III. Wireless Technologies in Mobile Devices

Prof. Tsvetozar Georgiev
University of Ruse

1. First generation (1G)

- Although it has long become a part of our daily lives, wireless mobile communication is a rapidly developing branch of information technology and constantly has something new to show. For the relatively short period of time in which they have existed and been established - barely three decades, mobile communications have gone through several different stages of development, called "generations" by specialists.
- The first generation of mobile communications (1G) will be remembered for the huge portable phones, the coverage of which was relatively small, and the conversations conducted with them - extremely unprotected from eavesdropping.

1. First generation (1G)

2. GSM (Global System for Mobile Communications) (2G)

- What consumers today call GSM is actually an established second-generation (2G) mobile communications standard. It is distributed in European countries and offers a better level of protection of the exchanged information, as well as a large set of functional options - SMS, MMS, roaming, etc. The analogue of GSM for Asia is called CDMA and is characterized by the same features as GSM.
- With GSM technology, several users simultaneously share the same operating frequency without interfering with each other. The frequency is divided into several time slots, and each user transmits data only in the period of its time slot. In this way, all clients using the same data exchange frequency are alternated .

2. GSM (2G)

2.1. CSD (Circuit Switched Data)

- It is a second generation data transfer technology. One of the main problems with it is the slow connection. The maximum speed it offers is only 9.6 Kbps and is achieved with the so-called single time slot (single time slot). However, there are several timeslots in use at the same time, and it is theoretically possible for two or more of them to be merged. CSD is quite an outdated technology, but in practice some mobile operators still support this specification for data transfer.
- billed for the duration of the established connection between the workstations. This is inconvenient because, regardless of whether information is exchanged with the opposite system or not, the period for which the user is connected to it is billed.

2. GSM (2G)

2.1. CSD (Circuit Switched Data)

- Like dual ISDN channels that double 64 Kbps to 128 Kbps (this bundling is called aggregation), the timeslots used by CSD can be bundled. In the mobile world, aggregation is known as HSCSD (High Speed Circuit Switched Data) and includes optional radio communications enhancement.
- Some of the improvements include improving the algorithms for correcting errors that may have occurred during transmission in the radio frequency area. In CSD, it was found that a large part of the data exchange bandwidth between the two stations is covered by multiple error correction algorithms .

2. GSM (2G)

2.1. CSD (Circuit Switched Data)

- The improvement in HSCSD leads to a nearly 50 percent increase in the transfer rate, and so from 9.6 Kbps, the effective transfer reached about 14.4 Kbps in a single time slot. By combining several time slots, it becomes even possible to reach higher exchange rates - often times up to 57.6 Kbps.
- This method takes too much of the limited resources. Web browsing, for example, does not require a constant transfer because data is only sent when the page is changed. Therefore, the most suitable method in this case is packet switching.

2. GSM (2G)

2.2. GPRS (General Packet Radio Service)

- GPRS adds a packet switching layer to existing GSM mobile networks. The technology is a data transmission system that uses free channels in the GSM network.
- Unlike the legacy CSD (Circuit Switched Data) system, here multiple users share a single transmission channel, used only when some of them have a packet of information to send. In these cases, the entire free connection is transferred to them, while with CSD, a user occupies the entire connection while it is on, regardless of whether it sends anything or not.
- GPRS is charged per kilobyte of transmitted information, and CSD - per second.

2. GSM (2G)

2.2. GPRS (General Packet Radio Service)

- Since GPRS uses the free channels in the GSM network, the data transmission speed depends on the load of the given cell. If the number of calls in it is high, the GPRS channel narrows.
- GPRS class 10 means that there are 4 slots for receiving information and 2 for sending, but a total of 5 slots can be used at a given time (i.e,. 4+1 or 3+2). GPRS class 8 has 4 receive slots and 1 send slot (only supports 4+1). The speed at GPRS class 10 for receiving is 57.6 kbps (at 4+1) and for sending – 28.8 kbps (at 3+2) if the time slot speed is 14.4 kbps .

2. GSM (2G)

2.3. EDGE (Enhanced Data Rates for Global Evolution)

- EDGE is a method of increasing the bandwidth of the GSM network.
- In practice, EDGE is a way to encode signals more efficiently, through which more data or voice is transmitted over the same radio resource. EDGE is an upgrade to GPRS and cannot work by itself. In this sense, the EDGE technology is also known under the name EGPRS (Enchanted GPRS).
- If the GSM network supports EDGE in the user's location, EDGE is automatically used, which offers higher quality and speed at the same price.

2. GSM (2G)

2.3. EDGE (Enhanced Data Rates for Global Evolution)

- In theory, the maximum speed that can be obtained after aggregation of all eight time slots reaches 473.6 kbps. In most cases, the effective transfer using EDGE reaches 236 kbps.
- In practice, EDGE represents the last developed technology before the appearance and launch of the third generation of communications.

2. GSM (2G)

2G
2G
Year 1991
Standards GSM, GPRS, EDGE
Technology Digital
Bandwidth Narrow Band
Data rates < 80 - 100 Kbit/s
SMS / MMS

3. 3G

3.1. UMTS (Universal Mobile Telecommunications System)

- UMTS is a third generation (3G) mobile communications standard. It provides up to five times higher data transfer speed than GPRS: up to 384 kbps for data download and up to 64 kbps for upload.
- With the help of the UMTS network, services such as video calling, high-speed Internet access, e-mail or watching TV on the mobile phone can be used.
- Often UMTS technology is called 3G for short.

3. 3G

3.2. HSPA (HSDPA/HSUPA)

- HSDPA (High Speed Downlink Packet Access) is a UMTS based technology. Quite often it is referred to as 3.5G. The HSDPA technology allows an increase in the maximum speed for downloading information up to 14.4 Mbps.
- HSUPA (High-Speed Uplink Packet Access) is a technology that allows an increase in the maximum speed for uploading information to 5.76 Mbps.

3. 3G


3G
3G
Year 2001
Standards UMTS / HSPA
Technology digital
Bandwidth Broad Band
Data rates up to 2 Mbit/s
SMS / MMS
Internet access
Video calls
Mobile TV

4. 4G

- 4G is a very different technology compared to 3G. The purpose of its creation in 2008 is to provide users with high speed, high quality and high capacity, while improving security and reducing costs for voice and information services, multimedia and Internet over IP.
- Applications include mobile web access, IP telephony, gaming services, high definition mobile TV, video conferencing, 3D TV and cloud services.

4. 4G

- The key technologies that have made this possible are MIMO (Multiple Input Multiple Output) and OFDM (Orthogonal Frequency Division Multiplexing).
- The two important 4G standards are WiMAX (now out) and LTE (widespread).
- LTE (Long Term Evolution) is a series of improvements to the existing UMTS technology.

4. 4G

- To be classified as 4G, telecommunications networks must be able to guarantee a maximum speed of 100 Mbps when used by mobile users. When used from a stationary device, their speed must be one gigabit per second.
- However, at the time the 4G standard was established, most of the existing infrastructure could not allow such speeds to be reached. This necessitated the search for ways in which the established speeds could still be achieved in practice. One of these ways is called LTE.

4. 4G

3.1. LTE (Long Term Evolution)

- LTE is more of a technology that should make it possible to reach 4G speeds, not a separate standard.
- In practice, if a network reaches 4G speeds using LTE, then that network can be called a 4G network .
- L TE technology is standardized. It is used by mobile operators as a supplement to the 3G offered services.

4. 4G

3.1. LTE (Long Term Evolution)

- The LTE radio interface uses OFDM (Orthogonal Frequency-Division Multiplexing) technology to transmit data from the base station to the phone (downlink).
- Transmission in the reverse direction (uplink) uses SC-FDMA (Single Carrier-Frequency Division Multiple Access – a modified version of OFDMA). This is one of the differences with respect to UMTS, which is based on WCDMA (Wideband Code Division Multiple Access).

4. 4G

3.1. LTE (Long Term Evolution)

- As part of LTE, a number of solutions have been developed that allow the end user to achieve speeds of up to 300 Mbps, and when using LTE-A (LTE Advanced) it is even 1 Gbps for the user.
- A convenience for operators is the possibility to use already existing frequencies. This enables a relatively quick start-up of the network, without the complicated process of obtaining new concessions. At the same time, network capacity is increasing. Better management of its resources and adaptation to user needs is possible.

4. 4G

3.1. LTE (Long Term Evolution)

- Three approaches to voice service delivery are taking shape in LTE networks:
  - VoLTE (Voice over LTE) implementation of the IP Multimedia Subsystem (IMS) - an architecture for delivering rich voice/multimedia services in a flat air IP network based on SIP (Session Initiation Protocol). Most superficially described, VoLTE allows the establishment of a peer-to-peer connection through a subscription server, which mediates the connection of devices participating in the communication;

4. 4G

3.1. LTE (Long Term Evolution)

- VoLGA (Voice over LTE Generic Access) - temporary, simple in architecture, but with fewer capabilities than VoLTE, a solution imposed by the lack of variety of devices to support VoLTE - in this protocol, the voice service is built over the private connectivity of the device of the user with the Internet;
- CSFB (Circuit Switched Fallback) - transfer of the call to the standard GSM infrastructure.

4. 4G

3.2. WiMAX (IEEE 802.16)

- WiMax (Worldwide Interoperability for Microwave Access) works according to the IEEE 802.16 standard. Such a standard, unlike other types of radio communications, it is able to provide subscribers with a higher data transfer rate, even at large enough distances in the absence of direct line of sight to the base station.
- These features of the technologies are very useful in the conditions of large and densely built cities. WiMax technology came before LTE and it is the first standard for broadband high-speed mobile communications that is designed to build networks in large cities. Another goal of this technology is to complement WPAN and WLAN and integrate into the global network all existing subscriber devices.

4. 4G

3.2. WiMAX (IEEE 802.16)

- There are two types of WiMax communication:
  - fixed;
  - mobile.
- There are also two different standards:
  - 802.16d;
  - 802.16e;
  - 802.16m.
- 802.16d is for fixed WiMax. This standard was approved in 2004. It is supported in areas with or without direct visibility.
- WiMax 802.16d access point is supported by fixed subscriber devices, such as fixed modems, which can be installed indoors and outdoors .

4. 4G

3.2. WiMAX (IEEE 802.16)

- 802.16e is the standard used to build mobile networks. It was approved in 2005.
- This technology is supported by mobile devices such as smartphones, tablets, netbooks, etc. In addition, these networks support a roaming feature.
- The 802.16e standard provides theoretical speeds of 100 Mbps over a range of up to 50 kilometers. But WiMAX, like all other wireless technologies, can operate at high speeds or long distances, but not both. In the field, similar networks (in the US) show speeds of 3 to 6 Mbps for receiving information and 1 Mbps for sending.

4. 4G

3.2. WiMAX (IEEE 802.16)

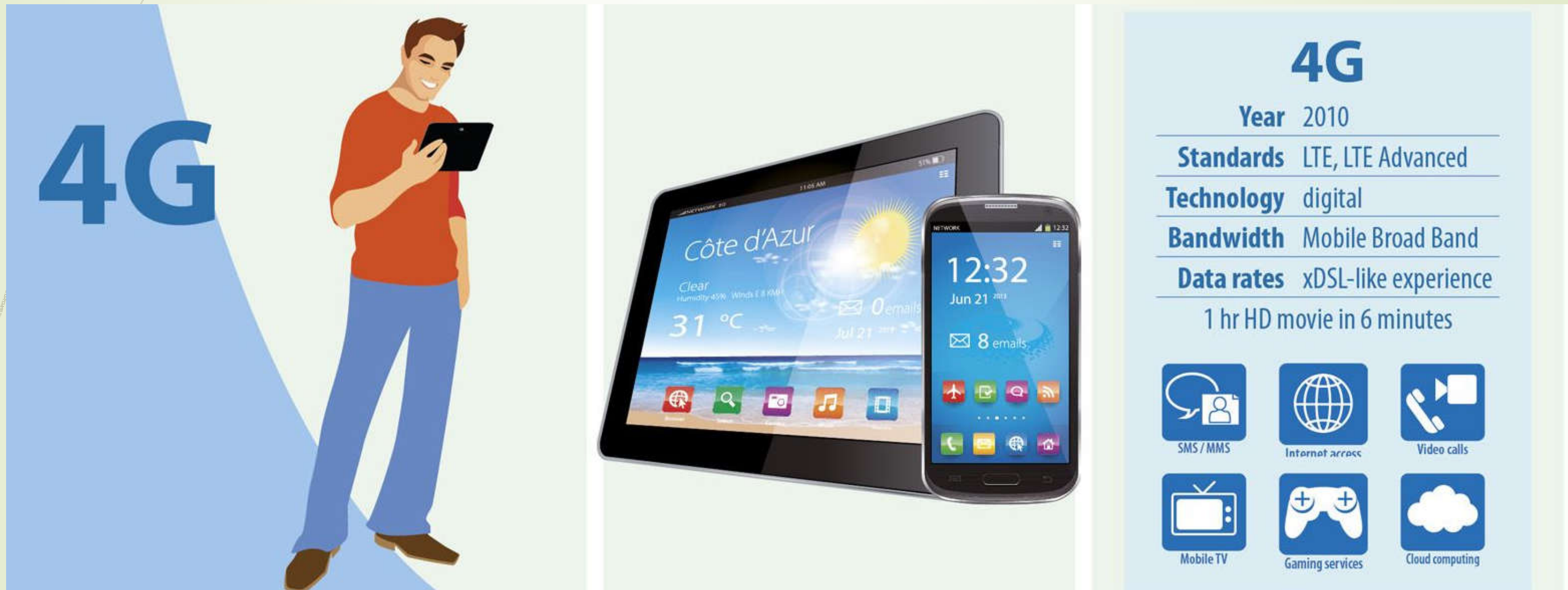
- The main difference between these two standards (802.16e and 802.16d) is that the first is designed to work with mobile devices that can move at a speed of up to 120 km/h, while the second is supported only by stationary devices. In addition, mobile WiMax supports a function of seamless switching between base stations during the movement of the subscriber.

4. 4G

3.2. WiMAX (IEEE 802.16)

- WiMAX2 (WirelessMAN-Advanced) is the next version of WiMax (IEEE 802.16m) from 2011.
- WiMAX2 supports MIMO technology, which means that additional antennas increase potential performance.
- The theoretical speed when receiving information through a fixed network is 1 Gbps, and when using a mobile network it will be 100 Mbps when receiving and 60 Mbps when sending information.

4. 4G


4G
Côte d'Azur
Clear
31 °C
0 emails
12:32
Jun 21
8 emails
4G
Year 2010
Standards LTE, LTE Advanced
Technology digital
Bandwidth Mobile Broad Band
Data rates xDSL-like experience
1 hr HD movie in 6 minutes
SMS / MMS
Video calls
Mobile TV
Gaming services
Cloud computing

5. 5G

- 5G is the fifth generation of wireless communication technologies supporting a cellular network. 5G communication requires the availability of communication devices (primarily mobile phones) built to support the technology.
- The frequency spectrum of 5G is divided into millimeter waves, medium frequency waves and low frequency. The low frequencies have a similar frequency range as the predecessor - 4G.
- 5G millimeter waves are the fastest. The frequencies are above 24 GHz, reaching up to 72 GHz, which is above the lower limit of the range of the internationally defined extremely high frequencies of radio waves. The range is small, so more cells are needed. Millimeter waves have difficulty passing through many walls and windows, so indoor coverage is limited.

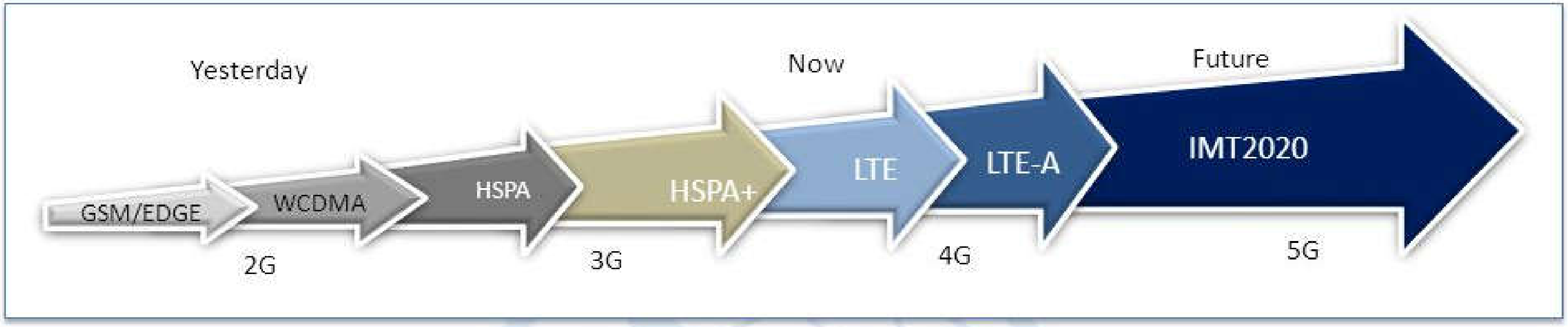
5. 5G

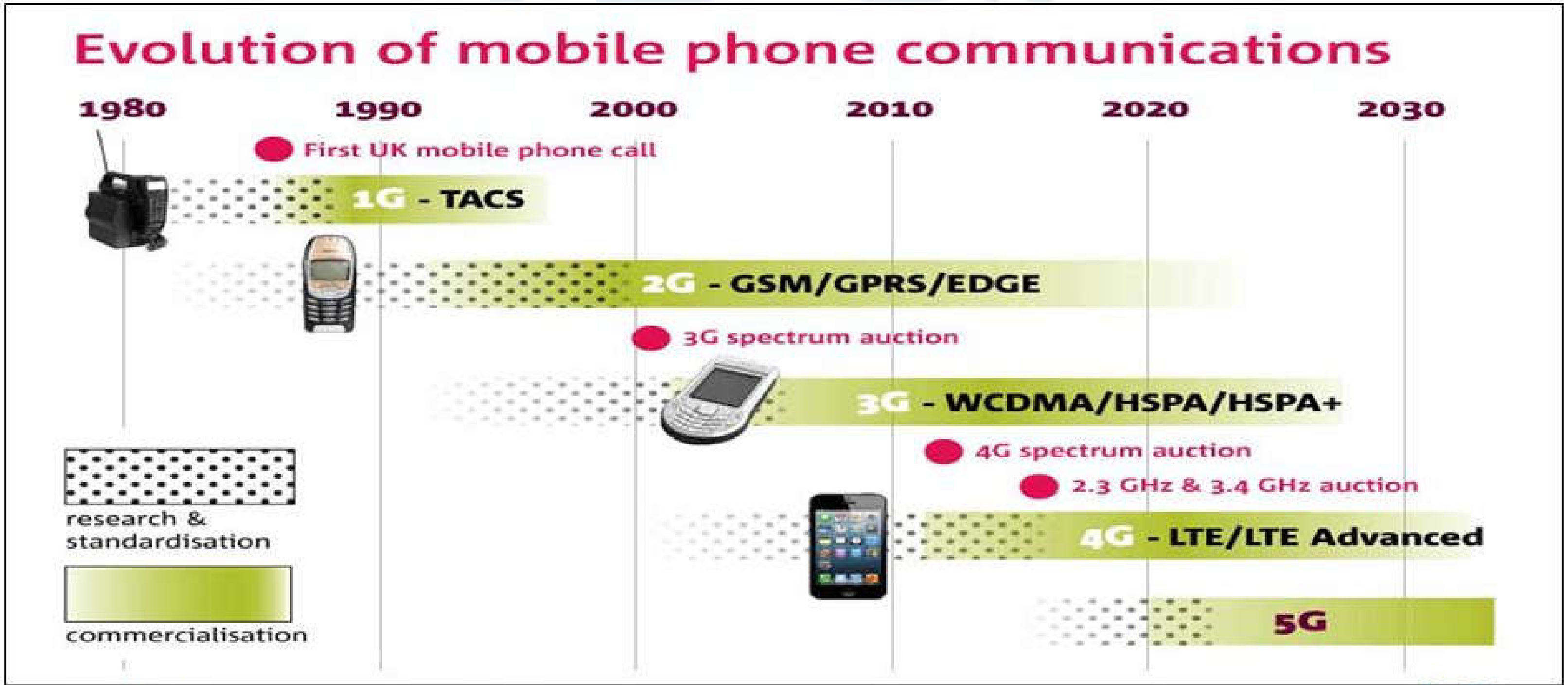
- 5G medium frequency waves are the most commonly used. Speeds at 100 MHz bandwidth are typically 100-400 Mbps. In labs and beyond, speeds can exceed 1 Gbps.
- used are from 2.4 GHz to 4.2 GHz. Sprint and China Mobile use 2.5 GHz, while other carriers use 3.3 and 4.2 GHz. Many territories can be covered by 5G by renewing existing cells, making it a cheaper solution.
- Medium frequency networks have better coverage, bringing the price close to 4G. 5G low frequency offers similar capacity as advanced 4G.

5. 5G


5G
Data rates / applications
5G
Year 2020-2030
Standards –
Technology digital
Bandwidth Ubiquitous connectivity
Data rates Fiber-like experience
1 hr HD movie in 6 seconds
HD
3D
112
Smart grids
Connected house
connected heating
connected TV
connected appliances
Domotics
eHealth
Traffic priority
Entertainment
Apps beyond imagination
Smart Car
Car-to-car communication

Evolution of mobile networks





6. TETRA (Terrestrial Trunked Radio)

- TETRA is a standard developed by the European Telecommunications Standardization Institute (ETSI). The abbreviation TETRA comes from Terrestrial Trunked Radio - Terrestrial trunked radio station (radio system).
- In this area, ETSI is developing two main packages of standards: for a mobile communication system for voice and data - TETRA Voice plus Data (V+D) and for a mobile communication system for data - TETRA Packet Data (PD). The latter is not gaining popularity and almost all TETRA systems are based on the first standard.

6. TETRA

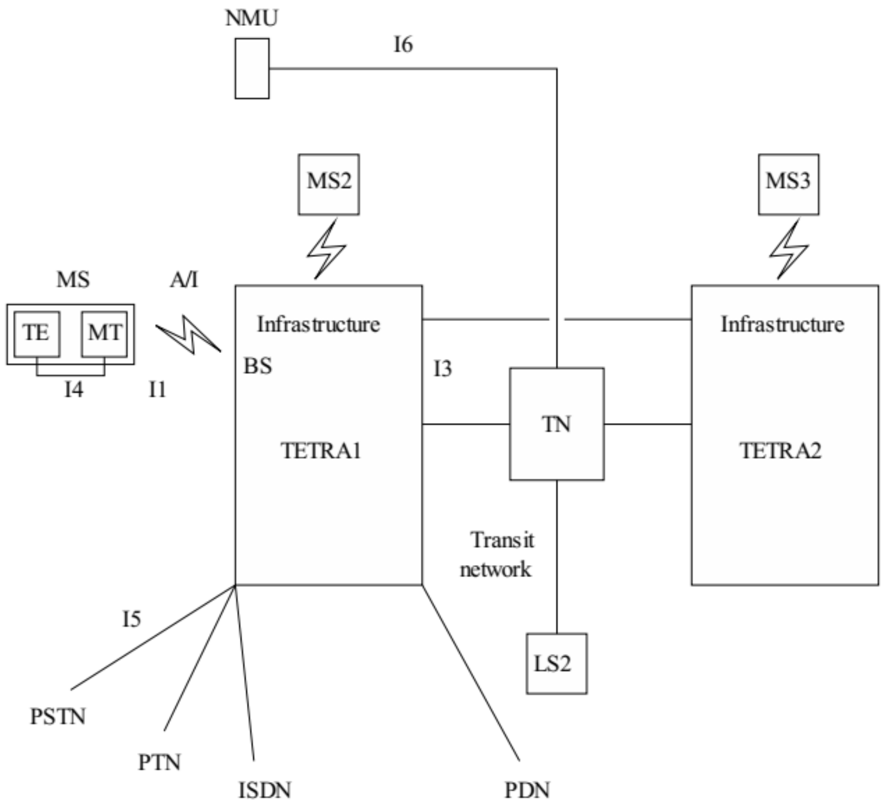
- The TETRA V+D suite of standards define the characteristics of a mobile system meeting the specific requirements of government organizations for security and defense - army, police, fire safety, civil defense, etc., as well as business organizations with many mobile users - railway transport, airports, taxi services, postal services, energy distribution, water supply, etc.
- Standard also describes system services, system interfaces, user registration and call handling procedures, radio interface encryption, etc.

6. TETRA

- The ETSI ETS 300 392-1 standard lays down the generalized model of a mobile network according to the TETRA standard. The main components of the mobile communication system, according to the model, are: mobile station, base station, regional communication center, main communication center and control center.
- The TETRA suite of standards defines the interfaces and services in the mobile communication system. The main standardized interfaces are:
  - I1 – radio interface between the mobile station and the base station;
  - I5 – interface to another mobile network according to the TETRA standard;
  - I6 – direct interface for connectivity between two mobile stations. It can be used to access a mobile station out of system range through another mobile station in system range and used as a relay station.

6. TETRA

TETRA voice plus data



BS: base station
ISDN: integrated services digital network
MS : mobile station
MT: mobile terminal
NMU: network management unit
PDN: public data network
PSTN: public switched telephone network
PTN: public telephone network
TE: terminal equipment

6. TETRA

- For the implementation of the I6 radio interface, a frequency resource has been set aside in the ranges 380-400 MHz and 410-430 MHz. The standard also provides for the use of frequency resources in the 150 and 900 MHz bands.
- The bandwidth of one radio channel is 25 kHz.
- The modulation used is digital.
- Communication between the mobile station and the base station is duplex. Duplexing is done by frequency. The formed radio channel is shared by 4 mobile stations.
- Time Division Multiple Access (TDMA) is implemented.

6. TETRA

- The basic voice services provided by a TETRA-compatible system are:
  - group call and conducting a conversation - the conversation is conducted only in a predefined group of subscribers, regardless of their location in the entire coverage area of the system;
  - private call and conversation - the conversation takes place between two subscribers. Time to establish connectivity is < 300 ms;
  - private calling and conversation between a mobile subscriber and a subscriber from other private or public telephone networks;
  - voice services in direct mode between two subscribers located outside the range of the system;
  - emergency call;
  - priority management services, late entry into a call, interrupting a call with a superior, etc.

6. TETRA

- The main data services are:
  - emergency alarm;
  - predefined status messages;
  - short messages;
  - packet data at a speed of up to 28.8 kbps.
- The basic data protection services provided are:
  - Access protection;
  - Traffic protection – built-in subscriber cryptors;
  - Ability to protect traffic "from end to end" (end to end encryption);
  - Remote deactivation of a mobile terminal.

6. TETRA

- The TETRA standard does not define the design, protocols and interfaces of the base station (country to regional switching center), regional switching center, main switching center and control center components. These components are specific to each TETRA mobile communication system manufacturer. Specific to each manufacturer are also the typical components of a private mobile network, such as operational dispatch console, radio management and network management. This makes internal system compatibility between equipment from different manufacturers difficult.
- TETRA is used for the needs of the military departments as a voice communication tool, data transfer and resource management tool.

7. Wi-Fi (802.11)

- Wireless computer networking combines several standards, the first of which has existed since 1997.
- The whole suite of wireless communication protocols is called 802.11, and according to different generations it can be variant a, b, g or n. The letters used for additional designation indicate the next (more advanced) level in the development of the protocol, regardless of whether it is a hardware or software update.

7. Wi-Fi (802.11)

7.1. Standard 802.11a

- The first generation protocol for building a wireless network was announced in 1997 by the IEEE (Institute of Electrical and Electronics Engineers).
- Its specifications are as follows: maximum connection distance up to 35 meters in a building and up to 120 meters in line of sight, average transfer rate 23 Mbps, maximum transfer rate 54 Mbps, operating frequency 5 GHz.
- The protocol has the technical name IEEE 802.11a, and the modulation of the signal takes place through the use of Orthogonal Frequency Division Multiplexing (OFDM).

7. Wi-Fi (802.11)

7.1. Standard 802.11a

- The advantages of this method are quite numerous, among which the most basic ones are the following: good resistance to a bad signal or the presence of strong disturbances in it; good resistance to interference; low sensitivity to errors in the time synchronization of individual packets; ability to use at small range frequencies, etc.
- OFDM also has its disadvantages, which are actually the basis for moving to more advanced methods in WiMAX - with OFDM, the signal is affected to an extremely strong degree by the Doppler effect, which occurs when the receiver moves.

7. Wi-Fi (802.11)

7.1. Standard 802.11a

- This is also due to one of the biggest disadvantages of WiFi in general - the use of a wireless network while moving at a higher speed is almost impossible, especially when there are greater distances.
- In addition to this, OFDM is also highly dependent on the frequency modulation of the signal, and if there are any problems in it, its use becomes almost impossible. The wiring of the receiver and its antenna in OFDM requires quite complex circuitry, which leads to another serious drawback - poor power efficiency, which makes 802.11a an unsuitable choice for laptops.

7. Wi-Fi (802.11)

7.2. Standard 802.11b

- An alternative to OFDM is used in 802.11b, where another modulation technique belonging to the spread spectrum family is used - Direct-Sequence Spread Spectrum (DSSS).
- The reason for the introduction of DSSS is the changed operating frequency – from 5 GHz it has been reduced to 2.4 GHz, which causes problems with signal interference both from other devices using this spectrum and from buildings in cities. Unlike OFDM, DSSS is extremely successful at matching more than one user on the same frequency channel without them interfering with each other. However, a disadvantage is the relatively low transfer speed due to the operating principle of DSSS modulation.

7. Wi-Fi (802.11)

7.3. Standard 802.11g

- In 2003, the IEEE proposed a revision of the 802.11 standard, denoted by the "g" prefix. The new 802.11g protocol inherits the same OFDM signal modulation, but unlike 802.11a, a completely different frequency spectrum is used here. While in the 1999 802.11a standard the operating frequency is 5 GHz, in 802.11g (and 802.11b) it is reduced to 2.4 GHz.
- Combining OFDM modulation technology with a lower signal frequency results in a maximum data transfer rate of around 54 Mbps combined with good penetration of the 2.4 GHz signal.

7. Wi-Fi (802.11)

7.4. Standard 802.11n

- The 802.11n wireless LAN standard was officially ratified by the IEEE (Institute of Electrical and Electronics Engineers) at the end of 2009 after 7 years of development.
- The standard is intended for creating wireless local area networks (WLANs), offering higher speed and greater range than Wi-Fi 802.11g. In 802.11n, two frequency channels (2.4 and 5 GHz) are used for connection purposes, and in earlier revisions only 2.4 GHz is used. The communication channel has been increased from 20 to 40 MHz.

7. Wi-Fi (802.11)

7.4. Standard 802.11n

- In earlier versions of the 802.11 specifications (up to n), all data is transmitted in a single stream (channel). At n specification the theoretical number of channels is 4, although in most cases only two are used. This also determines the total maximum transfer rate, which is calculated as the product of the maximum rate of each channel and the number of channels. For 802.11n, the theoretical maximum speed is 150 x 4 = 600 Mbps.
- For the first time in this standard, the MIMO (Multiple Input Multiple Output) technology is used, in which the signal is transmitted and received by several antennas at the same time.

7. Wi-Fi (802.11)

7.5. Standard 802.11ac

- The 802.11ac standard refers to the so-called fifth generation wireless networks. One of the main goals in developing this standard was to achieve gigabit speeds for wireless data transfer.
- Gb p s target for the new standard is achieved while maintaining backward compatibility. IN mixed networks all devices should communicate seamlessly with each other no matter what version of the 802.11 standard they support.
- 802.11ac operates in the radio frequency range below 6 GHz. At 802.11ac the standard relies only on the 5 GHz range, which is considered more efficient for data transfer.

7. Wi-Fi (802.11)

7.5. Standard 802.11ac

- The achievement of the growth of 802.11ac performance is achieved with a few changes. First of all, this is the doubling of the width of the communication channel - in 802.11ac it is already 80 MHz wide (by default), and in some cases it can be 160 MHz.
- With 802.11ac, the number of channels is increased to 8, and the transmission speed in each of them is determined by their width. At 160 MHz channel width, the transfer rate is 866 Mbps, which multiplying by 8, gives the maximum theoretical transfer rate that can be provided by the standard. In the case of 802.11ac this speed is almost 7 Gbps, which is 23 times faster than that provided by 802.11n.

7. Wi-Fi (802.11)

7.5. Standard 802.11ac

- Beamforming technology is used for the first time in the 802.11ac standard. It solves the problem of the radio signal power falling when it is reflected by various objects and surfaces. Thus, on reaching the receiver, the signal and all its reflections arrive with certain phase shifts, which reduce its total amplitude and in effect lead to attenuation.
- Beamforming eliminates this in the following way: the transmitter determines the approximate location of the receiver and, based on this information, forms a signal with a non-standard "shape" and direction.

7. Wi-Fi (802.11)

7.5. Standard 802.11ac

- While in the usual mode of operation the signal from the transmitter spreads evenly in all directions, in Beamforming mode the signal is directed to the supposed location of the receiver by means of several antennas.
- In this way, beamforming not only improves signal propagation in an open environment, but also helps to overcome obstacles, so that the quality of 802.11ac reception and transmission based devices using such a mode of operation should be significantly better than that of 802.11n under the same conditions.

7. Wi-Fi (802.11)

7.6. Standard 802.11ad

- It's 802.11ad another wireless standard, also known as WiGig. Despite the similarities in designations, however, 802.11ad is not a successor to 802.11ac.
- In fact, it is a question of two competing technologies that are developing in parallel, although with a view to achieving the same goal - crossing the gigabit barrier in wireless transfer. However, the approaches are different and while 802.11ac strives to maintain compatibility with previous Wi-Fi developments, 802.11ad technology starts clean.
- The main difference between these two technological solutions is the operating frequency, from which all other features follow. For 802.11ad the frequency is much higher compared to 802.11ac – 60 GHz instead of 5 GHz. The width of the communication channel is up to 2160 MHz.

7. Wi-Fi (802.11)

7.6. Standard 802.11ad

- At 60 GHz there will be far less interference, which is an advantage, but at this frequency the signal coverage area drops significantly.
- Mandatory condition for the normal operation of 802.11ad is the absence of walls and other serious barriers. 802.11ad technology will be effective at distances of up to several meters, as is the case with Bluetooth.
- The current draft version of 802.11ad has already achieved the original goal (speed of 1 Gbps), and the maximum theoretically achievable speed is 7 Gbps.

7. Wi-Fi (802.11)

Standard	Release date	Operating frequency	Transfer speed (average)	Maximum number of channels	Transfer rate (maximum)	Coverage (indoor)	Coverage (outdoor)
Legacy	1997	2.4 GHz	0.9 Mbps	1	2 Mbps	~20 meters	~100 meters
802.11a	1999	5 GHz	23 Mbps	1	54 Mbps	~35 meters	~120 meters
802.11b	1999	2.4 GHz	4.3 Mbps	1	11 Mbps	~38 meters	~140 meters
802.11g	2003	2.4 GHz	19 Mbps	1	54 Mbps	~38 meters	~140 meters
802.11n	2009	2.4 GHz / 5 GHz	130 Mbps	4	600 Mbps	~70 meters	~250 meters
802.11ac	2013	5 GHz	1 Gbps	8	7 Gbps	~35 meters	~120 meters
802.11ad	2012	60 GHz	1 Gbps		7 Gbps	~10 meters	

8. Bluetooth

- Bluetooth is an industry standard for a wireless personal area network (PAN). It provides a way to connect and transfer information between devices such as mobile phones, laptops, personal computers, printers, digital cameras, game consoles and even cars using a secure, short-range radio frequency.
- Bluetooth operates at a frequency of 2.4 GHz. The range varies depending on the class of the device: up to 1 m for Class 3, up to 10 m for Class 2 and up to 100 m for Class 3, often much less in practical conditions due to the presence of barriers.

8. Bluetooth

- There are several different versions of the standard:
  - In the first version **Bluetooth 1** the highest possible speed is 1 Mbps, but under normal conditions the maximum speed is 721 Kbps in one direction.
  - **Bluetooth 2.1+EDR (Enhanced Data Rate)** was approved in 2007 and supports a theoretical transfer rate of up to 3 Mbps.
  - **Bluetooth 3.0+HS (High Speed)** was approved in 2009 and supports a theoretical transfer rate of up to 24 Mbps.

8. Bluetooth

- **Bluetooth 4.0**. In late 2009, the Bluetooth Special Interest Group approved the Bluetooth 4.0 standard for wireless communications, which features lower power consumption. A tiny battery will power the Bluetooth 4.0 module, providing operation for several hours. The standard supports data transmission at a speed of up to 1 Mbps for small data packets, and a range of up to 100 meters. Products meeting the Bluetooth 4.0 specification will find a place in the medical, sports and entertainment industries. The technology will be built into both separate and combined chips, which will also be compatible with Bluetooth 2.1+EDR and Bluetooth 3.0+HS.

8. Bluetooth

- **Bluetooth 4.1** (Low Energy, LE). It was approved on December 4, 2013. There are improvements in terms of power consumption and the ability for mobile devices to perform multiple roles at the same time. This version makes connecting to devices easier, and pairing with a smartphone or tablet will not be mandatory. Bluetooth 4.1 offers better transfer speeds, IPv6 support, and enables devices to act as servers. Version 4.1 has been modified to avoid possible interference with LTE radios. It has a better sleep-wake cycle for the radio module, which will allow devices to connect without user intervention. Data transfer can be done at higher speeds. This option allows Bluetooth-enabled devices to act as both peripherals and hubs at the same time. Ability for Bluetooth devices to connect directly to the Internet by providing them with a dedicated channel that can be used for IPv6 communication.

8. Bluetooth

- **Bluetooth 4.2**. It was approved on December 2, 2014. One of the key improvements is the ability to work together between Bluetooth and LTE. The new specification provides protection against mutual noise by automatically coordinating the transmission of data packets. In addition, Bluetooth 4.2 increases the speed of data exchange between Bluetooth Smart devices. Thanks to a 10x increase in data packet size, performance is claimed to have increased by 2.5x while reducing power consumption. Bluetooth 4.2 allows devices to exchange data over the Internet using the IPv6/6LoWPAN protocol. This innovation will contribute to the development of the "Internet of Things" concept. According to forecasts, 28 billion different types of connected devices will be connected to the Internet in 2020. Bluetooth 4.2 is also much more secure. Devices with Bluetooth 4.2 support also provide a higher level of security. In particular, it becomes more difficult for cybercriminals to track devices via Bluetooth connections without the user's permission.

8. Bluetooth

- **Bluetooth 5.0**. In June 2016, the Bluetooth Special Interest Group (SIG) introduced the Bluetooth 5.0 specification. Bluetooth 5.0 has four times the range of the current v4.2 standard and will transfer data at twice the speed, from 1 Mbps up to 2 Mbps. In theory, devices that use Bluetooth 5.0 can communicate over a distance of up to 240 meters, which is four times greater than the range of 60 meters provided by Bluetooth 4.2.
- **Bluetooth 5.1**. The version was presented by the Bluetooth SIG on January 21, 2019. It allows the user to determine the location and direction from which the signal is coming with maximum accuracy.
- **Bluetooth 5.2.** Introduced on December 31, 2019. The version adds support for LE Audio (Low Energy Audio), which reduces power consumption, enables sound transmission, and adds features such as one set of headphones can connect to multiple audio sources or multiple headphones can be connected to a single source. It uses a new LC3 codec. BLE Audio also adds hearing aid support.
- **Bluetooth 5.3**. It was presented on July 13, 2021.

8. Bluetooth

9. RFID (Radio Frequency Identification)

- Radio frequency identification or often abbreviated RFID (Radio Frequency Identification) is a method of automatic identification of objects, in which data is read or written from identifiers on the object using radio waves .

9.1. Operating principle

- The technology is based on radio frequency communication between a specially made identifier (label, tag, card, keychain, sticker, etc.) and a reading device. Each identifier contains a chip with a recorded unique number and an antenna. Depending on the system configuration, when the number is "read" an action can be taken - for example, a door, barrier or other device can be activated - or the information can be fed to a computer.

9. RFID

9.1. Operating principle

- Some types of RFID devices allow multiple recording of information, which further expands the possibilities of their use. The distance from which the identifier can be "read" depends on many factors such as frequency, shape and size of the antennas, environment, etc. and can reach tens of meters when using active RFID identifiers.
- The possibilities that this technology offers are incomparably greater than those of the barcode: the information can be "read" from a distance and without direct visibility (when the goods are brought into the warehouse, directly on shelves or assembly lines); a large number of goods can be identified simultaneously; identifiers can contain a larger amount of information; reading can be done without human intervention; identifiers are resistant to external influences (temperature, moisture, chemicals, etc.); multiple recording of information is possible throughout the life cycle of the product.

9. RFID

9.2. Operating frequency

- Regardless of differences in implementation, frequency and software, each RFID system operates at a specific operating frequency.
  - **Low Frequency - Low Frequency (LF).** Frequencies between 30 and 300 kHz are considered low. Typically, LF RFID systems operate at 125 kHz, less often at 134 kHz. LF devices have a low speed of data exchange between the identifier and the reader, but are very resistant in the vicinity of metal, liquids, snow, etc. The stable behavior of these devices in an adverse environment is a very important characteristic of them, contributing to their widespread use. LF systems operating at 125 kHz are the most widespread in Europe (including Bulgaria), with access control systems being their most typical application .

9. RFID

9.2. Operating frequency

- **High frequency - High Frequency (HF).** Frequencies between 3 and 30 MHz. The standard frequency for an HF RFID system is 13.56 MHz. This type of systems are widespread, and their characteristics are also regulated by the international standards ISO 15693 and ISO 14443. This gives broad prospects for the use of HF devices in various fields and facilitates the introduction of such systems. Among the disadvantages is the unstable behavior of 13.56 MHz identifiers near metal or liquids, but this does not prevent their use in a large number of applications for tracking goods and tangible assets, in libraries, in the textile industry, for electronic payments and many others.
- **Ultra high frequency - Ultra High Frequency (UHF).** Frequencies between 300 MHz and 1 GHz. The typical frequency for a passive UHF system. In Europe it is between 865.7 - 867.5 MHz, in the USA: 902.75 - 927.75 MHz, in Thailand: 922.25 - 927.75 MHz. Active UHF systems operate on 315 or 433 MHz. Fast data transfer and low cost of identifiers are important advantages of UHF. The main disadvantage is their dependence on the environment and, above all, disturbances in the work in the presence of metals and liquids .
- **Microwave frequency**. Frequencies above 1 GHz. 2.45 or 5.8 GHz are used as standard. IDs can be very small in size, data transfer is fastest compared to other frequencies, but metals and liquids are a serious obstacle to the use of microwave systems.

9. RFID

9.3. Components of an RFID system

- Each RFID system consists of the following components:
- **Identifier**
- RFID identifiers can be classified according to different characteristics:
- Classification by form:
  - standard smart card (ISO 7816-1) with dimensions 86 x 54 x 0.76 mm;
  - Clamshell card measuring 86 x 54 x 1.8 mm;
  - key holder - different shapes and sizes;
  - sticker;
  - clock;
  - disc;
  - glass ampoule - for implantation under the skin of animals;
  - dowel, nail, etc.

9. RFID

9.3. Components of an RFID system

- **Identifier**
- Classification by power supply:
  - passive - do not have a built-in power supply (battery). Their simple design makes them very durable, with a lifespan of about 10 years, as well as very resistant to external conditions (temperature, moisture, chemicals, etc.). Their price is low compared to other types of identifiers, but they fall behind in reading distance.
  - active - have their own power supply built into the identifier. This allows them a greater reading distance and the possibility of embedding a microprocessor and performing additional functions (temperature measurement, monitoring of certain parameters).
  - semi-passive – have a power supply similar to active identifiers. The battery improves the reading distance. Some of them wait for a signal from the reader and thus save battery life.

9. RFID

9.3. Components of an RFID system

- **Identifier**
- Classification by read and write capabilities:
  - Read Only (RO) - during the manufacturing process, a unique number is written into the chip with the help of a laser, which cannot be changed later. They are widely used due to their low cost and simplicity of use. When communicating with the reader, RO identifiers send their number, thus identifying their carrier.
  - Write Once Read Many (WORM) - the write is done the first time the identifier is used. They have a good price/performance ratio, which is why they are widely used for business applications.
  - Read Write (RW) - can be overwritten many times (10-100,000, even more). Recording can be done both by the reader and by the identifier itself when using an active type. They can be used for many different applications, but their spread is limited by the still high cost.

9. RFID

9.3. Components of an RFID system

- **Reader.** A device that communicates via antenna with the identifier and performs reading and writing (for RW identifiers). The reader is an essential component of RFID systems. In different applications, it can contain an antenna, controller, memory. For some simpler applications, such as access control to residential buildings, elevators, the reader can be implemented as a stand-alone device, without connection to a computer and software. For mobile applications, hand-held terminals are used, often with the added capabilities of a pocket computer .
- **Antenna.** The antenna transmits an electromagnetic signal from the reader, which is sent to the identifier and powers it, and the identifier in turn returns a response to the reader. This is how information is sent and received. Correct antenna placement and geometry is particularly important for read distance. The dimensions and type of antennas are related to the operating frequency of the RFID system. Often the antenna is integrated into the reader.

9. RFID

9.3. Components of an RFID system

- **Controller.** The controller is the module allowing communication and control of the reader from a computer. Its presence in the systems is mandatory if it is necessary to use the information read from the identifiers in computer systemsThe controller passes the instructions to the identifiers and in the event of writing.
- **Software Assurance.** The software processes, stores and visualizes the information in the RFID systems. Software options vary by application:
  - building entry/exit registration, access restriction and time reporting;
  - registration of goods and receipt in warehouse;
  - tracking the movement of an identifier in a production chain, etc.
- Based on the accumulated information, reports can be prepared, information can be sent to another system, instructions can be given to the controller, etc.

10. NFC (Near Field Communication)

- **10.1. Technology**
- It is a technology for high-frequency wireless data transmission at close range. It is a more advanced version of existing RFID standards. Devices that have NFC built in can both read and transmit data to another similar device nearby (within a few cm, the range of NFC).
- Participants in NFC communication are two devices, one of them may be active and the other passive. Or both are active. The signal is transmitted at a frequency of 13.56 MHz and begins to be lost after a distance of about 4 cm. In theory, however, the NFC specification supports operation at greater distances.

10. NFC

- **10.1. Technology**
- Different devices can use the NFC standard, and they can be considered either passive or active depending on how the device works .
- Passive NFC devices include the so-called "tags" (labels, stickers or other microchips) or other small transmitters that can send information to other NFC devices without needing to be powered by their own power source. They do not actually process the information sent from other sources and cannot connect to other passive components. They often take the form of interactive signs on walls or advertisements .

10. NFC

- **10.1. Technology**
- Active devices are capable of both sending and receiving data and can communicate with each other as well as with passive devices. Active NFC devices are most commonly found in smartphones, but card readers in public transport and touch payment terminals are also good examples of the technology. Recently, the technology has spread to tablets, watches, bracelets, etc.
- NFC can send extremely small segments of information due to the low maximum speeds (between 106 kbps and 848 kbps). NFC is similar to Bluetooth.
- The idea behind the technology is not file sharing or long-term communication, but pairing, starting a transfer, or physically specifying two communicating devices.

10. NFC

- **10.1. Technology**
- standard currently has three different modes of operation for compatible devices. These are:
  - **Peer-to-peer** is the most commonly used mode in smartphones, which allows two NFC devices to exchange different pieces of information with each other. In this mode, both devices switch between an active state when sending data and a passive state when receiving.
  - **The read/write mode** is a one-way data transfer when the active device, possibly a smartphone, connects to another device to read information from it. This is the mode used when interacting with an ad's NFC tag.
  - **Card emulation**, where the NFC device can be used as a smart or contactless credit card to make payments or plug into public transport systems.

10. NFC

- **10.1. Technology**
- **An NFC tag** is a microchip containing a small amount of memory attached to an antenna that can store information intended to be transferred to another device, such as a mobile phone. It does not contain any batteries and is powered by proximity to a mobile phone, tablet (or other NFC device).
- The tag is usually a sticker about the size of a postage stamp. But it can also be embedded into key chains, bracelets, and more.
- They typically contain data between 96 and 8192 bytes in size and are most often read-only, but may also be rewritable.

10. NFC

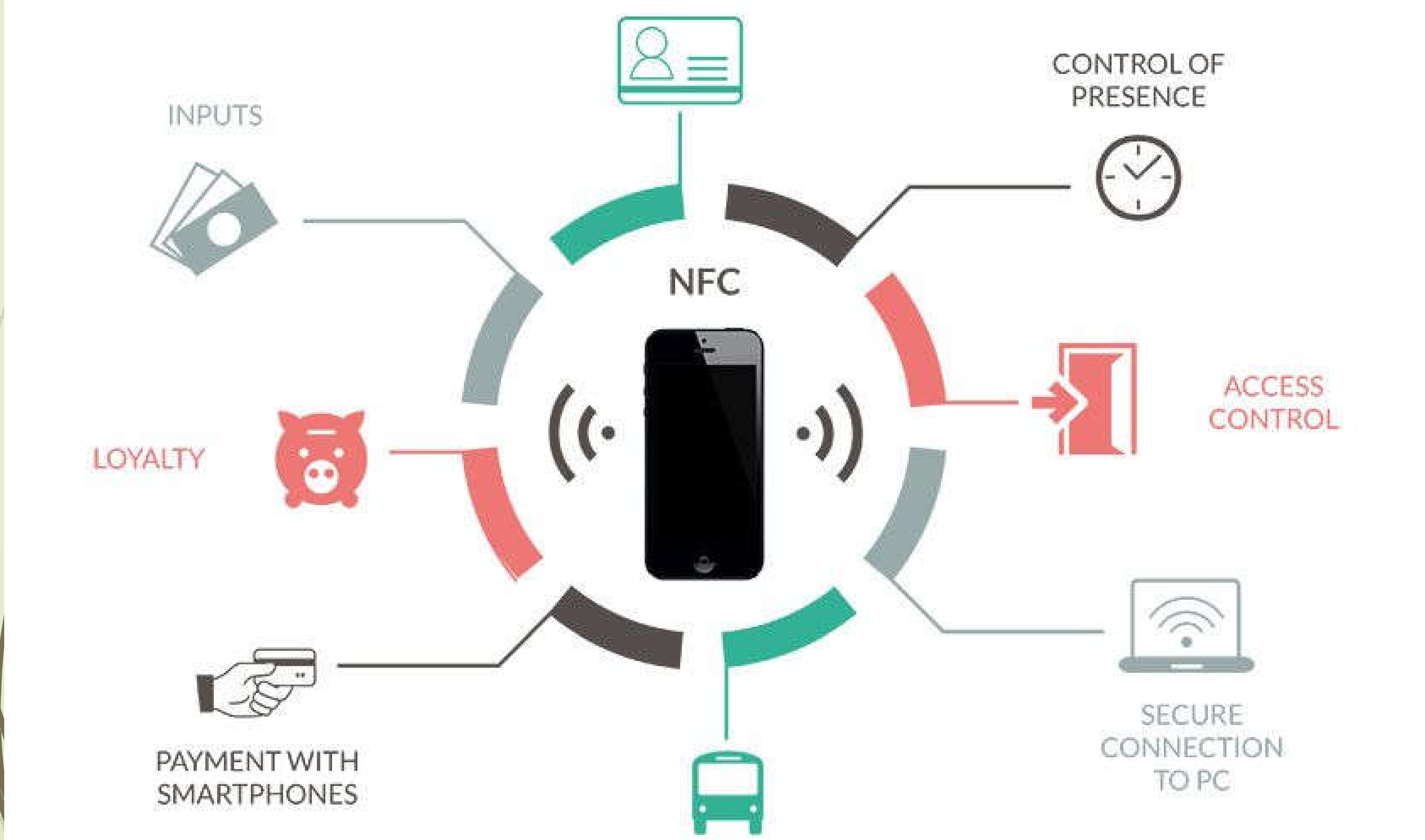
- **10.2. Advantages**
- The advantages of NFC over existing wireless data transfer formats are several. The range of action is small, which limits the possibility of "intercepting" the information, for example when paying in a store. There is also no danger of them stealing money from the bank account "tied" to the phone if they walk by it with an NFC reader.
- While the technological response time of Bluetooth is relatively long, NFC technology connects devices instantly, in a fraction of a second.
- Last but not least, no additional manual settings are required before using NFC.

10. NFC

- **10.3. NFC usage**
- It can be used to extract information from product packaging with NFC tags, because with this technology one side does not need to have its own power supply. Passive NFC tags are temporarily charged by the field induction of the mobile device.
- In order not to convey too much information, tags usually contain a link that leads to a web page or content in a given application. The idea is similar to that of QR codes, but in no way depends on the lighting conditions and the qualities of the camera of the device being used.

10. NFC

- **10.3. NFC usage**



11. LI-FI (Light Fidelity)

- Li-Fi (Light Fidelity) is a two-way, high-speed and completely wireless network communication technology similar to WI-FI. It is based on the transmission of data through light.
- Li-Fi was invented by Professor Harald Haas of the University of Edinburgh, Scotland in 2011 when he demonstrated that the light of just one LED could transmit far more data than a cell tower. The speed achieved in laboratory conditions is 224 Gbps.

11. LI-FI

- Li-Fi technology uses data exchange using visible light (Visible Light Communication, VLC) - electromagnetic radiation with a frequency of 400 to 800 THz. A coding reminiscent of Morse code is used - turning on and off a light in a certain way, enabling the exchange of a binary code. The new technology transmits data in the light spectrum invisible to the human eye and uses energy much more efficiently than Wi-Fi .
- However, Li-Fi is still not widely used because it has one major drawback – the light cannot pass through walls and other obstacles, so its use is limited only within a room. On the other hand, this property makes the technology much more secure. This also means that there will be less interference between devices.

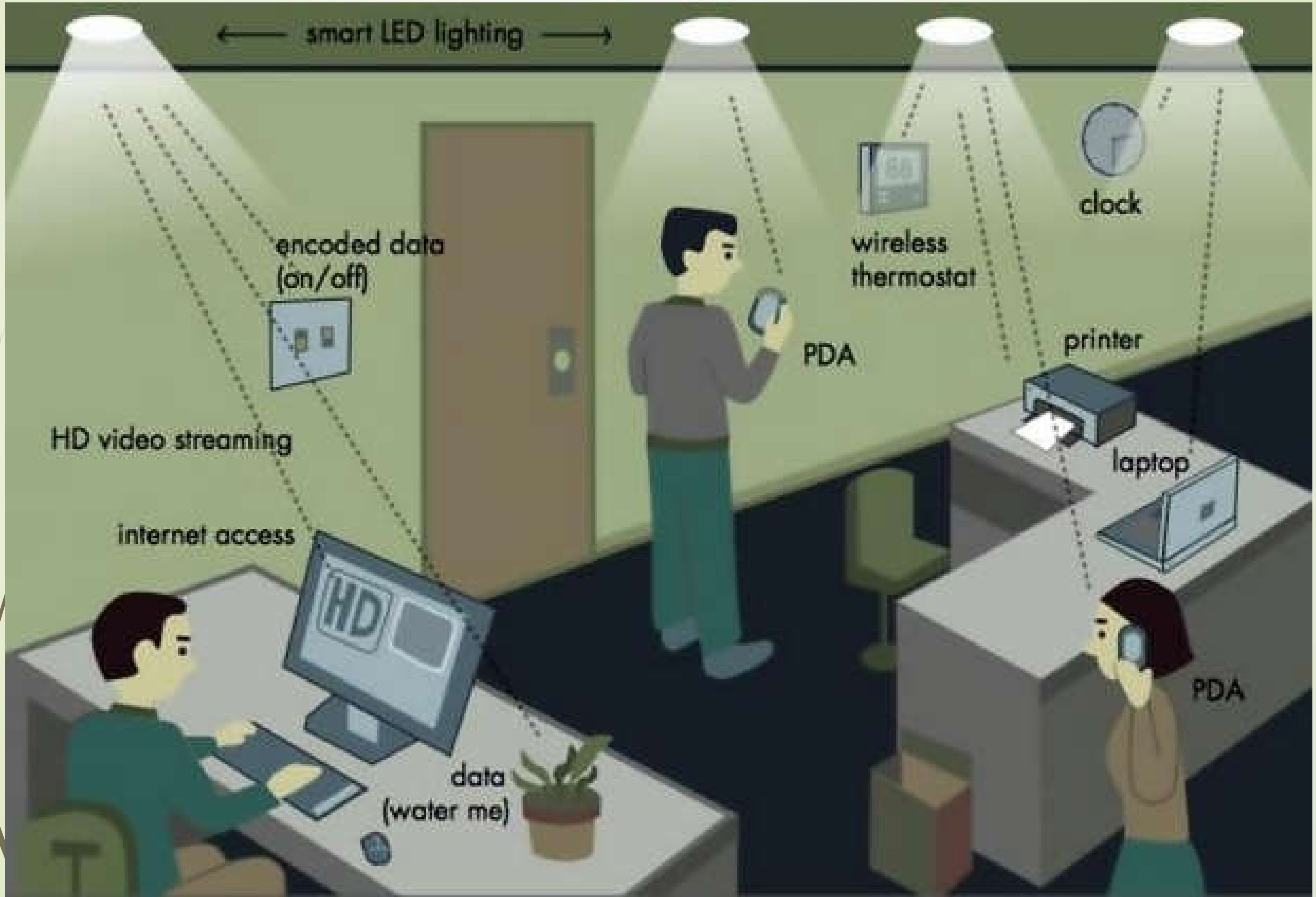
11. LI-FI

- This problem of propagation to different premises can be overcome by using a large number of repeaters. Work on Li-Fi continues, with significant contributions from companies such as Velmenni, pureLi-Fi and Oledcomm - they are trying to create more efficient repeaters and new light sources that will ensure higher data transmission speeds.
- Efforts are currently focused on a Li-Fi data transmission standard that will satisfy both manufacturers and end users. According to analysts, Li-Fi will begin to displace Wi-Fi as early as the end of this decade, offering 100 times higher data transfer speeds.

11. LI-FI

- For the first time in the world, Li-Fi was used in the real world in offices and production buildings in the capital of Estonia - Tallinn.
- In real-world conditions, the achieved speed of 8 G bps, which is 100 times faster than the average wireless Wi-Fi connection speed these days.

11. LI-FI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encoded data
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HD video streaming
internet access
PDA
wireless
thermostat
clock
printer
laptop
PDA
data
(water me)