential scientists, considered by the historians of science the best experimentalist in the history of science.
It was by his research on the magnetic field around a conductor carrying a direct electric current that Faraday *established the basis for the concept of the electromagnetic field* in physics.
He showed that the electromagnetic field generated by charged bodies and magnets extended in the empty space around by lines of flux, used too as way to visualize electric and magnetic fields.
Faraday also established that there was an underlying relationship between magnetism and light by discovering in 1845 year the magneto-optical effect: the plane of vibration of a linearly polarized light beam incident on a glass piece rotates when a magnetic field was applied in the direction of beam propagation.
Faraday invented the first electric motor, the first electrical transformer, the first electric generator and the first dynamo, so Faraday can be called without any doubt**, the *father of electrical engineering*.** However, the scientists of his time widely rejected his ideas.
In his honour, at the 1881 International Congress of Electricians in Paris was introduced officially the name “farad” symbol F for the SI unit of electrical capacitance - the body ability to store electrical charge.

The Scottish mathematical physicist **James Clerk Maxwell** (1831-1879) understood Faraday’s ideas and taking in consideration the Faraday, Ampere, Gauss laws did the notable achievement in 1865 year to formulate the *classical theory of electromagnetic radiation* in his publication “A Dynamical Theory of the Electromagnetic Field” bringing together for the first time electricity, magnetism and light as manifestations of the same phenomenon, electromagnetic waves traveling in space at light speed.
Maxwell's equations for electromagnetism producing an unified model of electromagnetism represent one of the greatest advances in physics. The unified model of electromagnetism has been called "the second great unification in physics" after the first one realised by Isaac Newton.
The first major unification in physics was Isaac Newton's realization that the same force that caused an apple to fall at the Earth's surface, the gravity, was also responsible for holding the Moon in orbit about the Earth and this universal force would also act between the planets and the Sun, providing a common explanation for both terrestrial and astronomical phenomena.
Maxwell’s equations are a set of partial differential equations that together with the Lorentz force law form the foundation of classical electromagnetism, classical optics and electric circuits.

MICHAEL FARADAY

Lorentz force is the action of electric and magnetic fields on a point electric charge: a particle of electric charge q moving with the velocity **v** in the presence of an electric field **E** and a magnetic field **B** experiences a force $\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$.

The English self-taught electrical engineer, mathematician and physicist **FSR Oliver Heaviside** (1850-1925) reformulated the Maxwell's original twenty field equations in more convenient four equations. Their formulation and meaning are:

$\nabla\mathbf{E} = q/\varepsilon_0$	The electric flux leaving a volume is proportional to the electric charge q inside
$\nabla\mathbf{B} = 0$	There are no magnetic monopoles; the total magnetic flux through a closed surface is zero
$\nabla \times \mathbf{E} = - \partial\mathbf{B}/\partial t$	The electric field **E** induced in a closed circuit is proportional to the rate of change of the magnetic flux it encloses
$\nabla \times \mathbf{B} = \mu_0 (J + \varepsilon_0 \partial\mathbf{E}/\partial t)$	The magnetic field **B** induced around a closed loop is proportional to the electric current plus the displacement current (rate of change of electric field) it encloses

Nabla or *del* symbol ∇ represents in mathematics the vector differential operator.

ε_0 is the vacuum permittivity or the permittivity of free space, measure of the amount of resistance encountered when forming an electric field E in classical vacuum and its value is:

$\varepsilon_0 = 8.8541878176\times10^{-12}$ F/m

μ_0 is the vacuum permeability or the permeability of free space, measure of the amount of resistance encountered when forming a magnetic field B in classical vacuum and its value is:

$\mu_0 = 4\pi \times 10^{-7}\ \text{H}\cdot\text{m}^{-1} \approx 1.2566370614\ldots\times10^{-6}\ \text{H}\cdot\text{m}^{-1}$ or $\text{N}\cdot\text{A}^{-2}$

James Clerk Maxwell is considered the leading theoretical physicist of the 19^{th} century.

International Electrotechnical Commission in 1930 year honoured James Maxwell by naming the CGS unit of magnetic flux the "maxwell" symbol Mx.

The dramatic confirmation of Maxwell's theory that light itself is an electromagnetic wave challenged experimentalists to generate and detect electromagnetic radiation.

The first electromagnetic transmission-reception was made by the British-American inventor, experimenter and music professor **David Edward Hughes** (1831-1900) in 1879 year, but was not conclusively proven to be transmission through the air of electromagnetic waves or merely electromagnetic induction.

JAMES MAXWELL

Experiments done by the German physicist **Heinrich Rudolf Hertz** (1857 –1894), who engineered instruments to transmit and receive electromagnetic waves pulses, used in 1886 year experimental procedures that excluded all other known wireless phenomena.
To emit radiation, to build a “transmitter”, Hertz used a high voltage induction coil, an original form of capacitor called condenser or Leyden jar and a “spark-gap” device connected in series.
He caused a spark discharge between the spark-gap poles (2 cm radius) oscillating at a frequency determined by the values of the capacitor and the induction coil.
To detect the emitted radiation, to build a “receiver”, Hertz used 1 mm thick copper wire, bent into a 7.5 cm diameter circle, at one end with a small brass sphere and at the other end with a pointer directed to sphere at a distance controlled by a screw mechanism (hundredths of mm).
The receiver was designed so that oscillating back-forth electric current in the “receiver” wire would have the frequency of the "transmitter" current. The presence of oscillating charge in the receiver would be signalled by sparks across tiny gap between pointer and sphere.
In other experiments, Hertz established beyond any doubt that light is a form of electromagnetic radiation by measuring the speed of electromagnetic radiation and founding it to be the same as the light’s speed and showing that the radio waves’ reflection and refraction were same as light’s.
Hertz's proof of the existence of airborne electromagnetic waves led to an explosion of experiments with this new form of electromagnetic radiation called *Hertzian waves* until approximately 1910 year when the term *radio waves* became current.
Heinrich Rudolf Hertz's experiments caused large interest in radio waves research.
Inventions that followed used the radio waves to transfer information through space.
Eventually, successful wireless telegraph, audio radio and later television were developed commercially.
Hertz died young in 1894 year before his discoveries were implemented into a practical form, unaware of the practical importance of his radio wave experiment about which he said:
“It's of no use whatsoever... just an experiment that proves Maestro Maxwell was right - we just have these mysterious electromagnetic waves that we cannot see with the naked eye. But they are there." About the ramifications of his discoveries Hertz said: "Nothing, I guess."
International Electrotechnical Commission in 1930 year honoured Heinrich Hertz by naming the SI unit of frequency, the one cycle per second unit, the "hertz" symbol Hz.

HEINRICH HERTZ

The German physicist **Wilhelm Conrad Roentgen** (1945-1923) on 8 November 1895 discovered a kind of rays that could travel through solid wood or flesh and impress photographic plates as light. After some considerable investigation, he understood that he discovered a new kind of rays and he named them “X” (unknown).

The French physicist **Antoine Henri Becquerel** (1852-1908) in 1896 year discovered that uranium salts produce rays which he called “uranium rays”, proved to be a blend of three kinds of radiation of which one is “gamma” γ.

FIRST EXPERIMENTS

The Scottish philologist, astronomer, inventor and author **James Bowman Lindsay** (1799-1862*) introduced the concept of wireless telegraphy*.

In 1832 year, Lindsay gave a classroom demonstration to his students, of wireless telegraphy via conductive water. By 1854 he was able to demonstrate wireless transmission, using water as the transmission medium from Dundee city to Woodhaven village in Scotland situated at 3km distance. He obtained a patent for his system of wireless telegraphy through water.

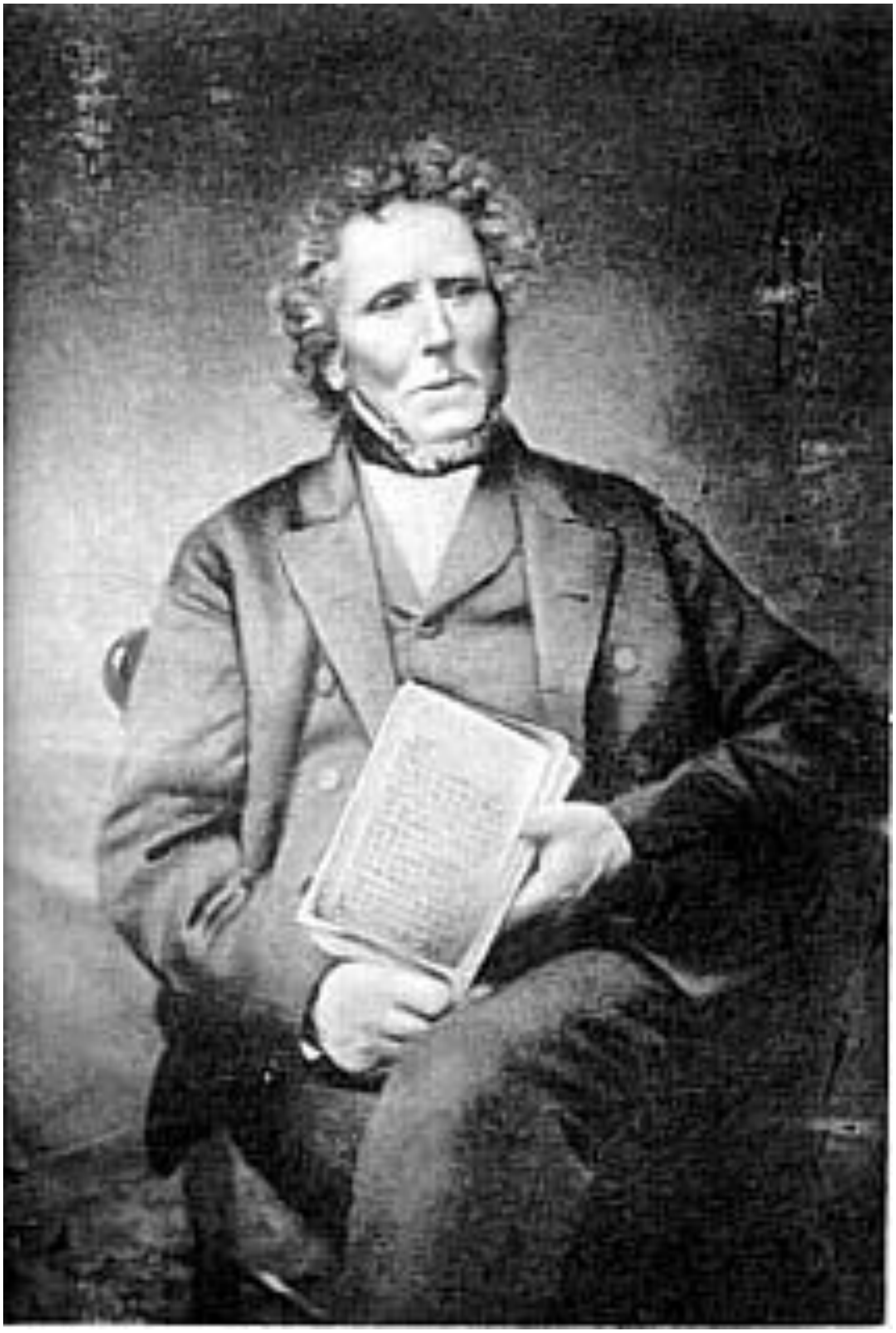
The American businessman and inventor **Thomas Alva Edison** (1847-1931), described as “America greatest inventor” in 1880s *patented an electromagnetic induction system he called grasshopper telegraphy*, which allowed telegraphic signals to jump the short distance between a running train and telegraph wires running parallel to the tracks. The system was successful technically but the train travellers were little interested in an on-board telegraph service.

To develop wireless telegraph systems were used both electrostatic and electromagnetic induction. But they had very limited commercial application.

Edison has no formal education but was a prolific inventor with 1093 patents in US and other many in UK, France and Germany. The phonograph, the motion picture camera, the stock ticker, the mechanical vote recorder, the electrical light bulb, the battery of an electric car, electric power generation and distribution, first industrial research laboratory are part of his inventions.

By experiments between the 1884 -1886 years, the Italian physicist and inventor **Temistocle Calzecchi-Onesti** (1853-1922) at Fermo in Italy demonstrated that *iron powder in insulated tube conducts electric current when under electromagnetic radiation* generally known as *radio waves.*

This primitive device was developed later in 1890 to become the first practical “radio detector” by the French physicist, professor and inventor **Edouard Eugene Desire Branly** (1844-1940).



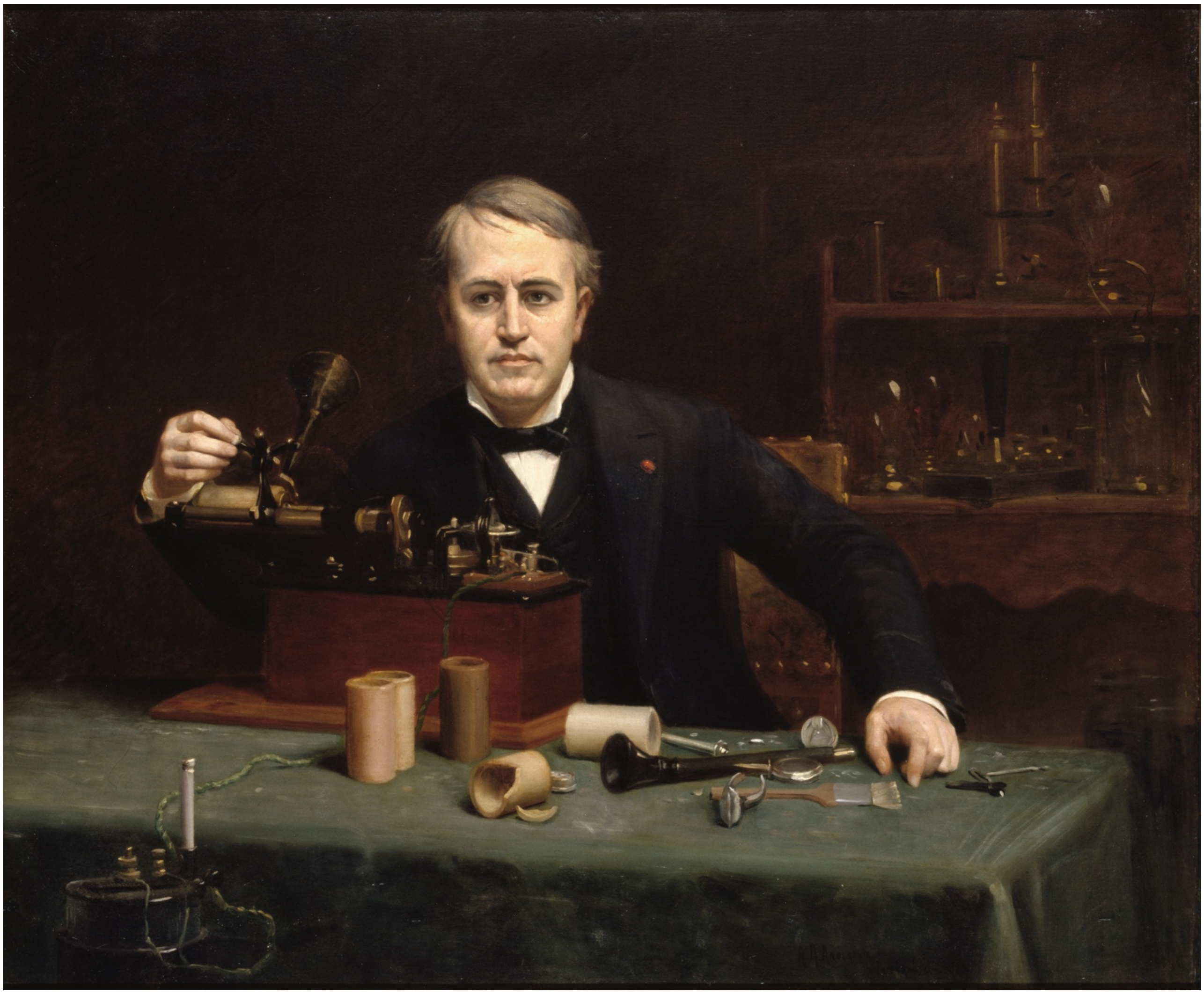
JAMES LINDSAY

The British physicist and writer **Sir Oliver Joseph Lodge** (1851-1940) used it as “coherer” in 1893 year. The *coherer* is considered a primitive form of radio signal detector used in the first radio receivers during the wireless telegraphy era at the beginning of the 20th century.
It was used also in the first commercially successful radio transmission system between 1894 and 1896 years by the Italian electrical engineer and inventor Guglielmo Marconi.

The Welsh electrical engineer and inventor **Sir William Henry Preece** (1834-1913) was the most successful *creator of an electromagnetic induction telegraph system* beginning with tests across the Bristol Channel in 1892, able to telegraph across gaps of about five kilometres. However, his induction system required extensive lengths (km) of antenna wires, at both the sending and receiving ends.

The Brazilian Catholic priest inventor **Father Roberto Landell de Moura** (1861-1928) between 1890 and 1894 years *conducted wireless transmissions in telegraphy and telephony* over distances of up to 8 kilometres, demonstrating a radio broadcast of the human voice on 3 June 1900. In 1904 year, he obtained three patents for: Wave Transmitter, Wireless Telephone, Wireless Telegraph

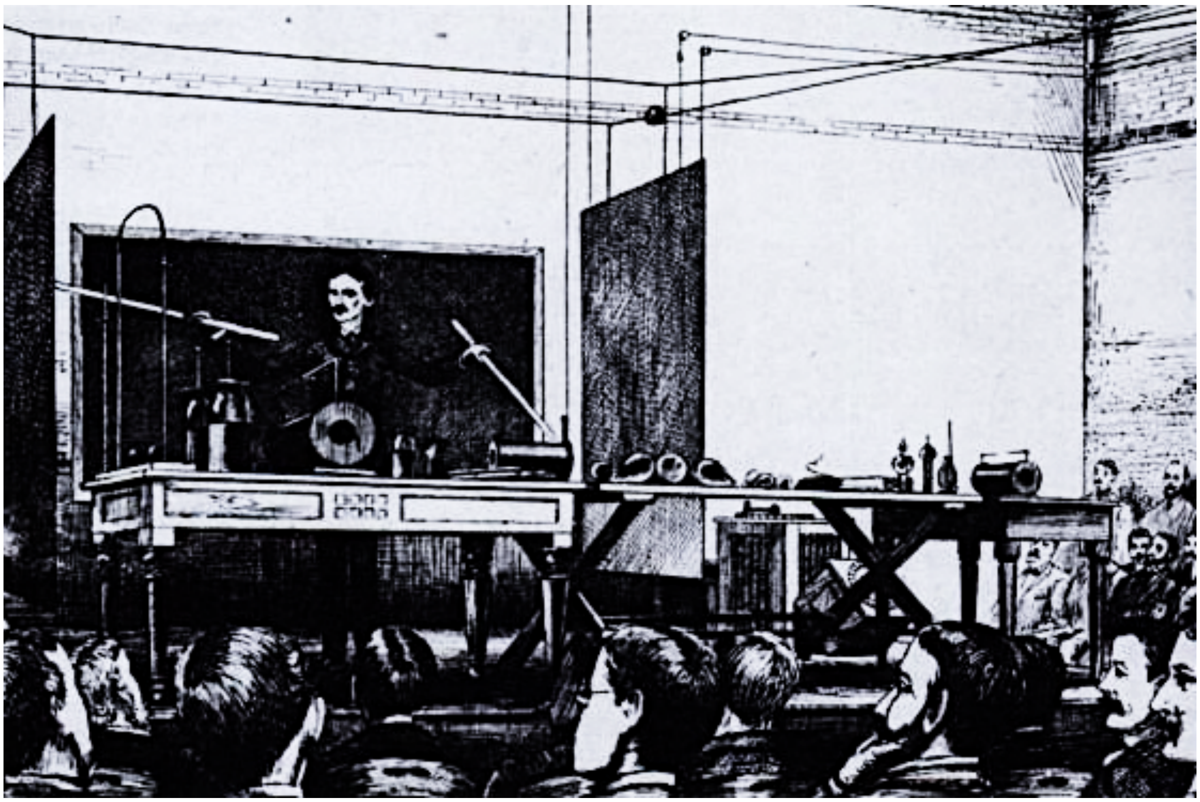
The Serbian-American inventor, electrical engineer, mechanical engineer, physicist and futurist **Nikola Tesla** (1856-1943) after 1890 year *experimented to transmit electric power through inductive and capacitive coupling,* which is *wirelessly,* using spark-excited radio frequency resonant transformers now called *Tesla coils.*
Tesla did *public demonstrations of wireless transmission,* lighting Geissler tubes and incandescent bulbs from across a stage in his attempt to develop a wireless lighting system based on near field inductive and capacitive coupling.
Tesla found that by using a receiver LC circuit in resonance with a transmitter LC circuit he can increase the distance at which he can light a lamp. *This resonant inductive coupling is used nowadays in short-range wireless power systems*.
Tesla called attention to the fact that by taking his electric oscillator, grounding one side of it and connecting the other to an insulated body of large surface, it should be possible to transmit electric oscillations to a great distance and to communicate intelligence in this way to other oscillators in sympathetic resonance therewith. This was going far toward the invention of radio-telegraphy.
In 1891 year, he *developed various electrical generators*, devices that convert mechanical energy to electrical energy in the form of alternating current AC with the frequency of 15000 cycles per second. Alternating current AC is an electric current, which periodically reverses direction whereas a direct current DC flows only in one direction.



THOMAS EDISON

On 3 February 1892 Nicola Tesla presented at the Institution of Electrical Engineers of London the lecture “Experiments with Alternate Currents of High Potential and High Frequency”, when he *suggested that messages could be also transmitted without wires* and *the telephony could be rendered practicable across the Atlantic Ocean*. The lecture was repeated on 4 February at the Royal Institution London and on 19 February at the Societe Francaise de Physique in Paris.
In February 1893 Tesla presented the lecture “ On Light and Other High Frequency Phenomena” at the Franklin Institute, Philadelphia and in March 1893 he repeated the presentation before the National Electric Light Association, St. Louis. On 25 August 1893 before the International Electrical Congress Tesla delivered the lecture “Mechanical and Electrical Oscillators”.
In his experiments Tesla *exhibited transmission and radiation of radio frequency energy or electromagnetic power transfer & proposed to be used for telecommunication of information too*.
The English-American electrical engineer and editor **Thomas Commerford Martin** (1856-1924) published in 1893 year the book “ The Inventions, Researches and Writings of Nikola Tesla” detailing the work of Nikola Tesla which contained coupled oscillation circuits each having capacitors & inductors in series.
In 1897 year, the *Tesla method* was described in New York, USA as what is *known today as the Wireless Power Transfer WPT*. Wireless power techniques mainly fall into two categories:
* non-radiative (near field) - power is transferred by inductive or capacitive coupling.
Tesla demonstrated that for the first time when he lit Geissler tubes and even incandescent light bulbs from across a stage.
* radiative (far-field or power beaming) - power is transferred at long distances by beams of electromagnetic radiation as microwaves or laser beams aimed to receiver.
In 1898, Tesla developed a radio-controlled robotic boat driving the boat remotely around the waters of Manhattan from a set of controls at Madison Square Garden.
Tesla proposed a "World Wireless System" that was to broadcast both information and power worldwide, including the building of more than thirty transmission-reception stations, large high-voltage wireless power stations near major population centres of the world.
By the end of 1900 year the financier J. P. Morgan agreed to fund a pilot project, the Wardenclyffe project, able to transmit messages, telephony and even facsimile images across the Atlantic to England and to ships at sea.
Morgan was interested financially in shares in the company and half of all the patent income.
But Tesla decision in July 1901 to include wireless power transmission met Morgan's refusal to fund the changes and by 1904 year the investment stopped.

NICOLA TESLA



Nikola Tesla demonstrating wireless transmission of power and high frequency energy at Columbia College, New York, in 1891.

The two metal sheets were connected to his Tesla coil oscillator, which applied a high voltage oscillating at radio frequency.

The electric field ionized the gas in the long partially-evacuated Geissler tubes he is holding (similar to modern neon lights), causing them to emit light without wires.

N. Tesla's Wardenclyffe Wireless Station /Wardenclyffe Tower/Tesla Tower

Located in Shoreham, Long Island, New York - seen in 1904 year

Since today global demand for energy, two Russian physicists **Leonid** and **Sergey Plehanov** intend to realize their project for wireless energy transmission once proposed by the 20th century scientist Nikola Tesla. They say that solar panels and an upgraded Tesla tower could solve the present global energy problem.
Tesla displayed his scientific imagination and created widespread interest in his brilliant demonstrations. By doing that he stimulated the scientific imagination of many others.
Tesla obtained hundreds of patents worldwide (more than 1,200 patents) for his inventions, but there are also inventions, not accounted for, hidden in archives or without patent protection.
There has been stated that Tesla actually discovered alternating electric current AC, produced the first AC induction motor, invented radio (preceded Marconi with few years), discovered the arc light and broadcasted the first television signals. Tesla‘s electromagnetic receivers were more responsive than coherers used later by others. He too worked on wireless remote-control devices.
Some say more, that Nikola Tesla was the genius who created the modern world: electric cars, radio, the bladeless turbine, wireless communication, spark plugs, fluorescent lighting, the induction motor, the telephone repeater, the rotating magnetic field principle, the poly-phase alternating current system, alternating current power transmission, the Tesla Coil transformer.
And in addition, the principles he discovered and the mechanisms he invented led to TV, MRI, X-ray machines, radio telescopes, radar. He envisioned the smart phone and wireless Internet.
He was one of the few who combined the brain of a calculator with the imagination of a scientist.
Tesla used mathematics to arrive at many of the concepts that he turned into inventions.
He did his engineering drawings in detail without ever measuring a line and the machined parts from his drawings fit perfectly. But very few of his subtle mathematical calculations of his designs exist in journals and in conformity with the saying “publish or perish” he is considered today an engineer and an inventor but not a scientist. But his genius is recognized.
Some sources say that the names of Thomas Alva Edison and Nikola Tesla were announced by the Swedish Academy to share the 1912 Nobel Prize in Physics but ultimately the prize was awarded to Swedish inventor engineer Nils Gustaf Dalen for the invention “automatic regulators for use in conjunction with gas accumulators for illuminating lighthouses and buoys".
In 1960 year, the General Conference on Weights and Measures honoured Nicola Tesla by naming the SI unit of magnetic flux density, the “tesla” symbol T.

The Italian inventor and electrical engineer **First Marquis of Marconi Guglielmo Giovanni Maria Marconi** (1874-1937*) opened the way for modern wireless communications in the year 1895 by transmitting the 3 dots Morse code for the letter “S” over a distance of 3 km using electromagnetic waves.*

Marconi read about the experiments of Heinrich Hertz and also read about Nicola Tesla's work. He understood that radio waves could be used for wireless communications.
Marconi's early apparatus was a development of Hertz's laboratory apparatus into a system designed for communications purposes.
In July 1896, Guglielmo Marconi presented his invention as a new method of telegraphy to the attention of William Henry Preece, then engineer-in-chief to the British Government Telegraph Service, interested himself in the development of wireless telegraphy by the inductive-conductive method. Preece stated at the Royal Institution in London that Marconi had invented a new relay, which had high sensitivity and delicacy.
By 1897 year, Guglielmo Marconi *did more demonstrations with a radio system for signalling over long distances*. In 1899 year were transmitted messages across the English Channel.
In 1901 year he received in St. John's Newfoundland, Canada telegraphic signals across the Atlantic Ocean sent from his wireless station in Poldhu, Cornwall, England UK at ~3200 km.
At the turn of 20th century, Guglielmo Marconi developed the first apparatus for long distance radio communication.
By 1910 year different various wireless systems were referred as "radio".
Marconi was an entrepreneur, businessman and founder of The Wireless Telegraph & Signal Company in the United Kingdom in 1897 year, renamed Wireless Telegraph Trading Signal Company in 1900 year. Marconi's real contributions were engineering and commercial.
For contributions in development of wireless telegraphy Guglielmo Marconi was awarded the **1909 Nobel Prize for Physics.**

The Russian physicist **Aleksander Stepanovich Popov** (1859-1905), acclaimed in his homeland and some eastern European countries as the inventor of radio, in 1897 year succeeded to transmit radio waves over a distance of 5 km. He did not pursue their use for communications but used them to study thunderstorms.

The German physicist and inventor **Karl Ferdinand Braun** (1850-1918) *discovered* in 1874 year that can rectify alternating current by a point-contact semiconductor, called *cat's whisker detector* or *crystal detector - the first type of semiconductor diode*, an electronic component consisting of a thin wire that lightly touches a crystal of semiconducting mineral (usually galena).
In 1897 Braun built the first cathode-ray tube CRT and the CRT oscilloscope.
He was captivated by wireless telegraphy in 1898 year, when he joined the wireless pioneers.
He *introduced a closed tuned circuit in the generating part of a wireless transmitter and separated it from antenna by an inductive coupling. At receiver he used crystal detectors.*

GUGLIELMO MARCONI

Braun's British patent on tuning was used by Marconi in many of his tuning patents.
Braun experimented first wireless at the University of Strasbourg.
In 1899 year, he experimented on the shore of the North Sea and in 1900 year, radio telegraphy signals were exchanged regularly with the island of Helgoland over a distance of 62 km.
Light vessels in the river Elbe and a coast station at Cuxhaven independent town commenced a regular radio telegraph service.
Braun contributed significantly to development technology for radio and television.
Ferdinand Braun and Guglielmo Marconi shared the **1909 Nobel Prize for Physics** for contributions in development of wireless telegraphy.

In the early 20^{th} century, the Slovak inventor, architect, botanist, painter Catholic priest **Josef Murgas** (1864-1929) *did revolutionary work in wireless telegraphy.* In 1905 year, his company "Universal Ether Telegraph Co." organized a public test of its transmitting/receiving facilities. Josef Murgas obtained more patents related to his inventions in the wireless telegraphy.

TECHNOLOGY EVENTS

Fleming valve or *Fleming oscillation valve*, a "vacuum tube" or "thermionic diode" was invented in the year 1904 by the British electrical engineer and physicist **John Ambrose Fleming** (1849-1945). It was a tube with 2 electrodes, the first "diode" whose purpose was to conduct electric current only in one direction, used as *detector* for early radio receivers in electromagnetic wireless telegraphy. Later was used as *rectifier*, device that converts alternating current AC into direct current DC in the power supplies.

The American inventor, self-described "father of Radio" **Lee De Forest** (1873-1961) invented in the year 1906 the *Audion,* a vacuum tube with 3 electrodes actually the Fleming valve with a third electrode, the first "triode" that permits control the strength of tube electric current without consuming appreciable energy. It was used to build the first amplifying radio receivers and electronic oscillators.

In 1920 year, the commercial radio was established in U.S. with radio station WWJ in Detroit and radio station KDKA in Pittsburgh.

In January 1926 year the Scottish engineer and innovator **John Logie Baird** (1888-1946) demonstrated the first working mechanical television system. He invented the first colour television system and the first purely electronic colour television picture tube.

In 1929 year was established the British Broadcasting Corporation BBC.

In 1940 year the American, Bell Labs researcher **George Robert Stibitz** (1904-1995) recognized as one of the fathers of first digital computer, was able to transmit problems using "tele-printers", devices for communicating text over telegraph lines, to his "Complex Number Calculator" in New York and received the computed results back at Dartmouth College in New Hampshire. This was a *configuration of a centralized computer with remote terminal*s, which remained popular till 1950 year.

In 1946 year was heralded in press the "Giant Brain" a new computer with a computing speed 1000 times faster than electro-mechanical machines called the *Electronic Numerical Integrator And Computer* ENIAC. It was the first electronic digital general-purpose computer, able to simulate any "Turing machine".

Turing machine is an abstract machine that manipulates symbols according to certain rules. Given an algorithm, a Turing machine can be constructed to simulate the logic of that algorithm. The English computer scientist, mathematician, logician, cryptanalyst and theoretical biologist **OBE FRS Alan Mathison Turing** (1912-1954) invented the Turing machine.

He is considered the father of theoretical computer science and artificial intelligence.

In 1946 Motorola company in conjunction with the Bell System operated the *first commercial portable/mobile telephone service* Mobile Telephone System MTS in the USA.

In 1960s were launched for the first time the communication satellites. These first satellites could only handle 240 voice circuits. They have become essential in places where would be impossible to communicate by any other method.

In 1960 year appeared a new computer communication method and technology, called *Packet switching*, enabling data to be divided in packets and transmitted through different paths or nodes to one final point.

In December 1969 year emerged a 4 Node network linking University of California Los Angeles, Stanford Research Institute, University of Utah, University of California Santa Barbara. This network extended under the name *Advanced Research Projects Agency Network* ARPANET was based on concepts and designs of American engineer and computer scientist **Leonard Kleinrock,** Polish-American engineer **Paul Baran** (1936-2011), Welsh computer scientist **OBE FRS Donald Watts Davies** (1924-2000), American scientist **Lawrence Roberts**. As the project evolved, were developed protocols allowing multiple separate networks to join into a network of networks.

The American **Steve Crocker** in 1969 year invented the "Request For Comments" RFC to help record unofficial comments on the development of ARPANET.

In 1973 year, ARPANET added a non-US node, the NORSAR Project of Norway, followed by a node in London. In 1981 year, ARPANET had 213 nodes in USA.

In 1981 year, RFC introduced "Internet Protocol v4" IPv4 & "Transmission Control Protocol" TCP creating for ARPANET the protocol suite *Transmission Control Protocol/Internet Protocol* TCP/IP that much of Internet relies today. The Americans electrical engineer **Robert Elliot Kahn** and mathematician **Vinton Gray Cerf** with concepts of the French engineer **Louis Pouzin** invented TCP/IP communications protocols.
In 1982 year, RFC introduced the *Simple Mail Transfer Protocol* SMTP, a standard for electronic mail (e-mail) transmission. It was updated in 2008 year and is the protocol in widespread use today. ARPANET would eventually merge with other networks to form the modern *INTERNET* and many of the protocols the Internet relies today were specified through this process.

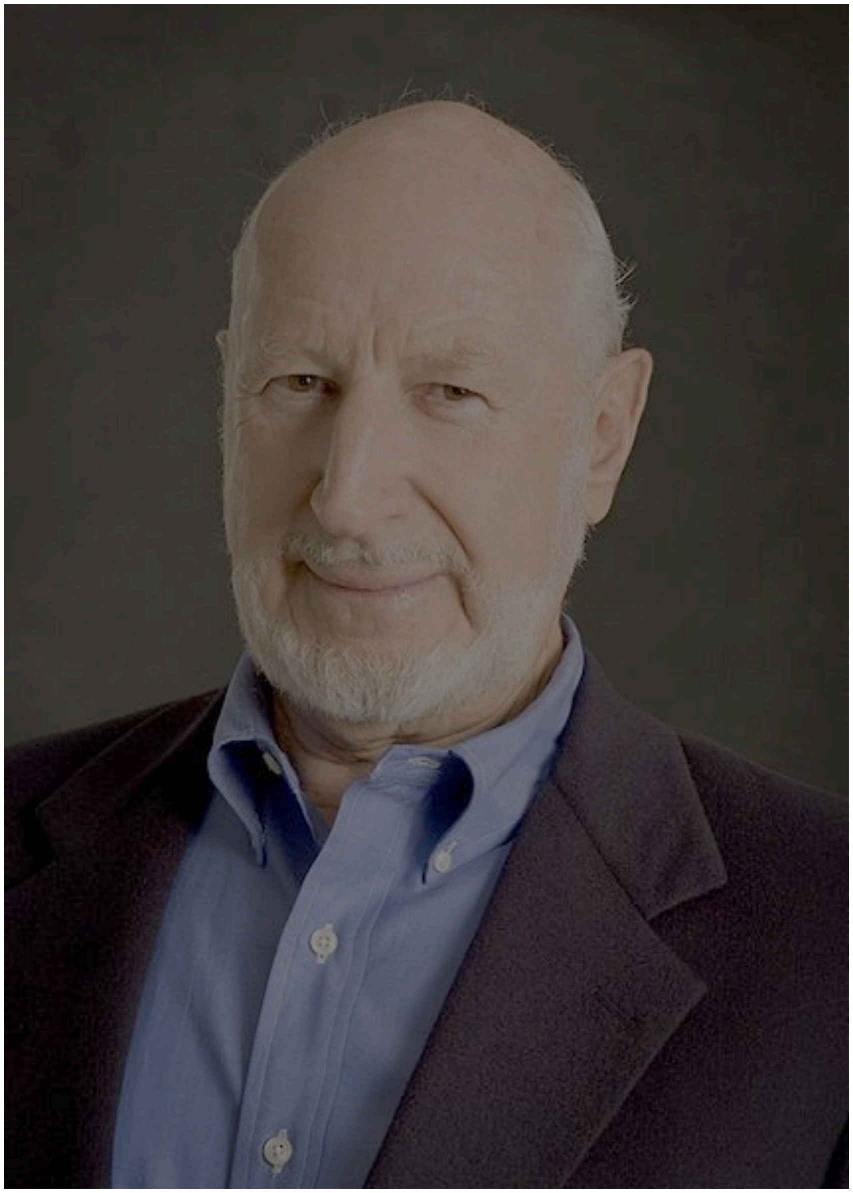
The Jewish-American engineer, computer scientist and professor at University of Hawaii **Norman Manuel Abramson** in 1960 year *developed the first computer network communicating by electromagnetic waves* / *the first wireless computer communication network* called ALOHAnet or ALOHA system or simply ALOHA using low-cost ham-like radios.
In the Hawaiian language the word "aloha" means affection/peace/compassion/mercy.
ALOHA had 7 computers deployed over 4 islands and a central computer on the Oahu Island.
ALOHA communicating without using phone lines, became operational in June 1971 year when demonstrated public the first wireless packet data network.

The first commercial automated cellular network (first generation cellular phones G1) was launched by the Nippon Telegraph and Telephone NTT corporation in Japan in 1979 year, followed by the launch of Nordic Mobile Telephone NMT system in Denmark, Finland, Norway and Sweden in 1981 year. They used analogue technology and offered only voice services.

Early laptop/portable computers appeared in 1980s with the first generation of wireless data modems developed by amateur communication groups.

In 1985 year, the Federal Communication Commission FCC, America's telecom regulator, transferred parts at 900MHz, 2.4GHz and 5,8GHz from ISM bands to communications entrepreneurs. ISM bands are portions of the radio spectrum reserved internationally for the use of radio frequency RF energy for **i**ndustrial, **s**cientific and **m**edical purpose.
Much later in 1997, inspired by the wire-line networking standard Ethernet was realised a common wireless standard. The equipment based on the new wireless standard operated under the name "Wi-Fi" in the 2.4 GHz and 5.8GHz bands, allowing data transfer at 2Mb/s and using spread spectrum technologies.

In 1989 year, the Voyager 2 spacecraft sent pictures of planet Neptune down to Earth laying the basis for satellite communication.



NORMAN ABRAMSON

Also, in 1989 year “World Wide Web” WWW was invented by the English scientist **Sir Timothy John Berners-Lee** when he proposed an information management system.

In 1996 year, RFC introduced a protocol that made possible the hyperlinked Internet, called *Hypertext Transfer Protocol* HTTP, an application protocol for distributed, collaborative, hypermedia information systems including graphics, audio, video, plain text and hyperlinks. HTTP is the foundation of data communication for the WWW, an information space where documents and other web resources are identified by Uniform Resource Locators URLs, are interlinked by Hypertext links and can be accessed by Internet.
The Internet access became wide spread using the old telephone and television networks.

Apple company’s laptop computers offered *first wireless connectivity in 1999 year* introducing Wi-Fi as an option under the name AirPort.
Wi-Fi is a short-range networking technology, an introduction in what will be possible with future wireless technology.
From now wireless communication has developed into a key element of modern society. Wireless communication has revolutionised the way the societies function, from satellite transmission, radio and television broadcasting, to the now ubiquitous mobile telephone.

In 1999 year, the Japanese firm NTT DoCoMo released the first “smartphones”. *Smartphone* is a cell mobile phone with an advanced mobile operating system that combines features of personal computer operating system with features useful for mobile use.
Smartphones became widespread in the late 2000s.
In 2007 Apple's iPhone was the first touchscreen smartphone to gain mass-market adoption. Most of smartphones produced from 2012 onward have high-speed, motion sensors and mobile payment features. 1 billion smartphones were in use worldwide in 2012. Global smartphone sales surpassed the sales figures for regular cell phones in early 2013.

Bluetooth technology was unveiled in year 1999 but only in 2000 year the manufacturers began to adopt it in mobile phones and computers.

In 2001 year, Apple company launched the *iPod,* which together with Apple's iTunes software, was the technology that really transformed the way people listened to music.
The device's sleek design made it desirable to own and with its large internal storage capacity was no longer necessary to carry around CDs or cassette tapes.

In 2003 year, the instant messaging application/computer program that provides online text message and video chat services called *Skype* has transformed the way people communicate across borders, speak and even video chat over WiFi. Initially only available as a desktop client, over time Skype was launched on mobile.

Nissan company manufactured a compact five-door hatchback electric car, a ***l****eading* ***e****nvironmentally-friendly* ***a****ffordable* ***f****amily car* LEAF*,* introduced in Japan and USA in Dec 2010 and in European countries and Canada in 2011 year.

IBM Watson is an artificially intelligent computer system capable of answering questions asked in an ordinary language. In year 2011, it competed on the American quiz show *Jeopardy* and beat the two greatest human champions. It represented an important milestone in the development of artificial intelligence AI - a field that has been progressing rapidly with innovations like the motion sensor Microsoft Kinect and the ordinary language voice command Apple Siri. In another breakthrough for AI, in 2016 year the artificial neural network *DeepMind* beat the world human champion at *Go*, an abstract strategy board game for two players in which the aim is to surround more territory than the opponent.

Google began testing self-driving vehicles in California in 2012 year with the intention to make them available by 2017. The cars have a top speed of 25 miles/hour and are designed to be perpetually in motion. If the concept becomes successful, it is thought that driverless cars could transform the way we move around cities in the future.

TERMS, CONCEPTS, TECHNICS & TECHNOLOGIES

Signal is a series of radio waves, light waves, electrical impulses.

Antenna or *aerial* is a rod, wire or other structure by which signals are transmitted or received as part of a radio (electromagnetic) transmission or receiving system, an essential component of all equipment using radio.

Wireless is used usually to describe communications in which electromagnetic waves carry an information signal over part/entire communication path from transmission to reception.

Carrier of message/information is the electromagnetic wave.

Message or *information* is the speech/voice, images/photos, business data.

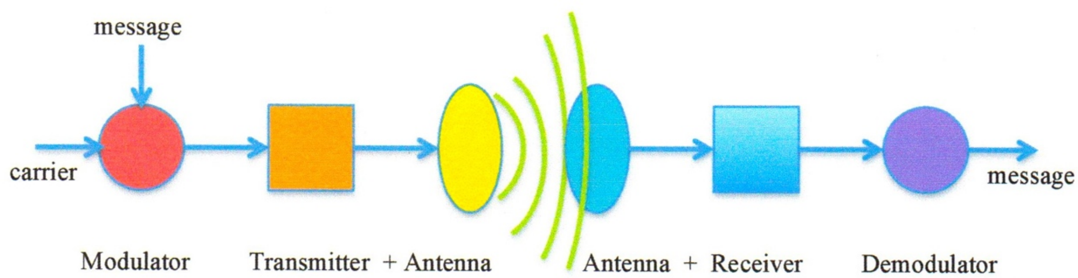
To be transmitted, the message/information is converted into an electrical form, an electric analogue or digital/discrete signal by suitable converters and added to the carrier. An analogue signal can be represented as a sum of simple sine waves of different frequencies in a frequency range w, the Fourier series. The modern technologies prefer the signal in digital/discrete form so the analogue signals are transformed in digital ones by “sampling”.

Sampling is the method by which an analogue signal with the highest frequency w is transformed in discrete samples or digital signal providing that the sampling rate exceeds 2w samples in conformity with the Shannon-Nyquist Theorem.

Modulation is the addition of message/information (in electrical form) to a carrier.

A device called *modulator* performs the modulation.
The information/message in electrical form is called the *modulating signal*.
The carrier wave has usually a much higher frequency than the modulating signal.
The modulation is done by varying/modulating one or more features of the carrier, for example: amplitude modulation, frequency modulation, phase modulation

Demodulation is the extraction of message from *modulated carrier*.
A device called *demodulator* performs the demodulation.



Communicating by electromagnetic waves

Bandwidth is a central concept in many fields, including electronics, information theory, digital communications, radio communications, signal processing and spectroscopy expressing the difference between the upper frequency and lower frequency in a continuous set of signal frequencies and is measured by *hertz* symbol Hz.

Communication channel is a concept in telecommunication and computer networking, referring to physical transmission medium/space/cable/wire of a signal or a multiplexed signal. The range of frequency of the electromagnetic waves that can be transmitted through a channel is called the *channel bandwidth* B and is measured by *hertz* symbol Hz.

Capacity is a concept used in connection with the communication channel. In electrical engineering, computer science and information theory, the *channel capacity* C is the upper bound of the rate at which information can be reliably transmitted over a communications channel and is measured by *bits per second* b/s.

The capacity C of a transmission channel with an **a**dditive **w**hite Gaussian **n**oise AWGN and **s**ignal to **n**oise ratio S/N, providing the channel bandwidth B, is stated by the Shannon-Hartley Theorem as $C = B \log_2(1+S/N)$ where:

B is the bandwidth given in Hz.

S/N is the signal-to-noise ratio expressed as a power ratio and is dimensionless.

C is the capacity measured in bits per second b/s if the logarithm is taken in base 2, or nats per second nat/s if the natural logarithm in base e=2.71828 is used.

Wider the bandwidth and lower the noise, greater the capacity of the communication channel.

Wider/*broader* the bandwidth of channel, greater is the information-carrying capacity of channel.

Data transfer rate DTR is the term for the amount of digital data that is moved from one place to another in a given time, that is the speed of travel of a given amount of data from one place to another, measured in *bits per second* b/s.

Greater the bandwidth of a given path, higher is the data/information transfer rate/speed.

Examples of data transfer rates are:

To the Internet a typical low-speed connection may be 33.6 kb/s.

On Ethernet local area networks, data transfer can be as fast as 10 Mb/s.

Network switches are planned to transfer data in the Tb range (1Tb=10^{12} bits).

Data transfer time between the microprocessor or RAM and devices such as the hard disk and CD-ROM player is usually measured in milliseconds.

In computers, data transfer is often measured in *bytes per second* B/s (1 byte=8 bits).

The highest data transfer rate to date is 14 Tb/s over a single optical fibre, reported by Japan's Nippon Telegraph and Telephone company NTT DoComo in 2006 year.

Broadband is a relative term, understood according to its context. Originally the word "broadband" used as "uncountable" was a concept in telecommunications meaning a wide band of electromagnetic waves frequencies, a technical term. Now "broadband" is a wide bandwidth data transmission with the ability to simultaneously transport multiple signals and traffic types. The medium can be coaxial cable, optical fiber, wire, wireless.

In consequence *broadband* is a high-capacity transmission technique using a wide range of frequencies, which enables a large number of messages to be communicated simultaneously.

In the context of Internet access, *broadband* is used to mean any high-speed Internet access that is always on and faster than the original Internet access technology, the traditional dial-up access, which was limited to 56 kb/s. The term became popularized through the 1990s as a marketing term for Internet access that was faster than the dial-up access.

The USA Federal Communications Commission FCC re-defined the *broadband,* to mean download speeds of at least 25 Mb/s and upload speeds of at least 3 Mb/s.

According to some standards, *broadband* means: having instantaneous bandwidths greater than 1 MHz and supporting data rates greater than about 1.5 Mb/s

Information capacity is a concept in Web hosting service, expressing the amount of data transferred to/from the website/server within a prescribed period of time and is measured in *gigabytes/time-period*.

To express the maximum amount of data-transfer each month it is used the term *monthly data transfer* which is measured in *gigabytes/month.*

Spectral efficiency, spectrum efficiency or *bandwidth efficiency* refers to the information rate that can be transmitted over a given bandwidth in a specific communication system.

It is measured in b/s/Hz.

Coverage is the concept indicating a geographic area where transceiver station can communicate. Broadcasters and telecommunications companies, in order to indicate to users the transceiver station's intended service area, produce *coverage maps* frequently.

The coverage depends on different factors: orography (mountains), buildings, technology, radio frequency, sensitivity & transmit efficiency of consumer equipment.

Electromagnetic waves of certain frequencies provide better regional coverage, while waves of other frequencies penetrate better through obstacles, such as buildings in cities.

The ability of mobile phones to connect to base station depends on the signal strength, which can be boosted by higher power transmissions, better and taller antennas or alternative solutions like in-building pico-cells. Normal Macro-Cell signals need to be boosted to pass through buildings, a problem in designing networks for large metropolitan areas with modern skyscrapers, hence the current drive for small-cells and micro-cells and pico-cells.

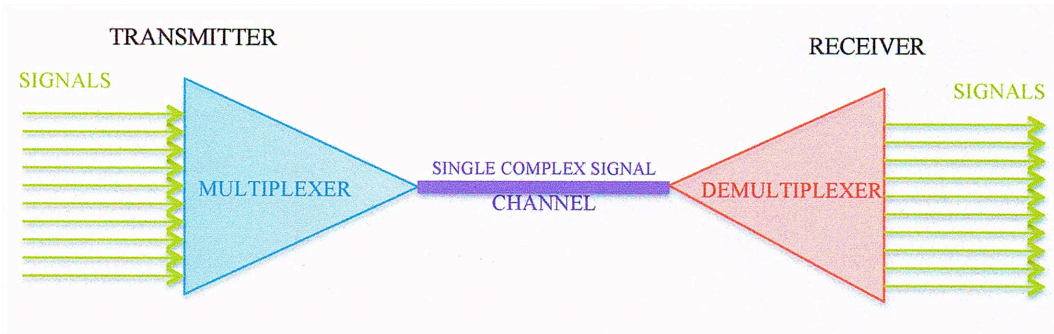
Signals also do not travel deep underground, so other transmission solutions are necessary for mobile phone coverage into underground parking garages and subways.

Seamless mobility is one of the paramount demands of the portable/mobile telephone users which gives the users access to mobile content with automatic switching between protocols, networks, communication channels, offers seamless access and connectivity across personal, local and wide area networks and allows the users to roam among home, office, car, hotspots, airports, campus and beyond without interruption.

Shared medium or *shared channel* is a medium/channel that serves more than one user at the same time, so the same communication medium/channel can be used by more transmitters.

Multiplexing or *muxing* is the concept by which multiple analogue or digital signals are sent at the same time over the same communication channel in a form of single complex signal: for example several telephone calls can use one wire.

The receiver recovers the separate signals by the method called *demultiplexing* or *demuxing.*



Multiple data signals are multiplexed as a single complex signal before transmitted over the communication channel and de-multiplexed at channel end

The American author and inventor **Major General George Owen Squier** (1865-1934) is credited with the development of the telephone carrier multiplexing in 1910 year.

Multiplexing is based on a multiple access protocol and control mechanism known as *media access control* MAC.

Media access control deals with issues such as addressing, assigning multiplex channels to different users and avoiding collisions. MAC is a component of the TCP/IP model.

The multiplexing is divided in more categories:

Space Division Multiplexing SDM - controls the radiated energy for each user in space.

SDM is achieved with multiple antenna elements forming a phased array antenna.

Examples are multiple-input and multiple-output MIMO, single-input and multiple-output SIMO and multiple-input and single-output MISO multiplexing.

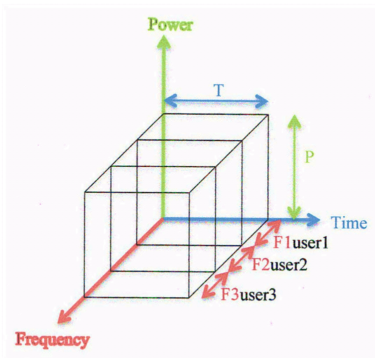
Polarisation Division Multiplexing PDM - is achieved using the polarisation of electromagnetic radiation for separation.

Frequency Division Multiplexing FDM - combines several signals in one by allocating to each signal a unique frequency band.

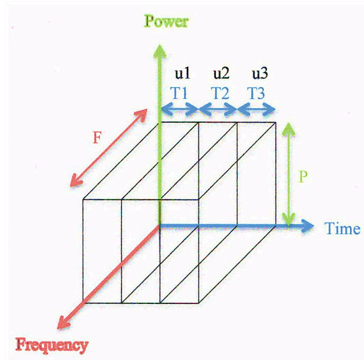
Time Division Multiplexing TDM - uses time to separate the signals, sending each signal through channel at different moments in time.

Code Division Multiplexing CDM - each user is assigned a special code sequence or “signature” to modulate its message signal, so all users are allowed to transmit over the same channel simultaneously.

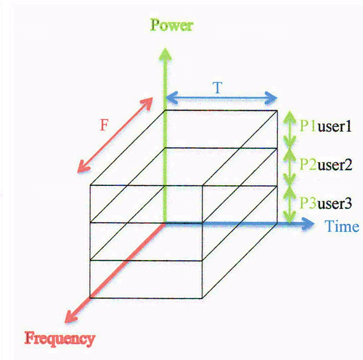
FDM, TDM and CDM multiplexing are realised by the multiple access techniques: frequency division multiple access FDMA, time division multiple access TDMA, code division multiple access CDMA.



FDMA



TDMA



CDMA

In FDMA the radio spectrum is divided into a set of frequency slots and each user is assigned a frequency slot to transmit. In TDMA several users transmit at the same frequency but in different time slots. In CDMA the users transmit at same frequency and time but the signals are modulated with high bandwidth spreading waveforms, called signature waveforms or codes, which have very low cross-correlation (similarity). In theory, CDMA, TDMA and FDMA have the same spectral efficiency but practically, each has its own challenges - power control in case of CDMA, timing in case of TDMA and frequency generation/filtering in case of FDMA.

Wireless is used in connection with information transmitters, information receivers or information transceivers (combined transmitters & receivers), computer networks, network terminals, remote controls, microwaves, infrared light, laser light, visible light, acoustic energy which transfer information without the use of wires.

Wireless connections may involve point to point communication, point to multipoint communication, broadcasting, cellular networks or other networks.

Wireless technology - technology that uses electromagnetic waves to transmit and receive data - it is used for long-range communications that are impossible or impractical to implement with the use of wires, to span a distance beyond the capabilities of typical cabling or financially impractical, to provide backup communications link in case of network failure, to link portable or temporary workstations, to remotely connect mobile users or networks.

Wireless networks include cell phone networks, computer networks as local area networks LANs or wide area networks WANs, wireless sensor networks, satellite communication networks and terrestrial microwave networks.

Wireless networking could be the method by which communications networks (collection of linked communication points or nodes), enterprise installations and homes avoid the costly process of introducing cables into a building or between various equipment locations.

Wireless communication networks are generally implemented and administered using the electromagnetic waves.

A wireless communication network has to offer *coverage, capacity, data rate/speed, continuity, security, quality of service, cost efficiency*. For example, wireless wide-area networks are limited by coverage in low traffic areas and by capacity in high traffic areas.

Wireless communication can develop a wide range of *services* like broadcasting services, portable/mobile communications services for voice and data including maritime, aeronautical, airplanes, land communications; it can also develop satellite, amateur radio, military, radio astronomy, meteorology and science services.

Bluetooth is a wireless technology standard for exchanging data over short distances using the radio electromagnetic waves UHF in the ISM band from 2.4 to 2.485 GHz for fixed and mobile devices and personal area networks PANs.

ZigBee is a specification for a suite of high-level communication protocols used to create personal area networks with small, low-power digital radios for home automation, medical device data collection and other low-power low-bandwidth needs, designed for small scale projects which need wireless connection. The technology defined by the ZigBee specification is intended to be simpler and less expensive than Bluetooth or Wi-Fi.

Z-Wave is a wireless communications protocol used primarily for residential control and automation market like wirelessly control lighting, security systems, home cinema, garage, spa, swimming pool, automated window, HVAC (**h**eating, **v**entilation, **a**ir **c**onditioning) and home access. Like other protocols and systems aimed at home and office automation market, a Z-Wave automation system can be controlled via the Internet.

Wi-Fi is a wireless technology that allows a computer, laptop, mobile phone or tablet device to connect at high speed to the Internet. The rise of the Internet and the consumer desire to be connected to it at all times drove deployment on high-speed data communications on Wi-Fi. The wireless industry organization Wi-Fi Alliance considers more than 15 billion Wi-Fi enabled devices in 2016 year. Wi-Fi technology is cheap and embedded in a growing number of devices, making it the technology of choice for the foreseeable future.

WiMAX is described as a standards-based technology enabling the delivery of wireless broadband access as an alternative to cable at 2-11 GHz. In practical terms, WiMAX would operate similar to Wi-Fi but at higher speeds, greater distances and for larger number of users.

Initially designed to provide 30 to 40 Mb/s data rates, with the 2011 update WiMAX provides up to 1 Gb/s for fixed stations. It could potentially erase the suburban and rural blackout areas that have no broadband Internet access because phone and cable companies did not yet run necessary wires to those remote locations.

Global area network GAN is proposed as the final step in the area network range. GAN is a type of interconnection of terminals that does not have a geographical limitation and can connect computers from various countries. It is a network regrouping several computers and LANs together in a bigger net.

MOBILE PHONE EVOLUTION

A *mobile phone* is a *portable telephone* that can make/receive calls over an electromagnetic wave link from any location in a certain geographical area.
A mobile phone is an electronic telecommunications device, a wireless handheld device that allows users to make calls and send text messages, among other features.
The mobile phone is one of the greatest successes of human communication.
The earliest generation of mobile phones could only make and receive calls, now they offer a long list of capabilities that bring an even longer list of challenges for service providers.
Today's mobile phones are packed with many additional features, such as web browsers, games, cameras, video players and even navigational systems.
The history of portable or mobile telephones can be broken into 8 periods: pre-cellular, first generation of cellular phone, second generation of cellular phone, third generation of cellular phone, fourth generation of cellular phone, fifth generation of cellular phone, sixth generation of cellular phone and seventh generation of cellular phone.

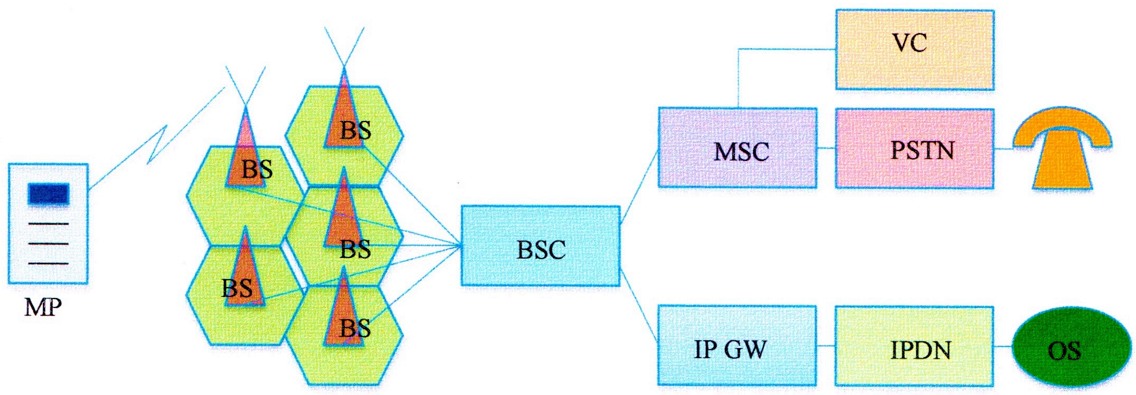
1. *Pre-cellular* period was the period of Mobile Radio Telephone systems, preceding the first generation of cellular telephones. These early mobile telephone systems are distinguished from earlier closed radiotelephone systems because are a commercial service, part of the public switched telephone network PSTN with own telephone numbers and not part of closed networks of police or taxi radio systems.
Motorola Company in conjunction with the Bell System (the system of companies led by the Bell Telephone Company) operated the first commercial mobile telephone service called "Mobile Telephone System" MTS in the USA in 1946 year, followed by "Improved Mobile Telephone Service" IMTS with the first automatic dialling in 1964 year.
West Germany launched "A-Netz" in 1952 year, UK launched "System1" in 1959 year,
USSR launched the first automatic mobile system in Europe "Altai" in 1965 year,

Norway opened “Televerket” in 1966 year, Finland launched “Autoradiopuhelin” ARP in 1971 year, West Germany launched in 1972 year the second commercial mobile phone network “B-Netz” which was the first not requiring human operators to connect calls.
These mobile telephones were placed in vehicles as cars or tracks but briefcase models there were also. Only few people were able to use this device because only 25 channels were available and they could connect to local telephone network only if it was in the range of 20 km.
In USA in parallel to IMTS was a competing mobile telephone technology called “Radio Common Carrier” RCC, which was operated by private companies and individuals.

The introduction of *cellular technology* for portable/mobile phones, greatly expanded the efficiency of the electromagnetic spectrum use. The mobile phone became the cell phone.
Cellular technology has multiple low-power transmitters of 100W or less.
Because the range of such transmitters is small, a large geographic area is divided into small geographic areas or cells each served by its own antenna. Different users in different, but non-adjacent, cells are able to use the same electromagnetic wave for a call without interference.
The hexagonal shape of cells provides for equidistant antennas at distance d function of radius R of hexagon $d=R\sqrt{3}$. As cells become smaller, antennas move from the tops of tall buildings or hills, to the tops of small buildings or sides of large buildings, finally to lampposts where they form microcells.
A simplified cellular system is illustrated further.
The mobile phone MP is wirelessly connected to the Base Station BS supported by the Base Station Controller BSC. Traditional voice circuit VC is supported through a Mobile Switch Centre MSC both directly and in connection to a public switched Telephone Network PSTN.
The BSC can also be connected to an IP Gateway/Router to support packet data services.

In next figure:

MP = Mobile Phone
BS = Base Station
BSC = Base Station Controller
MSC = Mobile Switching Centre
VC = Voice Circuit
PSTN = Public Switched telephone Network
IP GW = IP Gateway
IPDN = Internet Packet Data Network
OS = Operator Service



Basic Wireless Communication Cellular System

The history of cellular telephones covers the next 7 periods of the history of mobile telephones under the name of "generations". Each generation G has new features, which differentiate it from the previous one and generally refers to a change of system, technology, speed and frequency.

2. *First Generation* of cellular phone /1G/ was launched in Japan in 1979 year and developed around the world using different, incompatible analogue technologies. While Scandinavia developed the "Nordic Mobile Telephone" NMT system, in USA there was the "Advanced Mobile Phone System" AMPS, UK had the "Total Access Communications System" TACS, Germany developed "C-Netz". The result was a wide range of largely incompatible systems particularly in Europe, although AMPS system was used throughout USA.
A 7-cell reuse pattern was adopted for AMPS, which used analogue technology for frequency modulation FM in frequency band 800-900 MHz with FDM multiplexing, data rates 1-2.4 kb/s and offered only voice/speech services.

3. *Second Generation* of cellular phone /2G/ developed in 1980-1990 years reversed in digital the earlier analogue mobile experience 1G by using the new digital technology.
Second generation digital systems can be classified by their multiple access techniques as FDMA, TDMA or CDMA. In practice TDMA and CDMA are combined with FDMA.
In Europe, a common standard was adopted, partly due to government intervention, called "Group Special Mobile" GSM, which was the first 2G system.
Under the auspices of the European Technical Standards Institute ETSI, GSM was standardized in 1990 year with the new name "Global System for Mobile Communication", which described the protocols for 2G networks and first deployed in Finland in December 1991.
The standardized GSM could allow a mobile phone to be used outside the range of its home network, connecting to other available cell network by full international roaming, automatic location services, common encryption and relatively high-quality audio.

GSM is now the most widely used 2G system worldwide, in more than 200 countries.
In contrast, a variety of incompatible 2G standards developed in the United States of America.
The failure of USA to adopt a common 2G standard, with the associated benefits in terms of roaming and switching of handsets, led to first generation AMPS system remaining the most popular mobile technology in USA throughout the 1990s.
2G provides primary benefits as: digital encryption, spectrum significantly more efficient used and data services such as text, picture and multimedia messages. It uses the frequency bands 850-1900 MHz (GSM) and 825-849 MHz (CDMA) and data speeds/rates 14 kb/s - 64 kb/s.
Generation /2.5G/ developed in 2000-2003 years introduced the packet network to provide higher data speeds of 115kb/s -384kb/s.

4. *Third Generation* of cellular phone /3G/ allows significantly increased speeds/rates of transmission for data services. 3G phones can be used for Internet access, downloading music & videos, e-mail services and rapid transmitting images from camera phones.
An attempt to establish an international standard for 3G mobile was moderated through ITU, under the auspices of its International Mobile Telecommunications program in 2000 year called IMT-2000, which determined that 3G technology should be based on CDMA systems.
At the ITU's World Radiocommunication Conference in 2000 year, spectrum bands for IMT-2000 systems were allocated on a worldwide basis between 0.8 - 2.5 GHz. Data transfer speeds are in the range 384 kb/s - 2 Mb/s.
By year 2002, the only 3G system in operation was in Japan, although numerous companies have plans for 3G systems in the next years.

The growth in use of mobile telephones has been spectacular. From almost a zero base in the early 1980s, mobile penetration worldwide in 2002 year is estimated at 15.57 mobile phones per 100 people worldwide. But the level of penetration differs between countries. In the United States of America were 44.2 mobile telephones per 100 inhabitants; the penetration rates were 60.53 in France, 68.29 in Germany, 77.84 in Finland and 78.28 in the United Kingdom; the penetration rate in Australia was 57.75, in New Zealand 62.13 and 58.76 in Japan; India had only 0.63 mobile telephones per 100 inhabitants, Kenya had 1.60, China 11.17 and Malaysia 29.95.
The number of mobile phones exceeded the number of fixed-wire telephone lines in a variety of countries including Germany, France, United Kingdom, Greece, Italy and Belgium.
However, the fixed-lines outnumbered mobiles in the United States of America, Canada and Argentina. Penetration rates were close to equal in Japan already in 2001 year.
But mobile penetration is rising much faster than fixed lines in all countries.

5. *Fourth Generation* of cellular phone /4G/ stands for fourth generation of cellular phone communications standards. In 2008 year, ITU Radiocommunication Sector ITU-R specified the IMT-Advanced requirements for 4G systems to transmit and receive larger amounts of data and at higher rate/speed.

New requirements include increasing throughputs and bandwidths, increased spectrum efficiency and network capacity, lower delays and round-trip times.
The main goal of 4G technology, an all IP based network system, is to provide high speed, high quality, high capacity, security and low cost services for voice and data, multimedia and Internet. 4G aims to support current and emergent multimedia services, social networks and gaming, mobile TV, high-definition television HDTV and video teleconference, digital video broadcast DVB, multimedia messaging service MMS with improved quality of service.
4G wireless communication systems aim to allow indoor and outdoor peak data rates in the range of 1 Gb/s for stationary access and 100 Mb/s for vehicular mobility.
For 4G, North America has used electromagnetic waves bands in the range 700-2600 MHz, South America 2500 MHz, Europe 700-2600 MHz, Asia 800-2600 MHz, Australia & N Zealand 1800-2300 MHz and Multiplexing/Access Technologies: OFDM (orthogonal), MC-CDMA (multiple carrier), LAS-CDMA (large area synchronized), Network-LMDS (local multipoint distribution service).

From 1983 to 2014, worldwide mobile phone subscriptions grew to over seven billion, penetrating 100% of the global population. The wireless networking has become commonplace.

6. *Fifth Generation* of cellular phone /5G/ was initiated in 2015 year because the 4G devices created and consumed growing amounts of data and was designed to process that but also to allow a future wireless standard to address new applications underserved by existed wireless standards, each requiring a new and different set of key performance indicators KPIs.
Unlike previous generations of cellular, 5G is more than a new air interface, it is a completely new network architecture.
With mobile traffic expected to increase by a factor of 1,000 over the next decade, 5G technology is the next generation of mobile technology that is due to start arriving in 2020 year.
But 5G is not just another consumer-oriented service providing a lower latency, speedier version of 4G. Amongst its many objectives is an ability to deliver higher capacities and thus enable operators to serve more user devices in a given area. Many of these will be Internet of Things IoT or machine-to-machine M2M services of various kinds. Some will require mains power to drive more demanding M2M applications. Some will be low speed long life services, battery driven.
It will offer ultra-low latency for performance-wise applications like gaming, remote brain surgery and updating autonomous cars.
ITU-R coined in 2012 year the International Mobile Telecommunication system for 2020 and beyond called IMT-2020 that defined three cases for high-level use of 5G: enhanced mobile broadband eMBB, massive machine type communication, ultra-reliable machine type communication
eMBB envisions a peak-data rates of 10 Gb/s, 100x over 4G.
In September 2015, ITU-R finalized its vision of the 5G mobile broadband connected society, driving to the standardisation of 5G.

Data rates are empirically linked to available spectrum according to the Shannon-Hartley Theorem, which states that the capacity of transmission channel is a function of bandwidth and channel noise. As solution researchers have looked to electromagnetic waves of higher frequencies offering wider bandwidths.

With the spectrum below 6 GHz fully allocated, the spectrum above 6 GHz, specifically in the mmWave range, presents an attractive alternative to address eMBB use case.

mmWave technology is one of the new 5G technologies and is deployed quickly.

The large amount of contiguous bandwidth available above 24 GHz is needed to meet data throughput requirements and researchers have already shown through prototyping that mmWave technology can be used to deliver data rates above 14 Gb/s.

As the next step in the continuous innovation and evolution of the mobile industry, the fifth generation of cellular phone 5G will not only be about a new air interface with faster speeds, but it will also address network congestion, energy efficiency, cost, reliability and connection to billions of people and devices.

5G brings forward a real wireless world - the Wireless World Wide Web WWWW.

Qualcomm, a company of engineers, scientists and business strategists, envisioned 5G as much more than just a new generation of mobile, but rather a new kind of network that will transform industries, impact economies and societies and ultimately change the world. And to better understand this impact, the company recently commissioned the landmark research project called "The 5G Economy". Also, it is collaborating with industry leaders towards 5G commercialization.

Qualcomm vision for 5G is: enhanced mobile broadband, mission critical services, massive Internet of Things IoT

5G will advance mobile from largely a set of technologies connecting people-to-people and people-to-information to a unified connectivity - connecting people to everything.

In 2035 year, when 5G's full economic benefit should be realized across the globe, a broad range of industries - from retail to education, transportation to entertainment and everything between - could produce up to $12.3 trillion worth of goods and services.

The 5G value-chain alone could generate up to $3.5 trillion in revenue and support up to 22 million jobs.

Over time, the total contribution of 5G to the total global **g**ross **d**omestic **p**roduct GDP growth is expected to be the same as that of a country like India, the seventh largest economy in the world.

GDP is the monetary measure of the market value of all final goods and services produced in a quarterly/yearly period.

5G dominated the debate at the Mobile World Congress MWC held in Barcelona Spain between 27 February-2 March 2017 from standards development to spectrum harmonisation, from demonstrations to alliances. The year 2017 is the year providing us all an opportunity to think of new ways to manage spectrum beyond the simple split of shared or owned.

Multiple-Input Multiple-Output MIMO is a wireless technology that uses multiple transmitters and receivers to transfer more data at the same time at higher speeds. Massive MIMO will manage interference spatially and share spectrum in both frequency and space like never before.
New innovative technologies bring broader bandwidth, faster data rates and longer battery life.
A new module, a square device 2.8 inches each side, designed for use in 5G base stations was developed by the companies Ericsson and IBM. It consists of 4 monolithic integrated circuits and 64 dual-polarized antennas.
The biggest benefit of 5G will be enabling mobile operators to deliver data more cost effectively.
Despite 5G standards not being expected until 2020 year, twenty-five operators are testing across a wide range of bandwidths, ranging from sub-3GHz to 86GHz. Of the operators that have disclosed their test spectrum, currently the most commonly trialled wavelength is 28GHz, with eight operators using it, as well as 15GHz, which is being used in trials by seven operators.
According to Viavi, five operators have reached data rates over 35 Gb/s.
A survey commissioned by the Telecommunications Industry Association TIA and developed in collaboration with subject matter experts from InterDigital and Tolaga Research companies reached the conclusion:
“5G needs to be a *chameleon technology* if aims to achieve a unified network architecture, optimized to support agile business models and diverse applications with wireless connectivity”.
TIA is accredited by the American National Standards Institute ANSI to develop voluntary, consensus-based industry standards for a wide variety of Information and Communication Technologies ICT products, and currently represents nearly 400 companies.

7. *Sixth Generation* of cellular phone /6G/ will integrate 5G with telecommunication satellite networks, earth imaging satellite networks and navigation satellite networks, providing multimedia and Internet connectivity, weather information, position identifier, cheap and fast up to 11 Gb/s.
To broadcast such high-speed electromagnetic signals, Nano-Antennas will be implemented at different geographical positions along roadsides, villages, malls, airports, hospitals etc.
Fly Sensors will provide information to remote observer stations, which will check any activity in some areas.
The point-to-point wireless communication networks that transmit super-fast broadband signals through the air will be assisted by high-speed optical fibres lines to broadcast much secured information from transmitters to destinations.
Beside home automation and smart homes/cities/villages with the next step a connected smart globe, the networks would be involved in capturing energy from galactic world, natural calamities control, mind to mind communication.

8. *Seventh Generation* of cellular phone /7G/ would deal with space roaming.
A wireless world will demand access to information anytime, anywhere, at high speed with increased bandwidth at minimal cost and with better quality.

references

NIKOLA TESLA - ELECTRICAL WORLD 1917

HOW TO BECOME A WIRELESS OPERATOR - CHARLES B. HAYWARD 1919

RADIO TELEGRAPHY AND TELEPHONY - RUDOLF L. DUNCAN, CHARLES E. DREW 1929

EARTH, RADIO AND THE STARS - HARLAN TRUE STETSON 1934

ULTRA-HIGH-FREQUENCY TECHNIQUES - GLENN KOCHLER, HERBERT J. REICH, L. F. WOODRUFF & EDITOR J. G. BRAINERD 1942

SHORT WAVE WIRELESS COMMUNICATION - A.W. LADNER, C.R. STONER 1946

INSTRUMENT MANUAL - PAUL H. HUNTER 1947

THEORY AND APPLICATION OF MICROWAVES - ARTHUR B. BRONWELL, ROBERT E. BEAM 1947

FIELDS AND WAVES IN MODERN RADIO - SIMON RAMO, JOHN R. WHINNERY 1953

MICROWAVE ENGINEERING - A. F. HARVEY 1963

BAZELE ELECTROTEHNICII - A. TIMOTIN, A. TUGULEA 1964

FIELDS AND WAVES IN COMMUNICATION ELECTRONICS BY SIMON RAMO, JOHN R. WHINNERY, THEODORE VAN DUZER 1965

VLF RADIO ENGINEERING - ARTHUR D. WATT 1967

WAVE TRANSMISSION - F.R. CONNOR 1972

TUNNING IN TO NATURE - PHILIP S. CALLAHAN 1977

DIGITAL MICROWAVE RECEIVERS - JAMES BAO-YEN TSUI 1989

TESLA: MAN OF MYSTERY - MICHAEL X 1992

WIRELESS COMMUNICATION - ANDRES LLANA JR 1994

MOBILE RADIO TECHNOLOGY - GORDON WHITE 1994

NAVAL SHIPBOARD COMMUNICATIONS SYSTEMS - JOHN C. KIM, EUGEN I. MUEHLDORF 1995

WIZARD: LIFE AND TIMES OF NICOLA TESLA - MARC SEIFER 1996

WIRELESS PERSONAL COMMUNICATION SYSTEMS - STEPHEN NELSON, DEREK ROGERS, REG COUTTS 1996

THE PHYSICS OF INFORMATION TECHNOLOGY - NEIL GERSHENFELD 2000

WIRELESS COMMUNICATIONS PRINCIPLES AND PRACTICE - THEODORE S. RAPPAPORT 2002

WIRELESS COMMUNICATIONS & NETWORKS - WILLIAM STALLINGS 2005

WIRELESS COMMUNICATIONS - ANDREAS F. MOLISCH 2005

WIRELESS COMMUNICATIONS - ANDREA GOLDSMITH 2005

MOBILE AND WIRELESS COMMUNICATIONS - GORDON A. GOW, RICHARD K. SMITH 2006

HOW WIMAX WORKS - MARSHALL BRAIN, ED GRABIANOWSKI 2006

TESLA INVENTED RADIO, NOT MARCONI! - LOUIS E. FRENZEL 2007

WIRELESS COMMUNICATIONS FUTURE - WILLIAM WEBB 2007

A GUIDE TO THE WIRELESS ENGINEERING BODY OF KNOWLEDGE (WEBOK) -
G. GIANNATTASIO, J ERFANIAN, P.WILLS, H.NGUYEN, T. CRODA, K. RAUSCHER, X. FERNANDO, N. PAVLIDOU, K. D. WONG 2009

ADVANCED POWER MANAGEMENT TECHNIQUES IN NEXT GENERATION WIRELESS NETWORKS - RONNY YONGHO KIM, SHANTIDEV MOHANTY 2010

ENERGY HARVESTING ACTIVE NETWORKED TAGS (EnHANTs) FOR UBIQUITOUS OBJECT NETWORKING - M. GARLATOVA, P.KINGT, I. KYMISSIS, D. RUBENSTEIN, W XIAODONG, G. ZUSSMAN 2010

FUNDAMENTALS OF WIRELESS COMMUNICATION ENGINEERING TECHNOLOGIES - K. DANIEL WONG 2011

THE INCREDIBLE GENIUS THAT AMERICA IGNORED - MICHAEL MICHALKO 2012

A GUIDE TO THE WIRELESS ENGINEERING BODY OF KNOWLEDGE (WEBOK) - EDITOR ANDRZEJ JAJSZCZYK 2012

INCENTIVIZING TIME-SHIFTING OF DATA - S. SEN, C. JOE-WONG, SANGTAE HA, MUNG CHLANG 2012

EVOLVED MULTIMEDIA BROADCAST/MULTICAST SERVICE (EMBMS) IN LTE ADVANCED - DAVID LECOMPTE, FREDERIC GABIN 2012

OVERCOMING SPECTRUM SCARCITY - KATHY PRETZ 2012

LTE DEPLOYMENT: GETTING IT RIGHT THE FIRST TIME - ALLIE WINTER 2012

VINT CERF: A BRIEF HISTORY OF PACKETS - CHARLES SEVERANCE 2012

WIRELESS COMMUNICATIONS - JOSHUA S. GANS, STEPHEN P. KING, JULIAN WRIGHT 2012

TESLA: INVENTOR OF THE ELECTRICAL AGE - W BERNARD CARLSON 2013

TRANSMISSION TECHNIQUES FOR 4G SYSTEMS - MARIO MARQUES DA SILVA, AMERICO CORREIA, RUI DINIS, NUNO SOUTO, JOAO CARLOS SILVA 2013

REGULATIONS CONTINUE TO SHAPE WIRELESS INDUSTRY - DAN MEYER 2013
SMALL CELLS SET TO BE A BIG PART OF LTE - DAN MEYER 2013

WHERE ARE YOU, VoLTE? - ALLIE WINTER 2013

DEVICE-TO-DEVICE COMMUNICATIONS UNDERLYING CELLULAR NETWORKS - D. FENG, LU LU, YI YUAN- WU, G. FENG, S. LI 2013

SCALING MOBILE NETWORK SECURITY FOR LTE: A MULTI-LAYER APPROACH - PATRICK DONEGAN 2014

REVOLUTIONIZING MOBILE ASSURANCE IN THE ERA OF 4G/LTE - PATRICK KELLY, TARA VAN UNEN 2014

IT'S A MOBILE DEVICE REVOLUTION - ELENA NEIRA 2014

TAMING THE COMPLEXITY OF MM-WAVE MASSIVE MIMO SYSTEMS: EFFICIENT CHANNEL ESTIMATION AND BEAMFORMING - STEFANO MONTAGNER, STEFANO TOMASIN 2015

INVESTING IN HETNETS: CARRIER, VENDOR AND ANALYST PERSPECTIVES - MARTHA DEGRASSE 2015

FARADAY AND THE ELECTROMAGNETIC THEORY OF LIGHT - AUGUSTO BELENDEZ 2015

WHAT TECHNOLOGY INVENTIONS ARE REQUIRED TO MAKE 5G NEW RADIO NR A REALITY - JOHN SMEE, MATT BRANDO 2016

mmWAVE: BATTLE OF THE BANDS - SARAH YOST NI 2016

LiFi UNLOCKING UNPRECEDENTED WIRELESS PATHWAYS FOR OUR DIGITAL FUTURE - HARALD HAAS, NIKOLA SERAFIMOVSKI 2016

EVOLUTION OF MOBILE COMMUNICATION FROM 1(G) TO 4G, 5G, 6G, 7G … - AARTI DAHIYA 2016

THE ESSENTIAL ROLE OF GIGABIT LTE & LTE ADVANCED PRO IN A 5G WORLD - BASMUS HELLBERG, SUNIL PATIL 2017

TEN COMMUNICATION TECHNOLOGY TRENDS FOR 2017 - ALAN GATHERER 2017

PREPARING LINEARITY AND EFFICIENCY FOR 5G - NOEL KELLY, WENHUI CAO, ANDING ZHU 2017

5G FUTURE - STEVE MOLLENKOPF , QUALCOMM 2017

ERICSSON AND IBM ANNOUNCE 5G BASE STATION CHIP - MARTHA DEGRASSE 2017

TIGHT FOCUS TOWARD THE FUTURE - NILS WEIMANN, MARUF HOSSAIN, VIKTOR KROZER, WOLFGANG HEINRICH, MARCO LISKER, ANDREAS MAI, BERND TILLACK 2017

PUSHING THE ENVELOPE FOR HETEROGENEITY - KAMAL K. SAMANTA 2017

HOW LOW POWER WIDE AREA NETWORKS LPWANs ARE REVOLUTIONISING THE WIRELESS WORLD - BOYD MURRAY 2017

25 MOBILE OPERATORS ALREADY TESTING 5G TECHNOLOGY - GUY DANIELS 2017

mmWAVE AND MASSIVE MIMO IN NEXT-GENERATION WIRELESS SYSTEMS - MODERATOR: MIGUEL DAJER 2017

IEEE RELEASES DETAILS ABOUT ITS 5G AND BEYOND ROADMAP - KATHY PRETZ 2018

LIVE SCIENCE

WEBOPEDIA

TECHNOPEDIA

WIKIPEDIA

WIKIMEDIA COMMONS