Wireless and Mobile Networks

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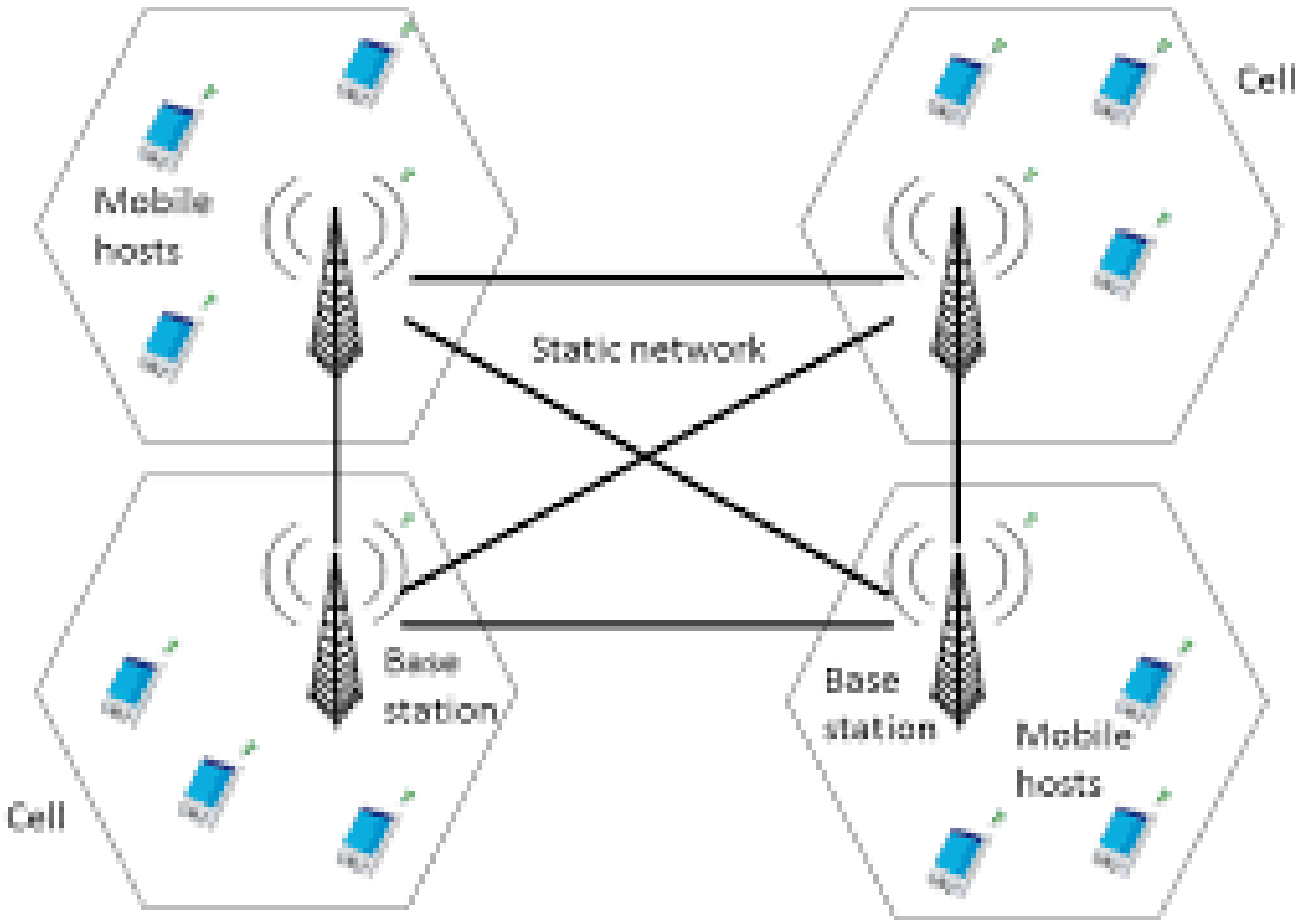
Chapter 3

Mobile Networks

Besides fixed wired networks, **the mobile networks** provide wireless connection and data transmissions. In addition to radio parts, the mobile network also includes the whole core network and fixed infrastructure to enable delivery of all kinds of services. With every new introduced generation, their capabilities are still growing and thus meet increasing requirements. Today, mobile networks utilizing digital concepts are the only alternative for the near and distant future.

Cellular network or mobile network is a communication network where the link to and from end nodes is wireless. The network is distributed over land areas called "cells", each served by at least one fixed-location transceiver (typically three cell sites or base transceiver stations). These base stations provide the cell with the network coverage which can be used for transmission of voice, data, and other types of content. A cell typically uses a different set of frequencies from neighboring cells, to avoid interference and provide guaranteed service quality within each cell.


Mobile
hosts
Static network
Cell
Base
station
Base
station
Mobile
hosts
Cell

When joined together, these cells provide radio coverage over a wide geographic area. This enables numerous portable transceivers (e.g., mobile phones, tablets and laptops equipped with mobile broadband modems, pagers, etc.) to communicate with each other and with fixed transceivers and telephones anywhere in the network, via base stations, even if some of the transceivers are moving through more than one cell during transmission.

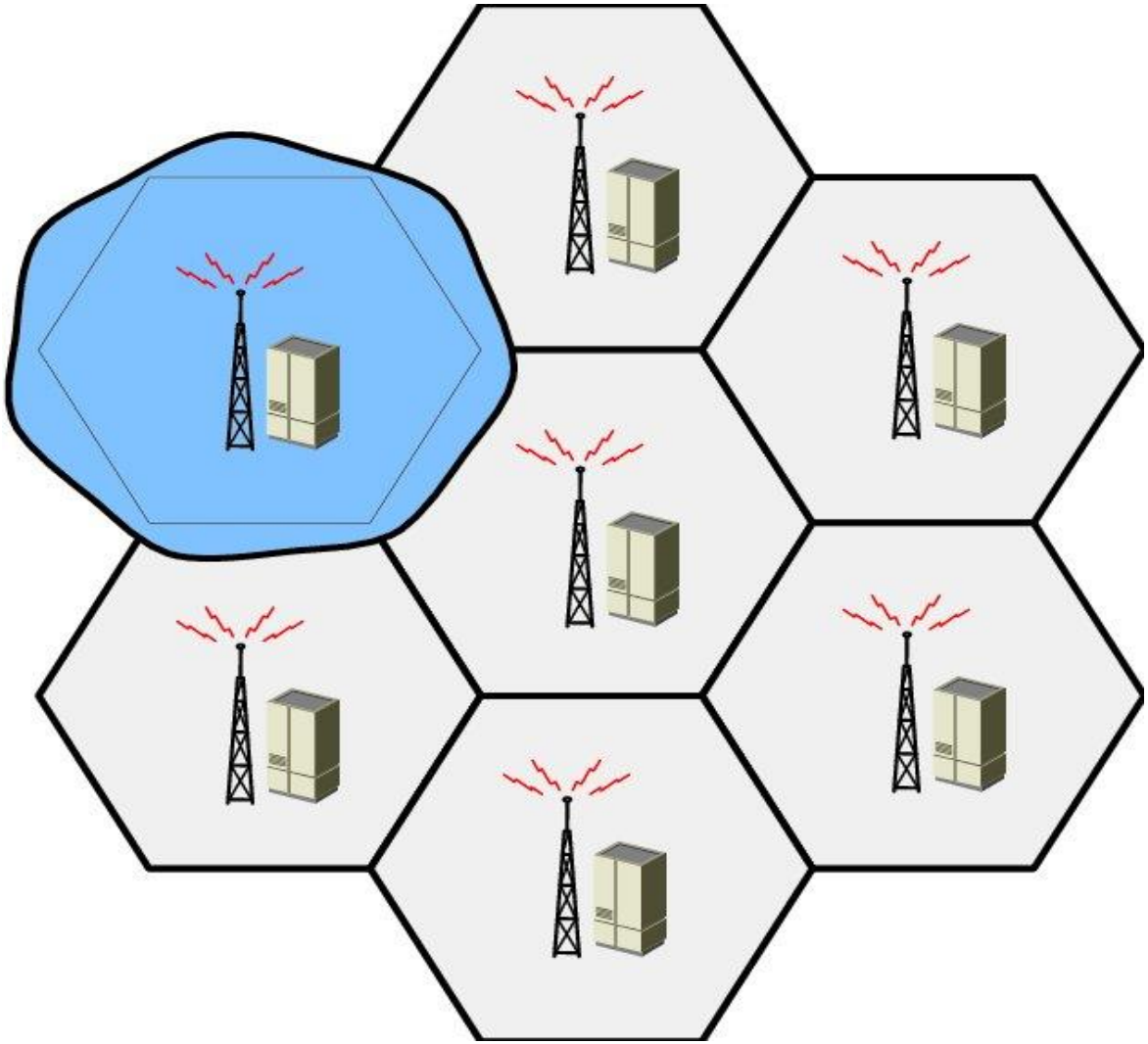
Cellular networks offer a number of desirable features:

- More capacity than a single large transmitter, since the same frequency can be used for multiple links as long as they are in different cells.
- Mobile devices use less power than with a single transmitter or satellite since the cell towers are closer.
- Larger coverage area than a single terrestrial transmitter, since additional cell towers can be added indefinitely and are not limited by the horizon.

Major telecommunications providers have deployed voice and data cellular networks over most of the inhabited land area of Earth. This allows mobile phones and mobile computing devices to be connected to the public switched telephone network and public Internet access. Private cellular networks can be used for research or for large organizations and fleets, such as dispatch for local public safety agencies or a taxicab company.

Mobile phones connection can be enabled by radio telecommunication resources and their operation usually follows the operation of fixed telephone networks. The final assembly consists of:

- framework of fixed BS (Base Station).
- MS terminals (Mobile Station).



A cluster of cells in a cellular network

The size of cells used in various mobile systems depends primarily on the type and purpose of the mobile system and **can be classified as follows**:

- femtocell (flats or offices) - intended for cover areas with low quality of signal from other cells, usually supposed to be indoor with radius of several meters.
- Pico cell (office and residential environment) signal range is from tens up to few tens of meters.

- microcell (urban areas w ith dense housing) - focused mainly to the slower moving participants (for example to a car in city traffic or pedestrians), coverage within a single cell is up to few hundreds of meters.
- macro cells (large and sparsely populated areas) - primarily oriented for the high speed moving participants (for example, vehicles on the roads), diameter of the macro cells is maximally up to few kilometers.

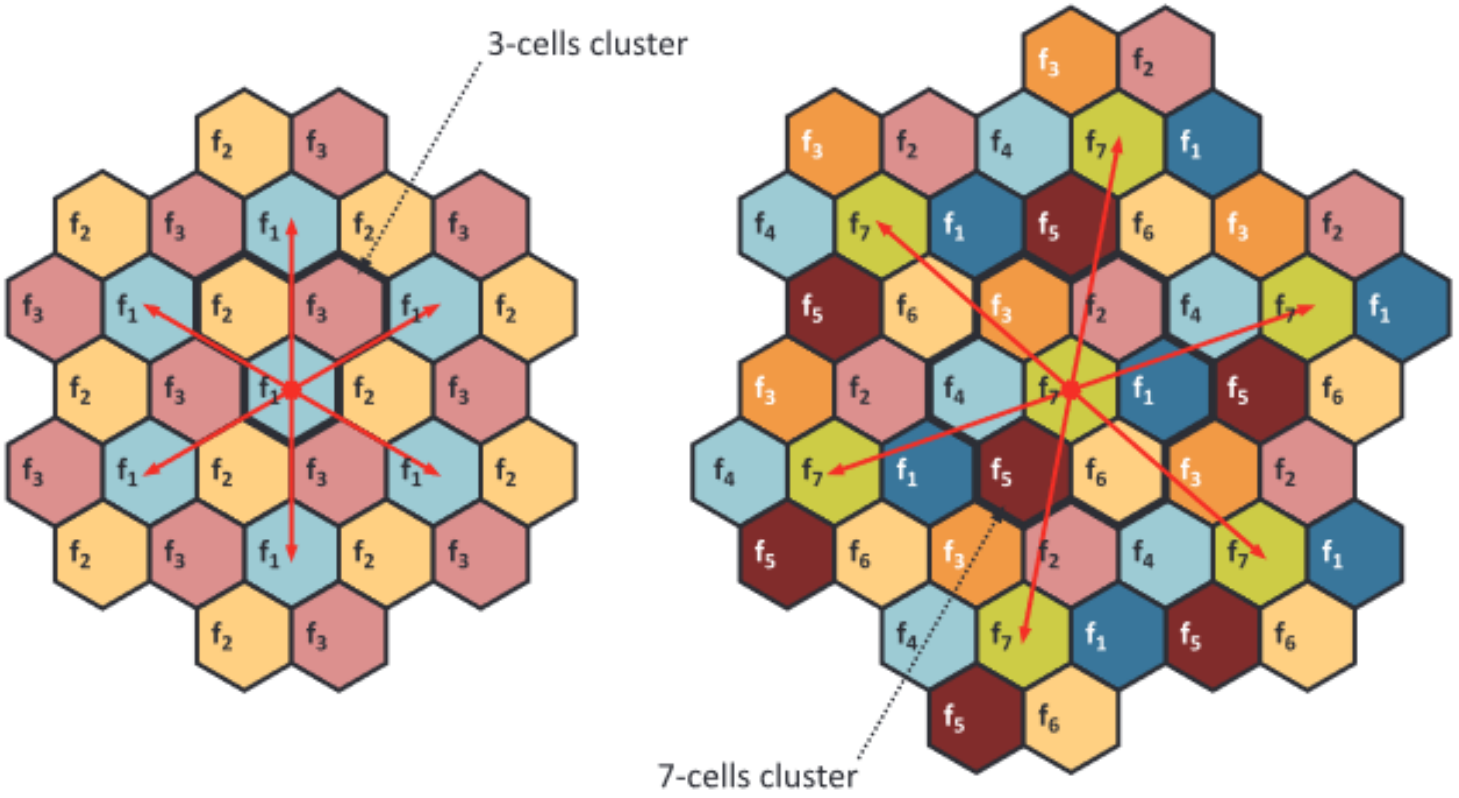
- satellite cell (area accessible by telecommunications satellite) - allows the connection in locations inaccessible for the previous cell types, signal range is dependent on the position of satellites, respectively on their orbit and the parameters of the transmitting and receiving device.

GSM System

The Global System for Mobile Communications (GSM) is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe the protocols for second-generation (2G) digital cellular networks used by mobile devices such as mobile phones and tablets. It became a global standard for mobile communications achieving over 90% market share, and operating in over 193 countries and territories.

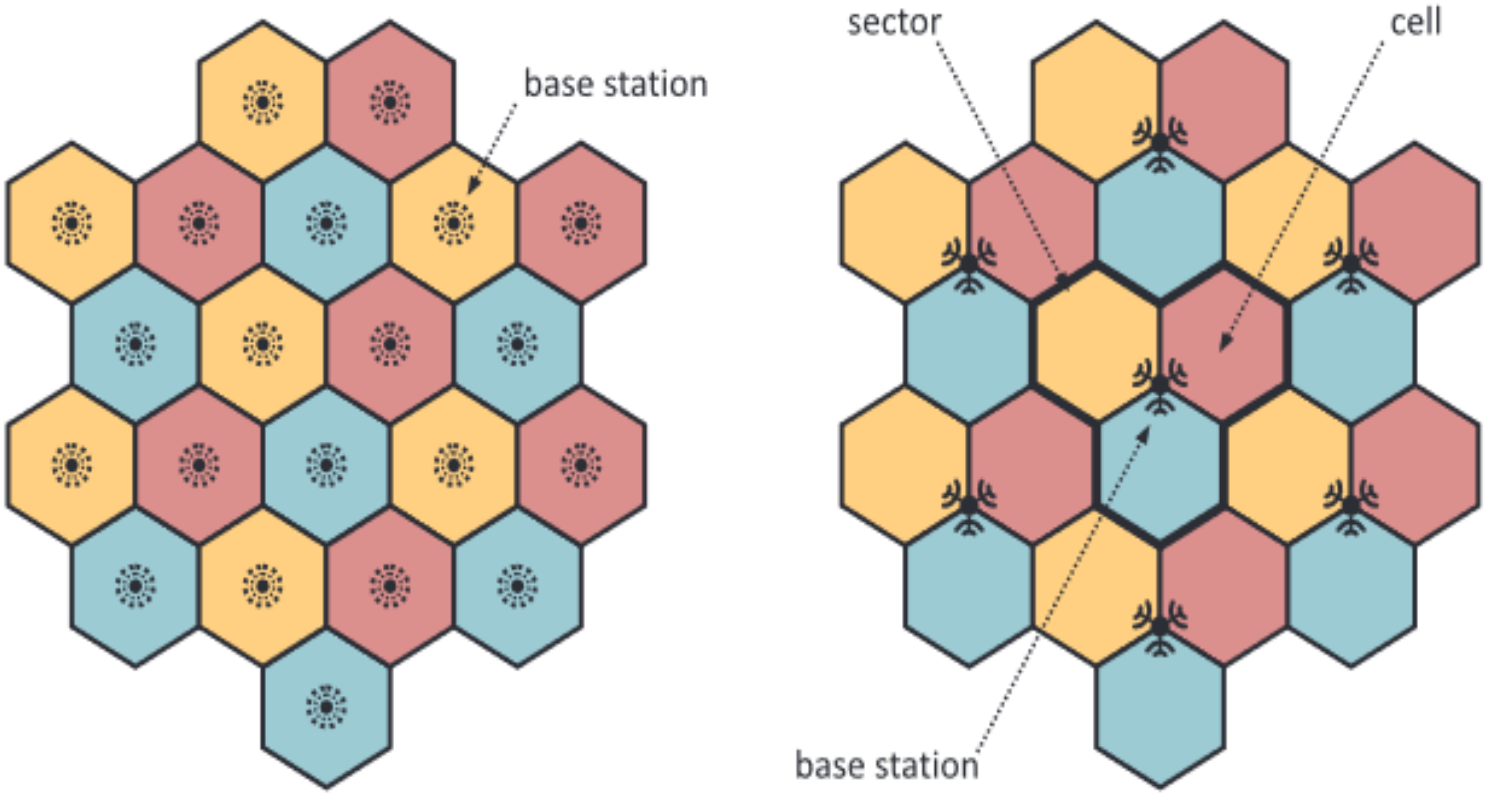
2G networks developed as a replacement for first generation (1G) analog cellular networks. The GSM standard originally described a digital, circuit-switched network optimized for full duplex voice telephony. This expanded over time to include data communications, first by circuit-switched transport, then by packet data transport via General Packet Radio Service (GPRS), and Enhanced Data Rates for GSM Evolution

Cellular structure of the GSM network is usually created by using macro cells with a diameter of up to few kilometers. Example of radio coverage of the territory based on the cellular principle. For cellular mobile network structure, a frequency planning is necessary. Frequency plan is working with three or seven frequencies. The same frequencies (f1 to f3 , or f1 to f7) can be used in any cluster. The area of all three or seven cells cluster is approximately equal to the average interference zone.



Distribution of operated territory into cells

Let us now divide a single cluster in the previous figure into 21 smaller cells (see figure below - section a)). The number of available channels is not so changed, but there is increased number of base stations to 21. However, we can significantly reduce the number of base stations by principle of **sectorization** to 7. This could be accomplished under condition that the individual base stations are not placed in the centres of cells, but in the intersection points of three adjacent cells forming one sector (see figure below - section b)).



a) network without sectorization

b) network with sectorization

Principle of sectorization of cellular network

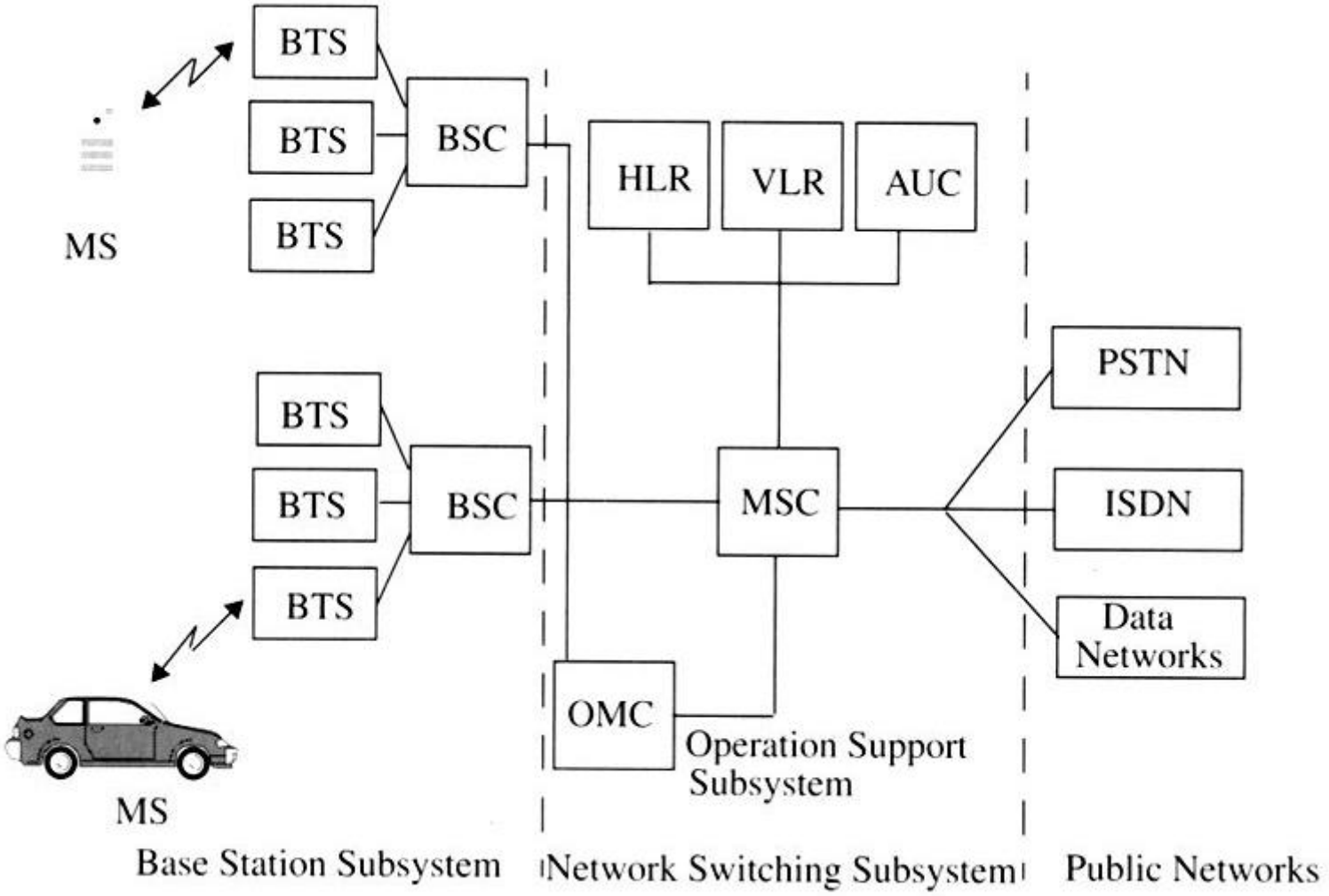
Three separated directional antennas with three transmitters and receivers will be used for each of these seven stations. The number of base stations in this case is the same as in the previous figure (section b)) with the distribution of the service area into cells, but configuration of a network is much more efficient due to operating characteristics (for example lower transmission power and increasing the number of mobile stations which can be simultaneously served).

Small cells (with range of approximately 10 up to 500 m) will be necessary to use in the areas with high density of users. In areas with lower density it is sufficient to deploy cells with larger radius (with range approximately 1 up to 10 km) and for very lightly loaded areas can be the cell diameter even few kilometers.

The whole basic structure of the GSM system is shown in the figure below. The basic structure of the GSM system can be divided into fundamental parts: Base Station Subsystem, Base Station Controller, Networks Switching Subsystem, and Operation Support Subsystem.

Base Station Subsystem (BTS): The MSs communicate with BTs. Several BTs are assigned to a BSC, whose main task is to allocate and release the free radio channels for communication with MSs and ensure the correct handover.

Operation of the system requires that each MS, which is in operation, provides the information to the system on its location, it means about the cell in which it is located . MS monitors also signals from nearest base stations and always selects the optimum BTS, through which the connection is established.


BTS
BTS
BTS
BSC
MS
HLR
VLR
AUC
PSTN
BTS
BTS
BTS
BSC
MSC
ISDN
Data
Networks
OMC
Operation Support
Subsystem
MS
Base Station Subsystem
Network Switching Subsystem
Public Networks

Base Station Controller (BSC) is a network element that controls and monitors a number of base stations and provides the interface between the cell sites and the mobile switching center (MSC).

A Mobile Switching Center (MSC) is a core part of the GSM/CDMA network system. It acts as a control center of a Network Switching Subsystem (NSS). The MSC connects calls between subscribers by switching the digital voice packets between network paths. It also provides information needed to support mobile service subscribers. Based on the size of the mobile operator, multiple MSC can be implemented.

Network Switching Subsystem (NSS) This subsystem includes in particular the MSC exchange, which is represented by a common type of telephone exchange that is supplemented by additional features resulting from the mobility of the MSs. These additional features are stored in various databases comprising:

- HLR (Home Location Register) – keeps track of all participants in the area. Authentication (identification) of subscriber is provided by AuC. Each participant of the network is stored only in a single HLR.

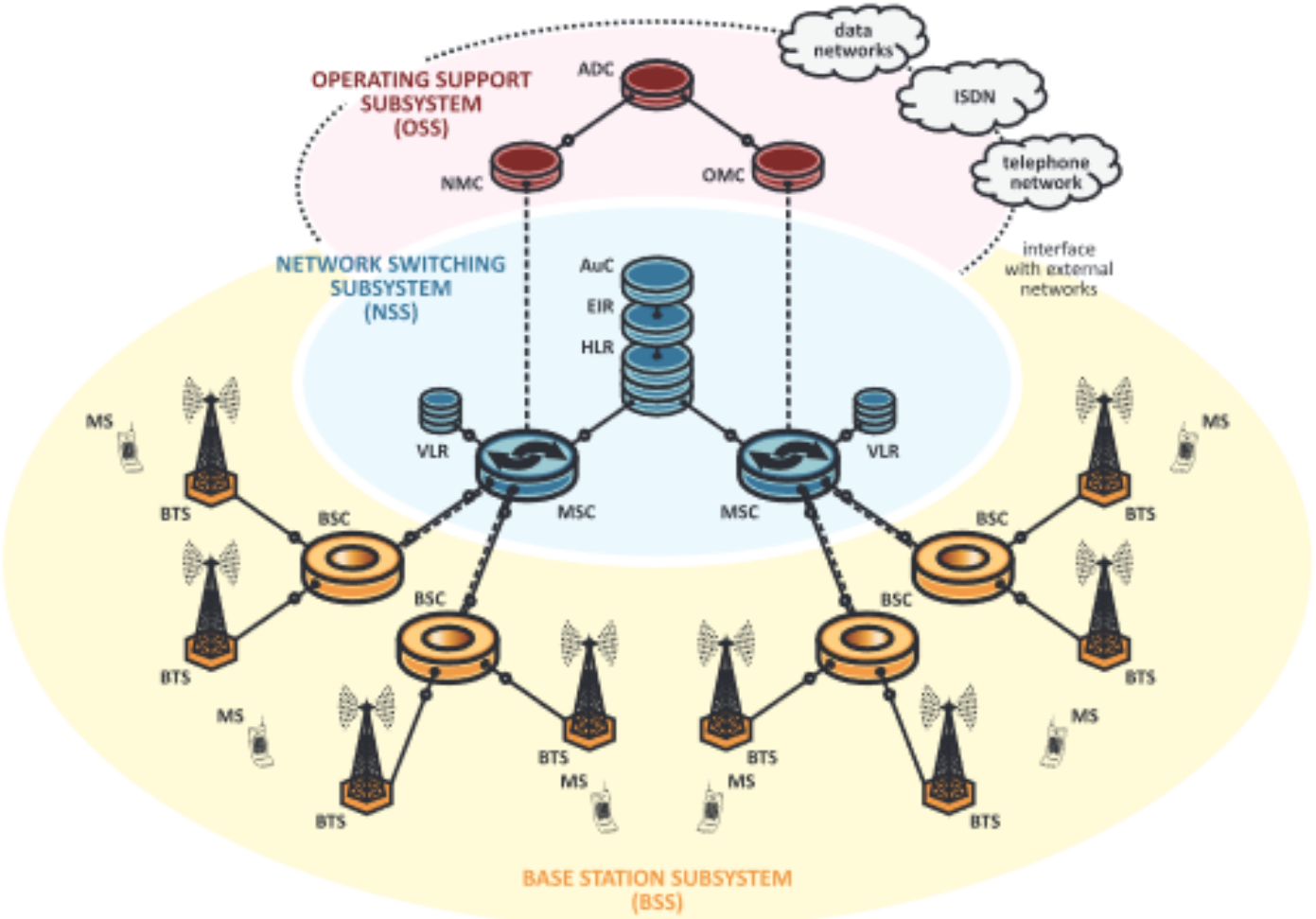
- VLR (Visitor Location Register) – temporarily stores the latest information on position of the MSs in the range of the MSC. The VLR always requires and obtains data from the HLR and if the MS leaves the visited area, the MS's related data are always deleted from the VLR.

The MSC is stationed between the base station and the Public Switched Telephone Network (PTSN). All mobile communications are routed from the base station through the MSC. The MSC is responsible for handling voice calls and SMS including other services like FAX. The MSC initiates call setup between subscribers and is also responsible for real time pre-paid billing and account monitoring. The MSC is responsible for inter- BSC handovers – between Base Station Controllers – and inter-MSC handover – between mobile switching centers.

A BSC initiates an inter-BSC handover from the MSC when it notices a cellphone approaching the edge of its cell. After the request is made by the BSC, the MSc scans through a list to determine adjacent BSCs and then proceeds to hand over the mobile device to the appropriate BSC. The MSC also works with the Home Location Register (HLR) – which stores location information among other relevant information – to keep up with the constant mobility of mobile devices. The MSc uses the database of the HLR to determine the location of each mobile device in order to provide proper routing of calls.

Operation Support Subsystem (OSS)

The OSS is responsible for the operation of BTS and NSS. It contains mainly supervisory block, ADC (Administrative Centre), addressing administrative tasks (e.g., report participation fees, billing, etc.), followed by a NMC (Network Management Centre) block providing overall management of information flow in the network, and operational and service block, OMC (Operation and Maintenance Centre), addressing the role of maintenance and operation of the network.

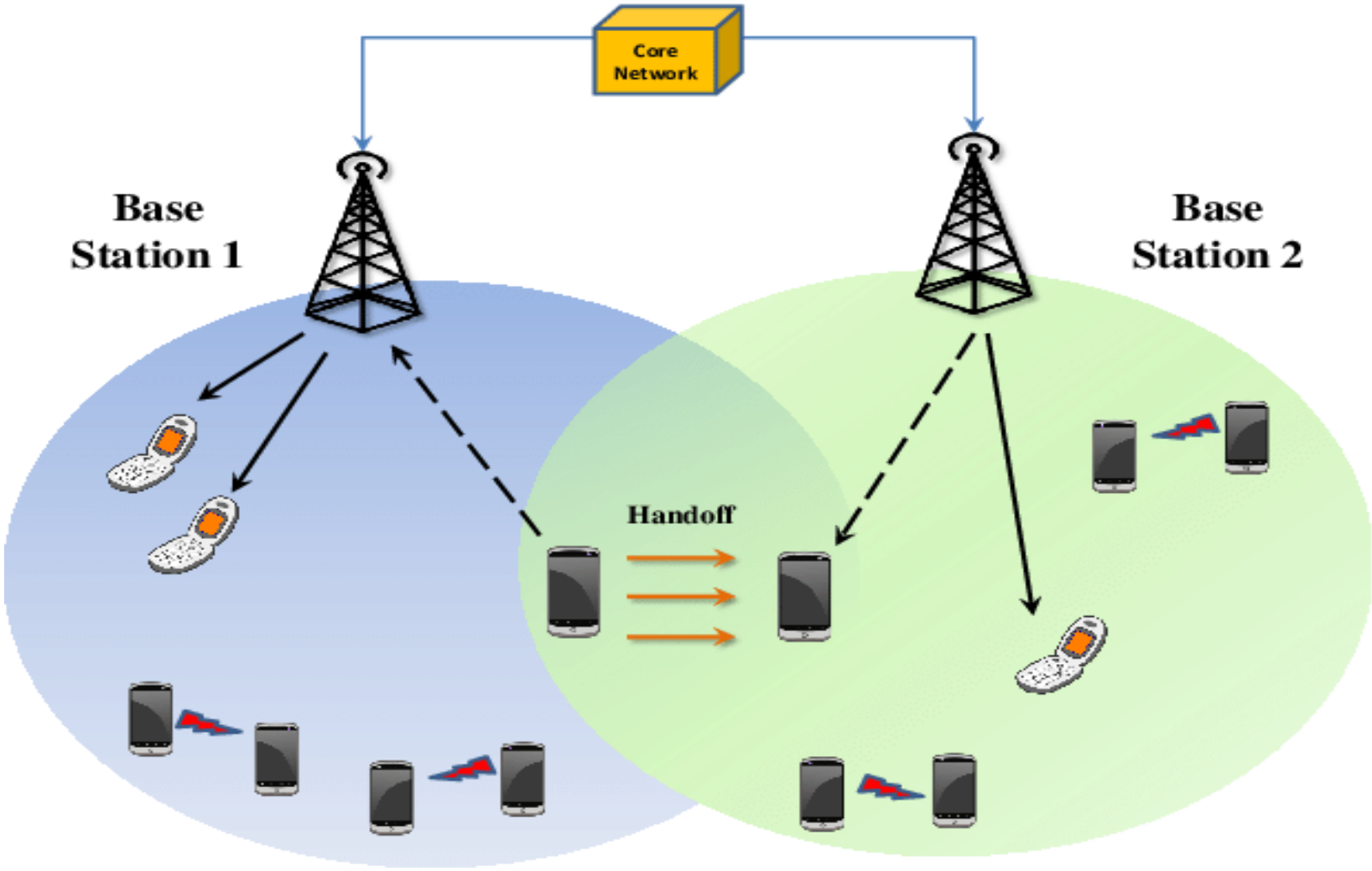


Architecture of GSM system

Handover

Handoff (or handover) is a control process initiated when a mobile moves from its current cell to its neighboring cell. A user of a mobile phone will be moving continuously. In such a situation, the mobile connection should also remain intact especially if the user is currently using the phone. This transfer of connection from one cell to another should be quick and in such a manner that user doesn't actually realize that a handoff has happened.

The handover manages a change of a current serving station to a proper target station during user's movement across the cells boundaries. The major purpose of handovers in mobile networks is to ensure continuous connection with high QoS or balance load in network. Tracking of current position of mobile station in the network enables continuous automatic connection established between the mobile and base station.

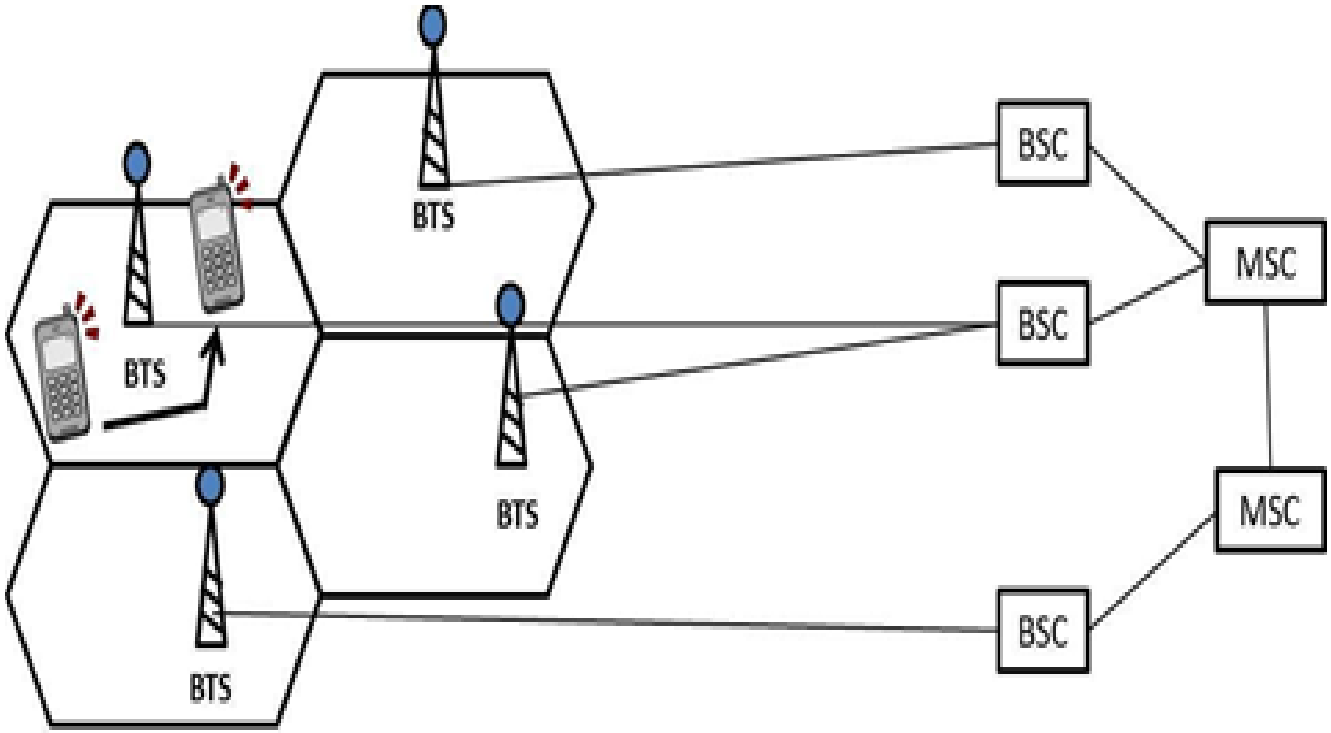


Handover (Handoff) in a cellular network

This indication is stored in the mobile network registers, which allows routing of connection to the called party directly in to the area where the station is currently located. On the basis of frequency planning communication channels with different frequencies in the adjacent cells are al ways used. When the mobile subscriber moves across the border lying between two different cells, it is always necessary to retune user's mobile station.

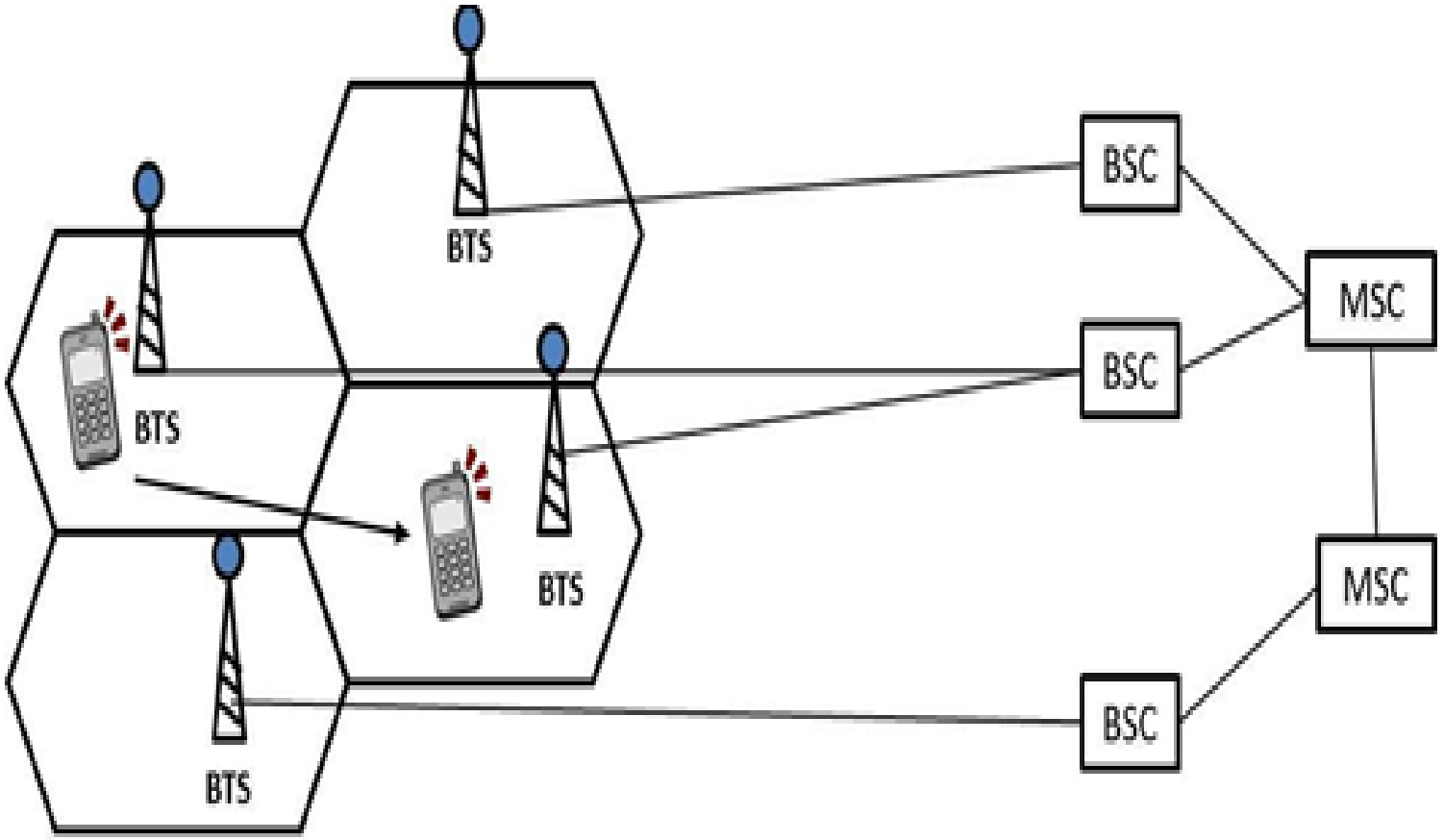
There are four basic types of handover in Cellular network:

1. Intra-cell handover: Such a kind of handover is performed to optimize the traffic load in the cell or to improve quality of a connection by changing carrier frequency.



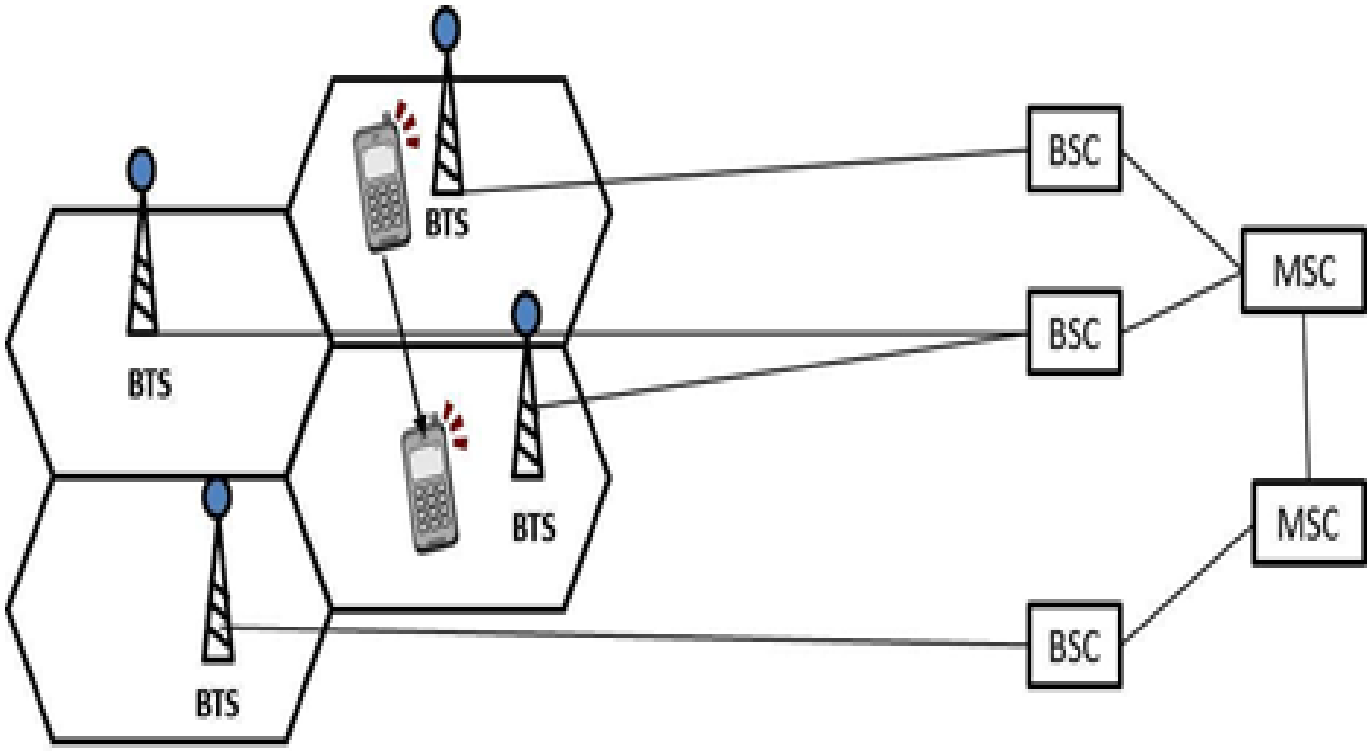
Intra-cell handover

2 Inter-cell handover: It is also known as Intra-BSC handover. Here the mobile moves from one cell to another but remains within the same BSC (Base station controller). Here the BSC handles the handover process.



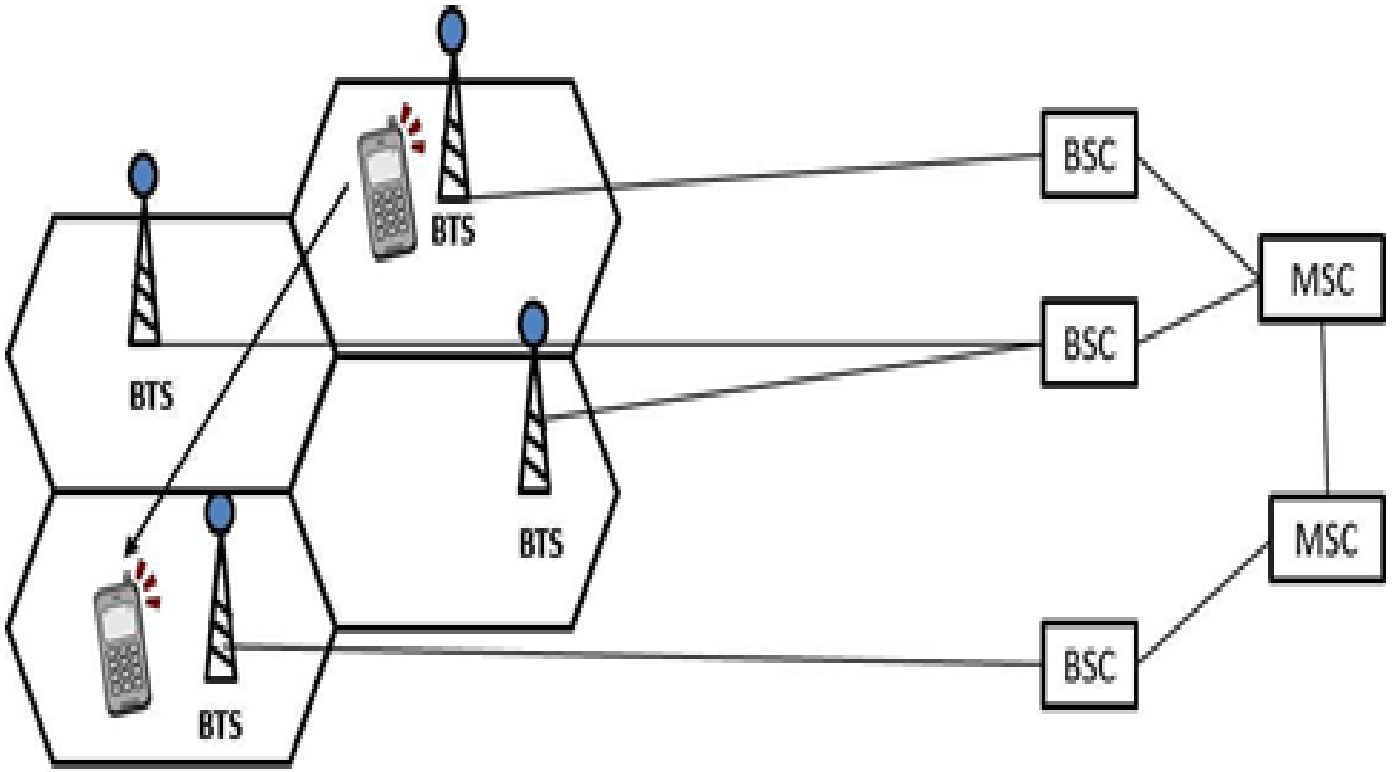
Intra-BSC handover

3- Inter-BSC handover: It is also called as Intra-MSC handover. As BSC can control only a limited number of cells, we might usually need to transfer a mobile from one BSC to another BSC. Here the MSC handles the handover process.



Inter-BSC handover

4 Inter-MSC handover: It occurs when a mobile moves from one MSC region to another MSC. MSC cover a large area. It can be imagined as a handover from Maharashtra MSC to Gujarat MSC while travelling.



Inter-MSC handover

Multiple Access

In each cell it must be ensured that the connection between one base station and a higher number of mobile stations in each period of time might be established and realized. **For this purpose the methods of the multiple access are used**. A dedicated frequency band for a given radio system can be accessed by one of the following methods:

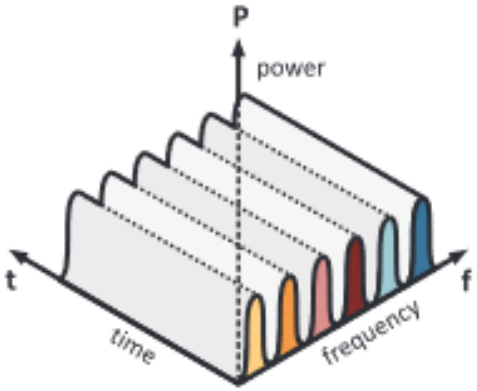
- FDMA (Frequency Division Multiple Access) divides the allocated frequency band into the sub channels and then assigns these sub channels to each communication channel.
- TDMA (Time Division Multiple Access) creates in a particular frequency sub channel the sequence of time slots and then its individual slots allocates to each communication channel on the principle of time multiplex.

- CDMA (Code Division Multiple Access) processes data sequence on each side of the transmitting channel by coding process through unique coding policy, which is deliberately different from the coding policy of all the other channels. Thus, the signals of each channel can be transmitted in the same frequency band, which is without time resolution. The communication channels are distinguished from each other on the receiving side on the basis of a unique coding policy, which was used for the coding at side of transmitting channel.

- OFDMA is a combination of time and frequency division multiple accesses. The available resources are split into subcarriers in a frequency domain and also into several time intervals in time domain. Then individual users have assigned not only one or several subcarriers but also a time interval for communication.

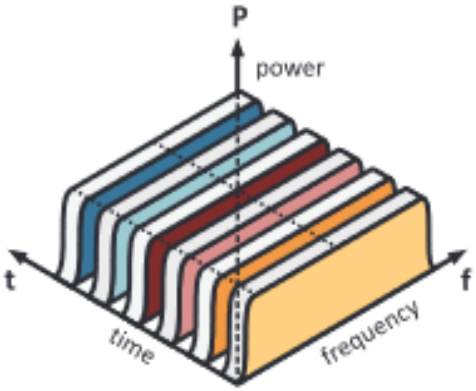
FDMA
(Frequency Division Multiple Access)

1 subscriber = 1 carrier



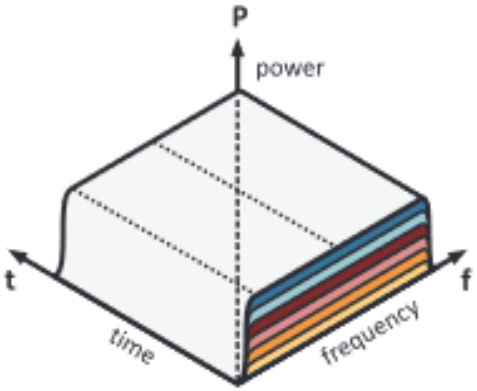
TDMA
(Time Division Multiple Access)

1 subscriber = 1 timeslot



CDMA
(Code Division Multiple Access)

1 subscriber = 1 unique code



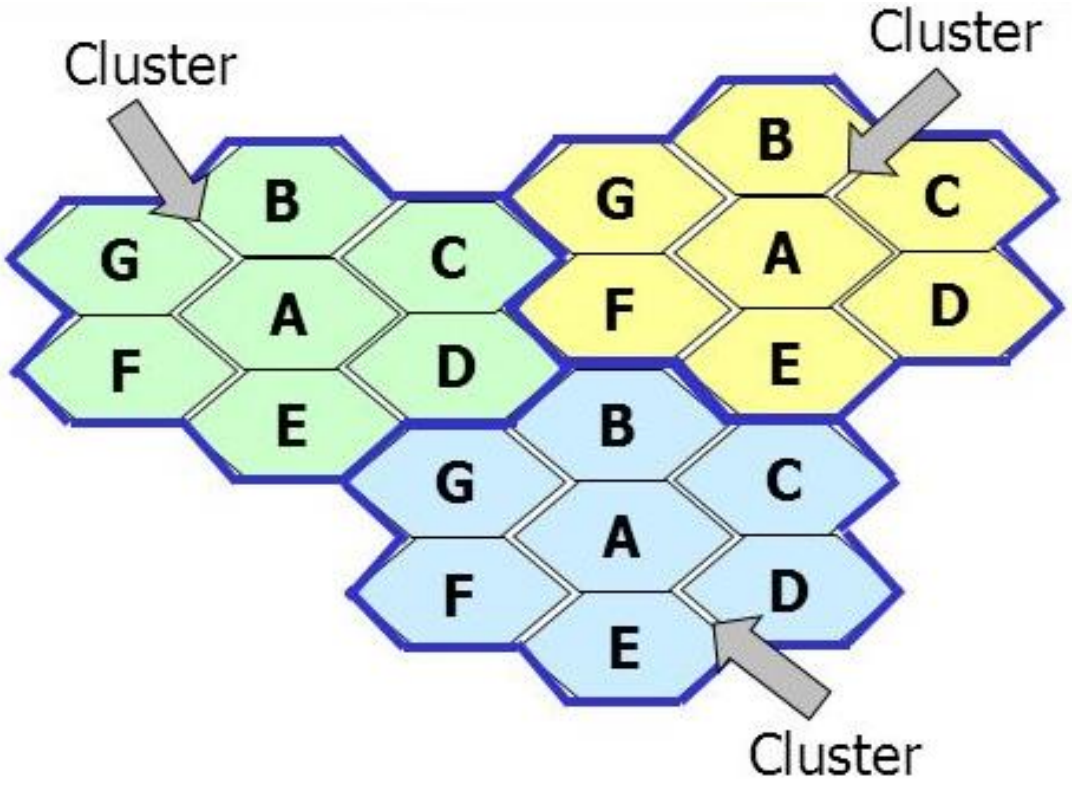
Multiple access methods

Frequency Reuse

Frequency reusing is the concept of using the same radio frequencies within a given area, that are separated by considerable distance, with minimal interference, to establish communication.

Frequency reuse offers the following benefits:

- Allows communications within cell on a given frequency
- Limits escaping power to adjacent cells
- Allows re-use of frequencies in nearby cells
- Uses same frequency for multiple conversations
- 10 to 50 frequencies per cell


Cluster
Cluster
B
G
C
A
F
D
E
B
G
C
A
F
D
E
Cluster

For example, when N cells are using the same number of frequencies and K be the total number of frequencies used in systems. Then each cell frequency is calculated by using the formulae K/N. In Advanced Mobile Phone Services (AMPS) when K = 395 and N = 7, then frequencies per cell on an average will be 395/7 = 56. Here, cell frequency is 56.

A Cluster: A Group of N cells that which collectively use the complete set of available frequencies

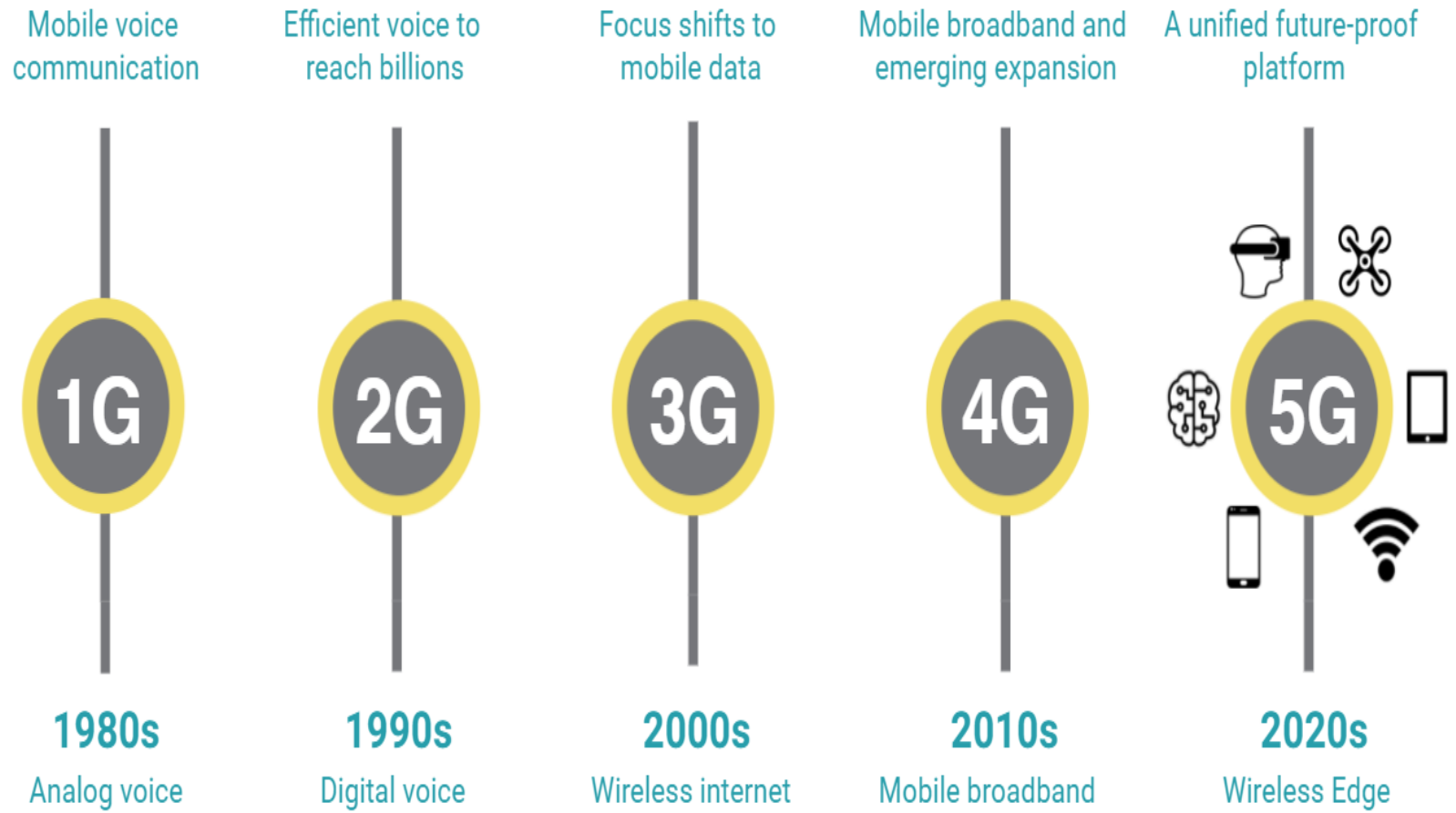
Total Number of Channels in the System:

$$C = MkN = MS$$

M: Number of clusters within the system
K: Number of channels per cell
N: Cluster Size
S: Number of available physical channels

Mobile Generations

Simply, the "G" stands for "**GENERATION**". While you connected to internet, the speed of your internet is depends upon the signal strength that has been shown in alphabets like 2G, 3G, 4G etc. right next to the signal bar on your home screen. Each Generation is defined as a set of telephone network standards , which detail the technological implementation of a particular mobile phone system. The speed increases and the technology used to achieve that speed also changes. For eg, 1G offers 2.4 kbps, 2G offers 64 Kbps and is based on GSM, 3G offers 144 kbps-2 mbps whereas 4G offers 100 Mbps - 1 Gbps and is based on LTE technology .


Mobile voice communication
Efficient voice to reach billions
Focus shifts to mobile data
Mobile broadband and emerging expansion
A unified future-proof platform
1G
2G
3G
4G
5G
1980s
Analog voice
1990s
Digital voice
2000s
Wireless internet
2010s
Mobile broadband
2020s
Wireless Edge

The aim of wireless communication is to provide high quality, reliable communication just like wired communication(optical fiber) and each new generation of services represents a big step(a leap rather) in that direction. This evolution journey was started in 1979 from 1G and it is still continuing to 5G. Each of the Generations has standards that must be met to officially use the G terminology. There are institutions in charge of standardizing each generation of mobile technology.

Each generation has requirements that specify things like throughput, delay, etc. that need to be met to be considered part of that generation. Each generation built upon the research and development which happened since the last generation. 1G was not used to identify wireless technology until 2G, or the second generation, was released. That was a major jump in the technology when the wireless networks went from analog to digital .

1G - First Generation: This was the first generation of cell phone technology. The very first generation of commercial cellular network was introduced in the late 70's with fully implemented standards being established throughout the 80's. It was introduced in 1987 by Telecom (known today as Telstra), Australia received its first cellular mobile phone network utilizing a 1G analog system.

1G is an analog technology and the phones generally had poor battery life and voice quality was large without much security, and would sometimes experience dropped calls . These are the analog telecommunications standards that were introduced in the 1980s and continued until being replaced by 2G digital telecommunications. The maximum speed of 1G is 2.4 Kbps .

2G - Second Generation: Cell phones received their first major upgrade when they went from 1G to 2G. The main difference between the two mobile telephone systems (1G and 2G), is that the radio signals used by 1G network are analog, while 2G networks are digital . Main motive of this generation was to provide secure and reliable communication channel. It implemented the concept of CDMA and GSM . Provided small data service like sms and mms.

Second generation 2G cellular telecom networks were commercially launched on the GSM. 2G capabilities are achieved by allowing multiple users on a single channel via multiplexing. During 2G Cellular phones are used for data also along with voice. The advance in technology from 1G to 2G introduced many of the fundamental services that we still use today, such as SMS, internal roaming , conference calls, call hold and billing based on services e.g. charges based on long distance calls and real time billing.

The max speed of 2G with General Packet Radio Service (GPRS) is 50 Kbps or 1 Mbps with Enhanced Data Rates for GSM Evolution (EDGE). Before making the major leap from 2G to 3G wireless networks, the lesser-known 2.5G and 2.75G was an interim standard that bridged the gap.

3G - Third Generation: This generation set the standards for most of the wireless technology we have come to know and love. Web browsing, email, video downloading, picture sharing and other Smartphone technology were introduced in the third generation. Introduced commercially in 2001, the goals set out for third generation mobile communication were to facilitate greater voice and data capacity, support a wider range of applications, and increase data transmission at a lower cost .

The 3G standard utilizes a new technology called UMTS as its core network architecture - Universal Mobile Telecommunications System. This network combines aspects of the 2G network with some new technology and protocols to deliver a significantly faster data rate. Based on a set of standards used for mobile devices and mobile telecommunications use services and networks that comply with the International Mobile elecommunications-2000 (IMT-2000) specifications by the International Telecommunication Union. One of requirements set by IMT-2000 was that speed should be at least 200Kbps to call it as 3G service.

3G has Multimedia services support along with streaming are more popular. In 3G, Universal access and portability across different device types are made possible (Telephones, PDA's, etc.). 3G increased the efficiency of frequency spectrum by improving how audio is compressed during a call, so more simultaneous calls can happen in the same frequency range. The UN's International Telecommunications Union IMT-2000 standard requires stationary speeds of 2Mbps and mobile speeds of 384kbps for a "true" 3G. The theoretical max speed for HSPA+ is 21.6 Mbps.

Like 2G, 3G evolved into 3.5G and 3.75G as more features were introduced in order to bring about 4G. A 3G phone cannot communicate through a 4G network , but newer generations of phones are practically always designed to be backward compatible, so a 4G phone can communicate through a 3G or even 2G network .

4G - Fourth Generation: 4G is a very different technology as compared to 3G and was made possible practically only because of the advancements in the technology in the last 10 years. Its purpose is to provide high speed , high quality and high capacity to users while improving security and lower the cost of voice and data services, multimedia and internet over IP. Potential and current applications include amended mobile web access, IP telephony , gaming services, high-definition mobile TV, video conferencing, 3D television, and cloud computing.

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 (has now fizzled out) and LTE (has seen widespread deployment). LTE (Long Term Evolution) is a series of upgrades to existing UMTS technology and will be rolled out on Telstra's existing 1800MHz frequency band. The max speed of a 4G network when the device is moving is 100 Mbps or 1 Gbps for low mobility communication like when stationary or walking, latency reduced from around 300ms to less than 100ms, and significantly lower congestion.

When 4G first became available, it was simply a little faster than 3G. 4G is not the same as 4G LTE which is very close to meeting the criteria of the standards. To download a new game or stream a TV show in HD, you can do it without buffering. Newer generations of phones are usually designed to be backward-compatible , so a 4G phone can communicate through a 3G or even 2G network. All carriers seem to agree that OFDM is one of the chief indicators that a service can be legitimately marketed as being 4G.

OFDM is a type of digital modulation in which a signal is split into several narrowband channels at different frequencies. There are a significant amount of infrastructure changes needed to be implemented by service providers in order to supply because voice calls in GSM , UMTS and CDMA2000 are circuit switched, so with the adoption of LTE, carriers will have to re-engineer their voice call network. And again, we have the fractional parts: 4.5G and 4.9G marking the transition of LTE (in the stage called LTE-Advanced Pro) getting us more MIMO, more D2D on the way to IMT-2020 and the requirements of 5G.

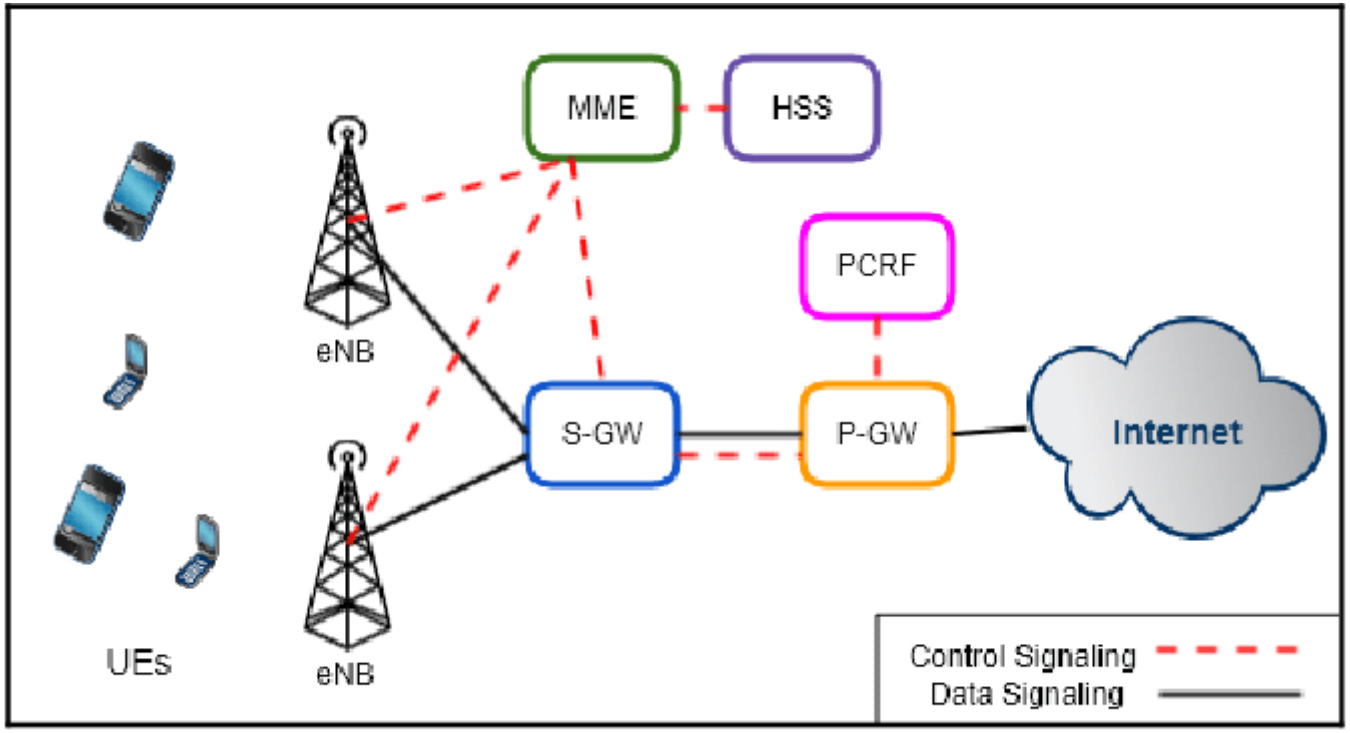
5G - Fifth Generation: 5G is a generation currently under development , that's intended to improve on 4G. 5G promises significantly faster data rates, higher connection density, much lower latency, among other improvements. Some of the plans for 5G include device-to-device communication, better battery consumption, and improved overall wireless coverage. The max speed of 5G is aimed at being as fast as 35.46 Gbps , which is over 35 times faster than 4G.

Key technologies to look out for: Massive MIMO , Millimeter Wave Mobile Communications etc. Massive MIMO, milimetre wave, small cells, Li-Fi all the new technologies from the previous decade could be used to give 10Gb/s to a user, with an unseen low latency, and allow connections for at least 100 billion devices . Different estimations have been made for the date of commercial introduction of 5G networks. Next Generation Mobile Networks Alliance feel that 5G should be rolled out by 2020 to meet business and consumer demands.

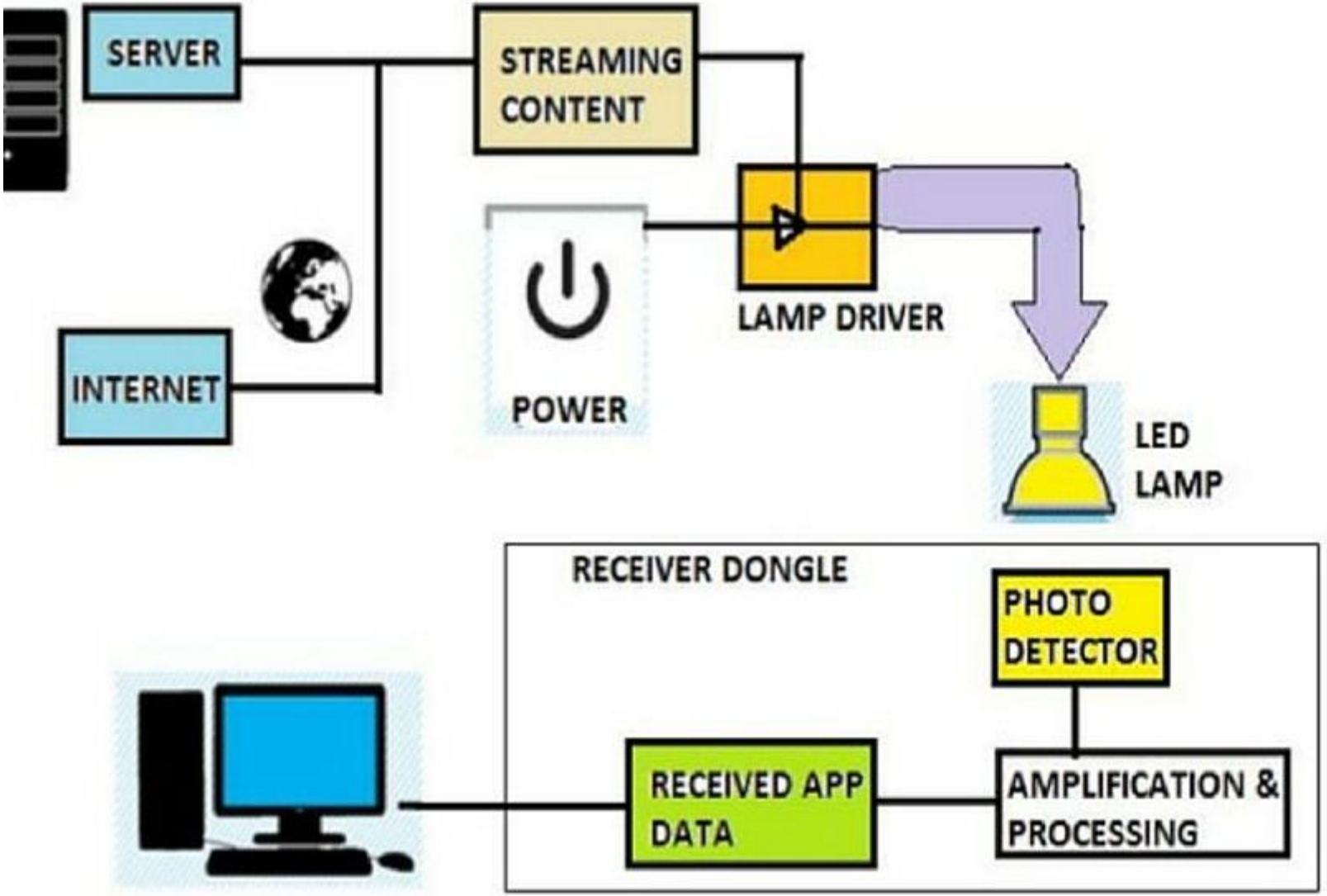
Comparison of All Generations of Mobile Technologies (1G - 5G).

Generation	1G	2G	2.5G	3G	3.5G	4G	5G
Start	1970-1980	1990-2000	2001-2004	2004-2005	2006-2010	2011-Now	Soon (2020)
Data Bandwidth	2 Kbps	64 Kbps	144 Kbps	2 Mbps	More than 2 Mbps	1 Gbps	more than 1 Gbps
Technology	Analog Cellular	Digital Cellular	GPRS, EDGE, CDMA	CDMA 2000 (1xRT, EVDO) UMTS, EDGE	EDGE. Wi-Fi	WiMax LTE Wi-Fi	wwww
Service	Voice	Digital Voice, SMS,Higher Capacity Packet Size Data	SMS, MMS	Integrated High Quality Audio, Video & Data	Integrated High Quality Audio, Video & Data	Dynamic Information access, Wearable Devices	Dynamic Information access, Wearable Devices with AI Capabilities
Multiplexing	FDMA	TDMA, CDMA	CDMA	CDMA	CDMA	CDMA	CDMA
Switching	Circuit	Circuit, Packet	Packet	Packet	All Packet	All Packet	All Packet
Core Network	PSTN	PSTN	PSTN	Packet N/W	Internet	Internet	Internet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal & Vertical	Horizontal & Vertical

LTE


MME
HSS
PCRF
eNB
S-GW
P-GW
Internet
UEs
eNB
Control Signaling
Data Signaling

Li-Fi


SERVER
STREAMING CONTENT
INTERNET
POWER
LAMP DRIVER
LED LAMP
RECEIVER DONGLE
PHOTO DETECTOR
RECEIVED APP DATA
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