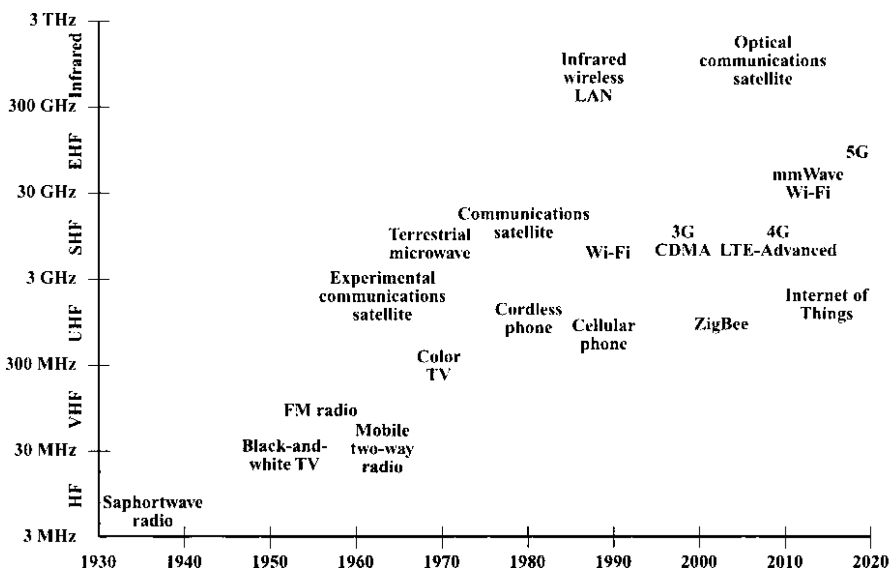
Wireless Communication System

History of wireless communications

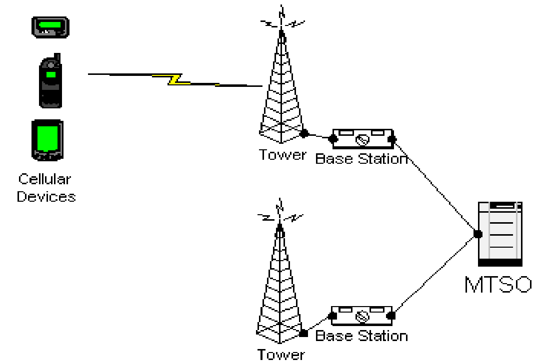
- Guglielmo Marconi invented the wireless telegraph in 1896, he sent telegraphic signals across the Atlantic Ocean (about 3200 km).
- Over the last century, advances in wireless technologies have led to the radio, the television, the mobile telephone, and communications satellites.
- Wireless networking is allowing businesses to develop WANs, MANs, and LANs without a cable plant.
- Communications satellites launched in 1960s
- The first-generation wireless phones used analog technology. These devices were heavy and coverage was patchy. The current generation of wireless devices is built using digital technology. Digital networks carry much more traffic and provide better reception and security than analog networks.



Some milestones in Wireless Communications

Evolution of mobile communications

- The first version of a mobile radio telephone being used in 1924.
- In 1926 telephone service in trains on the route between Hamburg and Berlin was approved.



- In 1935, Edwin Armstrong demonstrated FM and it has been the primary modulation technique used for mobile communication systems throughout the world.

- In 1946, the first public mobile telephone service was launched by BELL Laboratories in USA (543 users).
- A solution to this capacity problem emerged during the 50's and 60's when researchers at Bell Laboratories developed the ***cellular concept***.

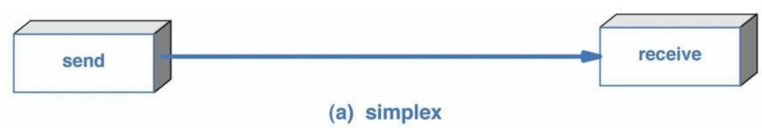
- In 1973, Martin Cooper (a Motorola researcher and executive) made the first mobile telephone call from handheld subscriber equipment.

- In 1983, the first analog cellular system deployed in Chicago, USA.

Classification of mobile radio transmission system

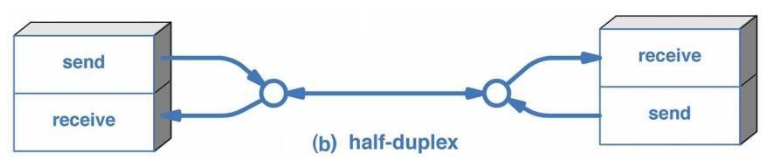
Mobile radio transmission systems may be classified as simplex, half-duplex or full-duplex.

- **Simplex systems**: communication is possible in only one direction.



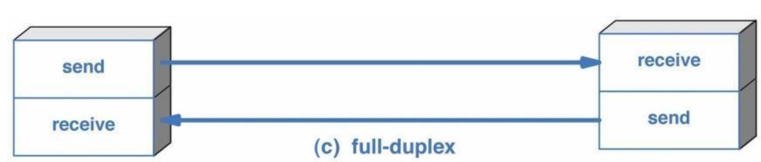
(a) simplex

- **Half-duplex**: radio systems allow two-way communication using the same radio channel for both transmission and reception.



(b) half-duplex

- **Full duplex**: systems allow simultaneous radio transmission and reception between a subscriber and a base station, by providing two simultaneous but separate channels (frequency division duplex, or FDD) or adjacent time slots on a single radio channel (time division duplex, or TDD) for communication to and from the user.



(c) full-duplex

Frequency division & Time division

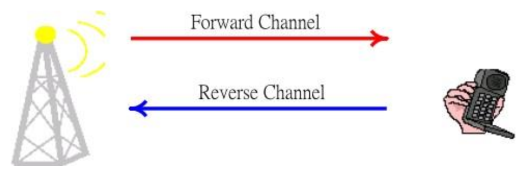
Frequency division duplexing (FDD)

Provides simultaneous radio transmission channels for the subscriber and the base station, so that they both may constantly transmit while simultaneously receiving signals from one another.

- At the base station, separate transmit and receive antennas are used.
- At the mobile unit, a single antenna is used for both transmission to and reception from the base station, and a device called a duplexer is used inside the mobile unit to enable the same antenna to be used for simultaneous transmission and reception.

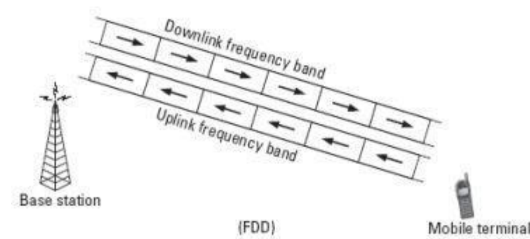
In FDD, a pair of simplex channels with a fixed and known frequency separation is used to define a specific radio channel in the system.

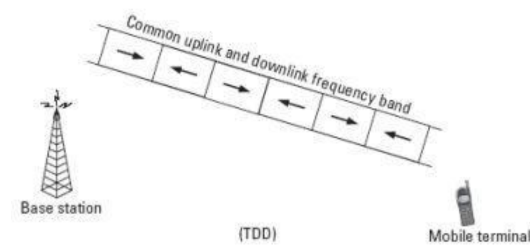
- The channel from a base station to the mobile user is called ***forward channel***.
- The channel from the mobile user to a base station is called the ***reverse channel***.



Time division duplexing (TDD)

- Shares a single radio channel in time, so that a portion of the time is used to transmit from the base station to the mobile, and the remaining time is used to transmit from the mobile to the base station.
- Only possible with digital transmission
- Very sensitive to timing.





Transmission types

- **Unicast** (point-to-point) transmission is made from one device to a single other device. It means that the packet is addressed to one receiver.
- **Broadcast** transmission is made from one device to all other devices. In this case there is just one sender, but the information is sent to all connected receivers.
- **Multicast** transmission is made from one device to a subset of the other available devices. In this case there is just one sender, but the information is sent to a group of receivers.

Types of wireless communication systems

The major types of wireless communication systems are:

a. Paging Systems

b. Cordless Telephone Systems
c. Satellite communication systems
d. Wireless LAN systems
e. Cellular Telephone Systems

The cost, complexity, performance, and types of services offered by each of these systems are different.

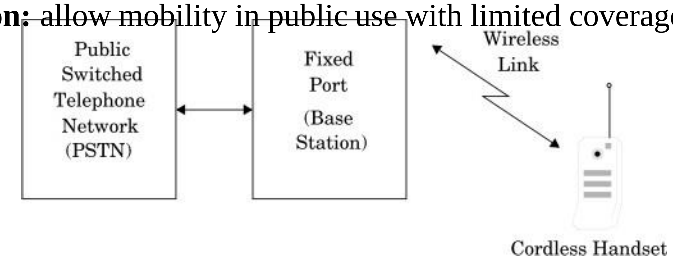
a. Paging Systems

- *Simplex* communication systems.
- Send brief messages to a subscriber, either text or voice messages.
- Consists of base stations which broadcast the page on a radio carrier to a paging receiver system.

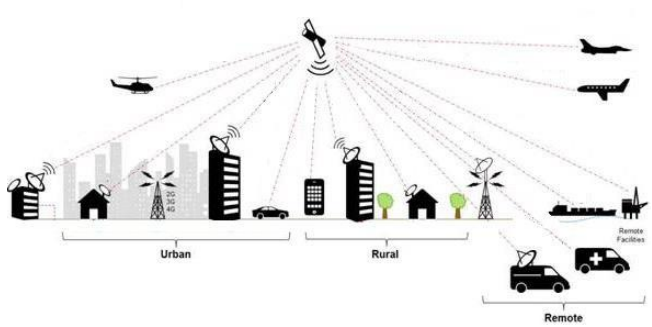
b. Cordless Telephone Systems

- *Full duplex* communication systems
- Wireless telephone network within a limited area.
- Consists of a portable handset, connected to dedicated base station, which is connected to the telephone network.

❖ **1st generation:** household environment
❖ **2nd generation:** allow mobility in public use with limited coverage.

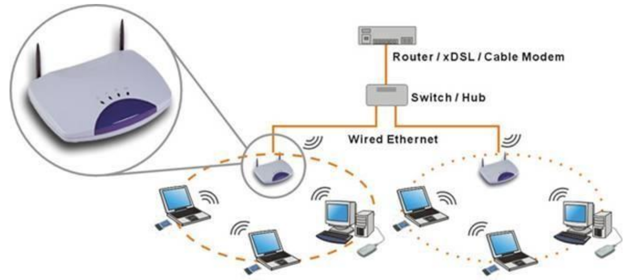


c. Satellite communication Systems



- Very wide range and coverage
- Very useful in sparsely populated areas: rural areas, sea, mountains, etc.
- Expensive base station (satellites) systems

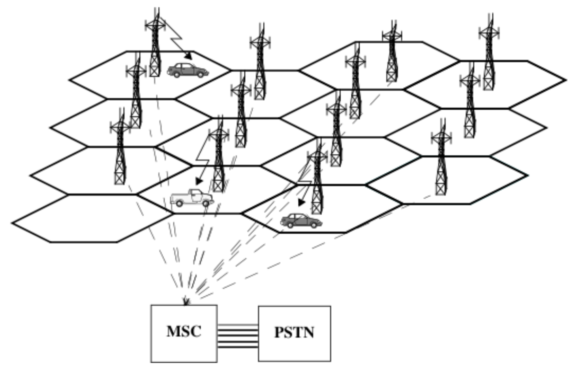
- **Wireless LAN (WLAN)**
- Low mobility (not for vehicular use) and High speed data transmission
- Confined regions – buildings and campuses
- Coverage: 100m – 300m per base station
- Uses the following bands (902-928 MHz, 2400-2483.5 MHz, 5725-5850 MHz)



- **Cellular Telephone Systems**

  The basic cellular system consists of:

  a. Mobile station (MS).
  b. Base stations (BS).
  c. Mobile switching center (MSC): also called Mobile telecommunications switching office (MTSO).



- Cellular systems accommodate a **large number of users** over a **large geographic area**, within a **limited frequency spectrum**.
- **High capacity** is achieved by limiting the coverage of each base station transmitter to a small geographic area called a ***cell*** so that the same radio channels may be reused by another base station located some distance away.
- **Handoff**: is a switching technique that enables a call to proceed uninterrupted when the user moves from one cell to another.

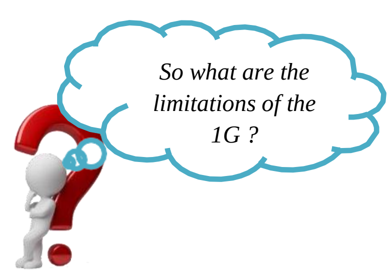
First Generation (1G) systems

The main characteristics of the first-generation cellular systems are

- **Analog** traffic channels using FM
- 416 channels per operator: 21 control channels, and 395 voice channels.
- The control channels are data channels operating at 10 kbps.
- large cells and omnidirectional base station antennas, therefore, the number of users that can be supported was quite limited.

Two main 1G systems are deployed:

1. **Advanced Mobile Phone Service (AMPS)**: developed in 1983 (in North America). Channel bandwidth is 30 kHz.
2. **Total Access Communication Systems (TACS):** developed in 1985 (in Europe). Channel bandwidth is 25 kHz.



Second Generation (2G) systems

Second-generation systems have been developed in early 90s to provide higher quality signals, higher data rates for support of digital services, and greater capacity. Moreover, The 2G systems provide:

- Digital voice coding and modulation
- Security (Encryption).
- Error detection and correction.

The key differences between the two generations are:

First Generation (1G) systems	Second Generation (2G) systems
Analog systems	Digital systems
FM is used for voice channels	GMSK (or QPSK) is used for digital traffic channels
No security.	Capable to encrypt the traffic to prevent eavesdropping.
Poor voice quality.	Very clear voice reception, because error detection and correction techniques are used.
No message service	Enable message service such as short message service (SMS) and Multimedia message service (MMS)

Beginning around 1990, a number of different second-generation systems have been deployed, such as Global system for mobile communications (GSM), and Interim Standard (IS-95) scheme.

	GSM	IS-95
Year introduced	1990	1993
Developed in	Europe	North America
BS transmission band	935~960 MHz	869~894 MHz
MS transmission band	890~915 MHz	824~849 MHz
Channel bandwidth	200 KHz	1250 KHz
No. of duplex channels	125	20
Modulation	GMSK	QPSK
Multiple Access	TDMA	CDMA

The GSM standard has gained worldwide acceptance as the first universal digital cellular system. With an initial bit rate of approximately 14 kbps.

2.5G systems

- ❖ Described as 2G technology combined with GPRS.
- ❖ 2.5G is an interim solution designed to allow for improved data rates.
- ❖ The main features of the 2.5G are:
- Ability to send and receive Email messages.
- Web browsing,
- Speed: 64-144 kbps

General Packet Radio Service (GPRS)

- GPRS is packet switched technology which based on existing GSM cellular network infrastructure and adds new packet-switching network equipment.
- Gives GSM subscribers access to data communication application such as e-mail and internet.
- Speed: up to 114 kbps.
- Physical channel is only assigned when data needs to be transmitted or received.

Enhanced Data Rates for GSM Evolution (EDGE)

- Provides up to 384 kbps rate.
- It is also referred to as Enhanced GPRS (EGPRS).

Third Generation (3G) systems

provides **High transmission rate and the support of multimedia services:** Very fast internet services, video calls, and mobile TV.

ITU's International Mobile Telecommunications view of 3G (IMT-2000):

- 144-kbps data rate available to users in high-speed motor vehicles over large areas.
- 384 kbps available to pedestrians standing or moving slowly over small areas.
- Support for 2.048 Mbps for office use.
- Support for both packet-switched and circuit-switched data services.

Generally, the technology planned is digital using TDMA or CDMA to provide efficient use of the spectrum and high capacity.

Universal Mobile Telecommunications System (UMTS)

UMTS is a third generation mobile cellular system for networks based on the GSM standard**,** developed and maintained by the 3GPP (3rd Generation Partnership Project).

3.5 G technology

High Speed Packet Access (HSPA)

HSPA extends and improves the performance of existing 3G mobile telecommunication networks utilizing the WCDMA protocols (also referred to as 3.5G). The HSPA specifications:

- increased peak data rates of up to
  - 14 Mbit/s in the downlink
  - 5.76 Mbit/s in the uplink.
- reduced latency
- Five times more system capacity in the downlink
- Twice as much system capacity in the uplink.

Pre-4G technology (3.9G)

- Mobile WiMAX standard (first used in South Korea in 2007),
- Evolved HSPA (HSPA+): Released in 2008 with worldwide adoption in 2010.
- Long Term Evolution (LTE) standard (first released in Oslo, Norway and Stockholm, Sweden since 2009).

Long Term Evolution (LTE) standard

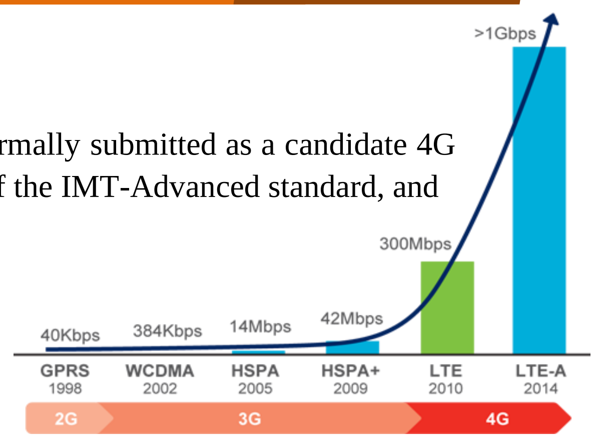
It is based on the GSM/EDGE and UMTS network technologies, main feachers are:

- Downlink peak rates of 300 Mbit/s,
- Uplink peak rates of 75 Mbit/s
- Quality of Service (QoS) provisions permitting a transfer latency of less than 5 ms in the radio access network (RAN).
- Has the ability to manage fast-moving mobiles
- Bandwidths is up to 20 MHz.
- Orthogonal frequency-division multiple access (OFDMA) for the downlink, Single-carrier FDMA for the uplink.
- Supports both FDD and TDD.

Fourth Generation (4G) systems

4G provides mobile broadband Internet access, with higher data rate and expanded multimedia services. The main features of the 4G systems are

- ❖ Higher speed.
- ❖ More security.
- ❖ Higher capacity.
- ❖ Lower cost than previous generations.
- ❖ Provides digital system with voice over-IP (VOIP) technology.
- ❖ IPv6 Core.
- ❖ Orthogonal frequency-division multiplexing (OFDM) is used instead of CDMA.
- ❖ IP network (packet swiching - no circuit switching)

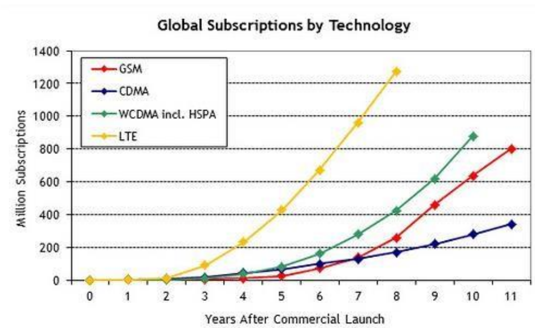


LTE Advanced (LTE-A) standard

It is a major enhancement of the LTE standard. It was formally submitted as a candidate 4G system to ITU in late 2009 as meeting the requirements of the IMT-Advanced standard, and was standardized by the 3GPP in March 2011.

The main features of the LTE-Advanced are:

- Higher capacity,
- Increased peak data rate,
  - Downlink 3 Gbps,
  - Uplink 1.5 Gbps
- Higher spectral efficiency (30 bps/Hz)
- Increased number of simultaneously active subscribers.
- LTE-Advanced can use up to 8×8 MIMO and 128 QAM in downlink direction.



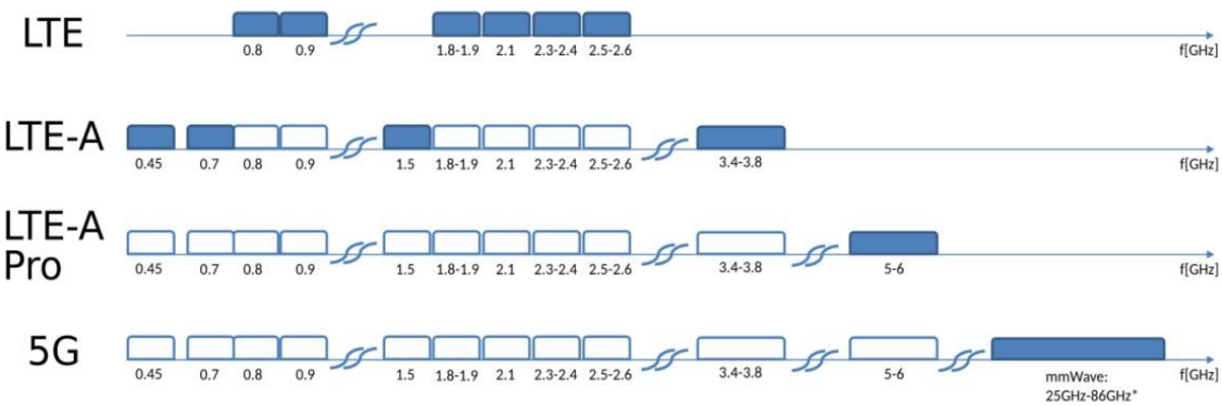
LTE Advanced Pro (LTE-A Pro)

- LTE-A Pro (Known as 4.5G) is released in the late 2015.
- It Incorporates several new technologies associated with 5G.

- 256-QAM.
- Massive MIMO.
- LTE-Unlicensed and LTE IoT.

Fifth Generation (5G) systems

- 5G is developed by 3GPP and deployed worldwide in 2019. The first country to adopt 5G on a large scale was South Korea.
- Have greater bandwidth, greater capacity, ultra-low latency, and higher speeds (up to 10 Gbps).
- In IMT-2020 standard, the 5G theoretical peak download speed is stated to be 20 Gbps and 10 Gbps upload speed.
- The increased speed is achieved partly by using higher-frequency radio waves than previous cellular networks. However, higher-frequency radio waves have a shorter range, requiring smaller cells.



- The air interface defined by 3GPP for 5G is known as New Radio (NR).
- For wide service, 5G networks operate on up to three frequency bands — low, medium, and high:

1. **<u>Low-band 5G</u>**
   - Uses a similar frequency range to 4G cellphones, 600-850 MHz,
   - The speed is little higher than 4G.
   - The base stations have a range and coverage area similar to 4G.
   - The speed is from 50 to 100 Mbit/s.
   - The maximum channel bandwidth defined is 100 MHz.

2. **<u>Mid-band 5G</u>**
   - Most widely deployed, and available in most metropolitan areas.
   - Uses microwaves of 2.5-3.7 GHz,
   - Speed = 100-900 Mbit/s,
   - The base stations have a range and coverage area up to several miles in radius.
   - Some regions are not implementing low-band, making this the minimum service level.
   - The maximum channel bandwidth defined is 100 MHz.

3. High-band 5G

- Uses frequencies of 25–39 GHz, near the bottom of the millimeter wave band. This requires placing 5G base stations every few hundred meters.
- Higher frequencies may be used in the future.
- Speeds in the gigabit per second (Gbit/s) range. mmWave had a top speed of 1.8 Gbit/s.
- The channel bandwidth from 50 MHz to 400 MHz.
- Higher frequency 5G signals cannot penetrate solid objects easily, such as cars, trees, and walls, because of the nature of these higher frequency electromagnetic waves. Therefore, high-band used in places like restaurants and shopping malls.

- The higher the frequency, the greater the ability to support high data-transfer speeds.
- Millimeter waves have a more limited range, requiring many small cells.
- A 5G network composed of networks of up to three different types of cells, each requiring specific antenna designs.
- Due to their higher cost, plans are to deploy these cells only in dense urban environments.
- Some 5G application services are:
  1. **enhanced Mobile Broadband (eMBB):** uses 5G as a progression from 4G LTE mobile broadband services, with faster connections, higher throughput, and more capacity. This will benefit areas of higher traffic such as stadiums, cities, and concert venues.
  2. **Ultra-Reliable Low-Latency Communications (URLLC):** refer to using the network for mission critical applications that require uninterrupted and robust data exchange.
  3. **Massive Machine-Type Communications (mMTC)** is used to connect to a large number of devices.
  4. **fixed fibre-like wireless access**: due to the increased bandwidth, the networks also used as general internet service providers for laptops and desktop computers as well as cell phones.
- 5G can support up to a million devices per square kilometer, while 4G supports only up to 100,000 devices per square kilometer.
- Millimeter waves have a shorter range than microwaves, therefore the cells are limited to a smaller size. Millimeter waves also have more trouble passing through building walls.
- Millimeter wave antennas are smaller than the large antennas used in previous cellular networks.

Massive MIMO

- MIMO (multiple input and multiple output) systems use multiple antennas at the transmitter and receiver ends of a wireless communication system. Multiple antennas use the spatial dimension in addition to the time and frequency ones, without changing the bandwidth requirements of the system.
- Massive MIMO antennas increases sector throughput and capacity density using large numbers of antennas and Multi-user MIMO (MU-MIMO). Each antenna is individually-controlled and may embed radio transceiver components.
- Massive MIMO was deployed in 4G as early as 2016 and typically used 32 to 128 small antennas at each cell. In the right frequencies and configuration, it can increase performance from 4 to 10 times.

Beamforming

- Multiple bitstreams of data are transmitted simultaneously in a technique called beamforming, the base station computer continuously calculates the best route for radio waves to reach each wireless device and organize multiple antennas to work together as phased arrays to create beams of millimeter waves to reach the device.
- Beamforming is used to direct radio waves to a target. This is achieved by shaping the radio waves to point in a specific direction. The technique combines the power from elements of the antenna array in such a way that signals at particular angles experience constructive interference, while other signals pointing to other angles experience destructive interference. This improves signal quality in the specific direction, as well as data transfer speeds.
- 5G uses beamforming to improve the signal quality it provides.
- Beamforming can be accomplished using phased array antennas.

NOMA (non-orthogonal multiple access)

- NOMA is a multiple-access technique for future cellular systems via allocation of power.
- NOMA enhances spectrum efficiency, reduces latency with high reliability, and offers massive connectivity.
- NOMA is divided into two categories: power-domain NOMA and code-domain NOMA.

Other advantages of 5G

- connects people to IoT devices.
- aids in disaster recovery efforts, providing real-time data for emergency responders.
- Remote surgeries.
- web of connected autonomous vehicles,
- remotely controlled robots,
- heterogeneous sensors connected to serve versatile applications
- multipurpose wireless network (World-Wireless World Wide Web)

Comparision between the generations of cellular mobile commnuications

Parameters	1G	2G	3G	4G	5G
Introduced in year	1983	1990	2000	2010	2019
Location of first commercialization	USA	Finland	Japan	South Korea	South Korea
Technology	AMPS, NMT, TACS	1S-95, GSM	UMTS, HSPA	LTE-A, WIMAX 2	5G LTE
Multiple Access system	FDMA	TDMA, CDMA	WCDMA	OFDMA	OFDM, BDMA, NOMA
Switching type	Circuit switching	circuit switching for voice and packet switching for data	Packet switching + Circuit switching	Packet switching	Packet switching
Speed (data rates)	2.4 Kbps to 14.4 kbps	14.4 Kbps	3.1 Mbps	> 300 Mbps	> 1 Gbps
Special Characteristic	First wireless communication	Digital version of 1G technology	Digital broadband, speed increments	Very high speeds, All IP	Extremely high speed and capacity, IoT, Massive MIMO
Features	Voice only	Multiple users on single channel	Multimedia features, Video Call	High Speed, real time streaming	High resolution video streaming,
Supports	Voice only	Voice and Data	Voice and Data	Voice and Data	Voice and Data
Internet service	No Internet	Narrowband	Broadband	Ultra Broadband	enhanced Mobile Broadband (eMBB)
Bandwidth	25, 30 KHz	200 KHz	5-25 MHz	100 MHz	400 MHz
Operating frequencies	800 MHZ	GSM: 900MHz, 1800MHz CDMA:800MHz	1.6-2.1 GHz	2-8 GHz	F1:600-850 MHz F2:2.5-3.7 GHz F3:25–39 GHz
Band (Frequency) type	Narrow band	Narrow band	Wide band	Ultra Wide Band	Ultra Wide Band
Advantage	Simpler (less complex) network elements	Multimedia features (SMS, MMS). Internet access and SIM introduced	High security. international roaming	Speed, High speed handoffs, MIMO technology, Global mobility	Extremely high speed, low latency, less energy consumption
Disadvantages	Limited capacity. not secure, poor battery life, large phone size, background interference	Low network range, slow data rates	High power consumption, low coverage, High cost of Spectrum licence	Hard to implement complicated hardware required	Less obstacle penetration for high frequencies
Applications	Voice Calls	Voice calls, Short messages, browsing (partial)	Video conferencing mobile TV, GPS	High speed application, mobile TV, Wearable devices	High resolution video streaming, IoT, wearable devices, Remote surgeries.