Chapter 6
Cellular Wireless Communications and Latest Trends

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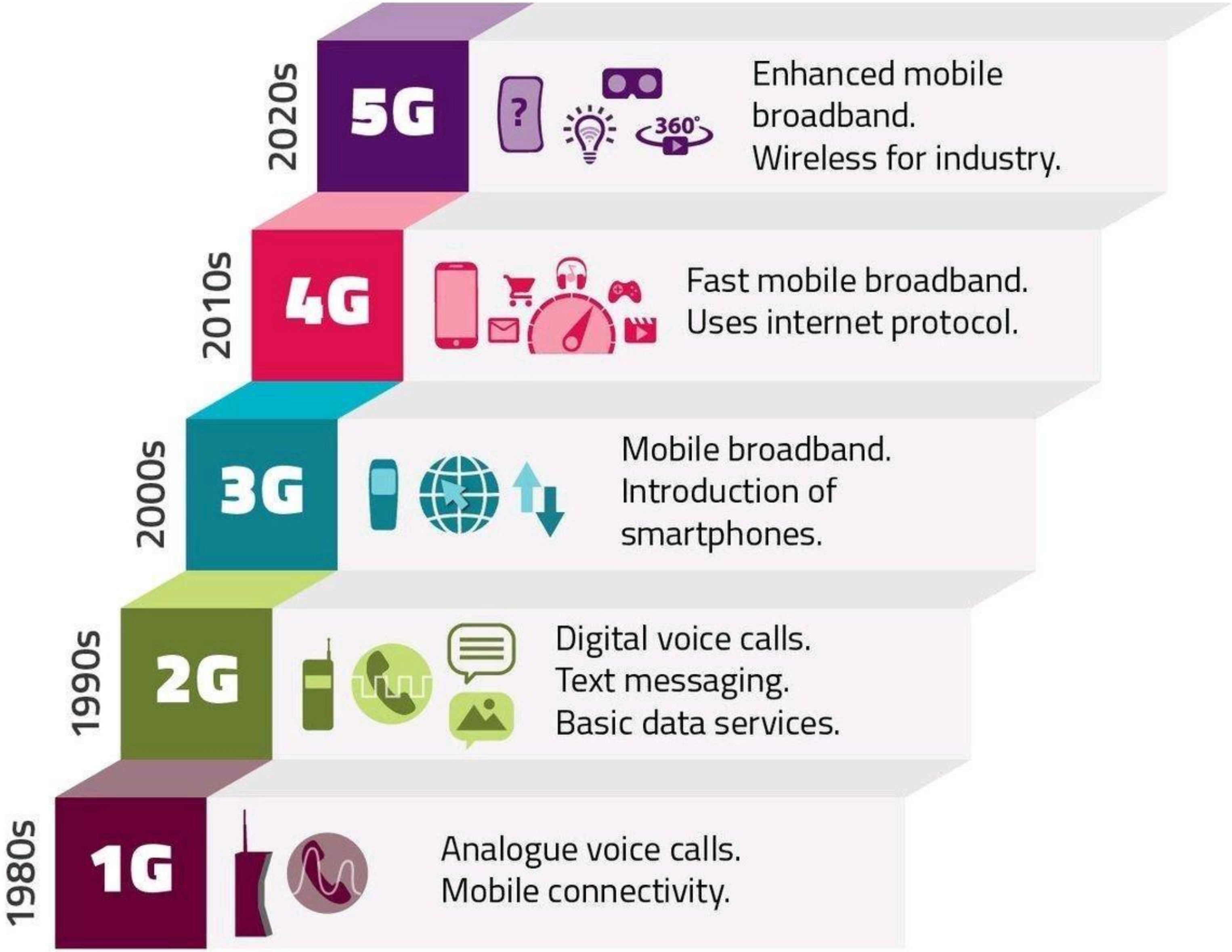
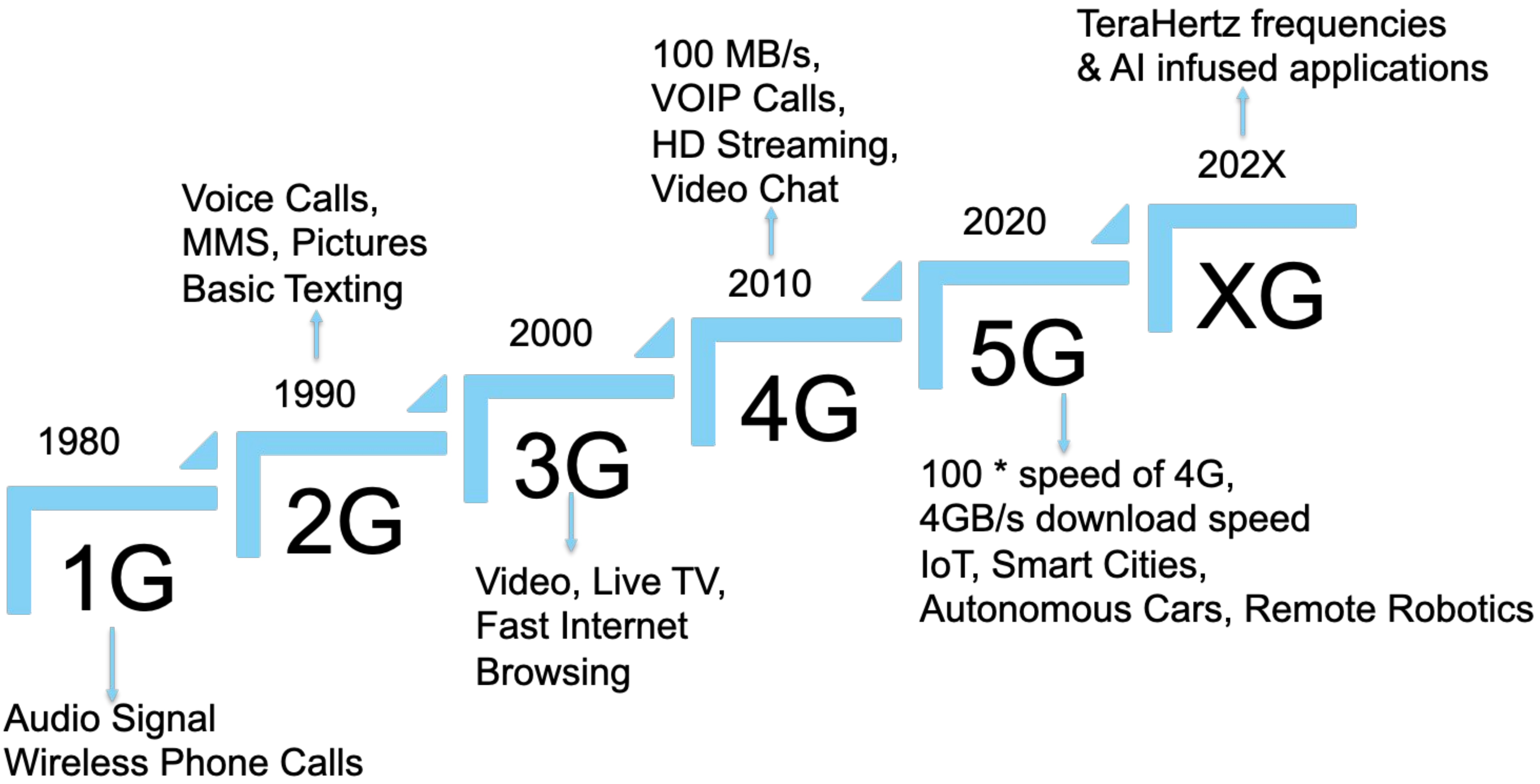
EVOLUTION OF WIRELESS TECHNOLOGY




1980
1G
Audio Signal
Wireless Phone Calls
1990
2G
Voice Calls,
MMS, Pictures
Basic Texting
2000
3G
Video, Live TV,
Fast Internet
Browsing
2010
4G
100 MB/s,
VOIP Calls,
HD Streaming,
Video Chat
2020
5G
100 * speed of 4G,
4GB/s download speed
IoT, Smart Cities,
Autonomous Cars, Remote Robotics
202X
XG
TeraHertz frequencies
& AI infused applications

1G – First generation mobile communication system

The first generation of mobile network was deployed in Japan by Nippon Telephone and Telegraph company (NTT) in Tokyo during 1979. In the beginning of 1980s, it gained popularity in the US, Finland, UK and Europe. This system used analogue signals and it had many disadvantages due to technology limitations.

Most popular 1G system during 1980s

- Advanced Mobile Phone System (AMPS)
- Nordic Mobile Phone System (NMTS)
- Total Access Communication System (TACS)
- European Total Access Communication System (ETACS)

Key features (technology) of 1G system

- **Frequency** 800 MHz and 900 MHz
- **Bandwidth:** 10 MHz (666 duplex channels with bandwidth of 30 KHz)
- **Technology:** Analogue switching
- **Modulation:** Frequency Modulation (FM)
- **Mode of service:** voice only
- **Access technique:** Frequency Division Multiple Access (FDMA)

Disadvantages of 1G system

- Poor voice quality due to interference
- Poor battery life
- Large sized cell phones (not convenient to carry)
- Less security (calls could be decoded using an FM demodulator)
- Limited number of users and cell coverage
- Roaming was not possible between similar systems

2G – Second generation communication system GSM

Second generation of mobile communication system introduced a new digital technology for wireless transmission also known as **Global System for Mobile communication (GSM).** GSM technology became the base standard for further development in wireless standards later.
This standard was capable of supporting up to 14.4 to 64kbps (maximum) data rate which is sufficient for SMS and email services.

Code Division Multiple Access (CDMA) system developed by Qualcomm also introduced and implemented in the mid 1990s. CDMA has more features than GSM in terms of spectral efficiency, number of users and data rate.

Key features of 2G system

- The uplink frequency range specified for GSM is 933 - 960 MHz (basic 900 MHz band only).
- The downlink frequency band 890 - 915 MHz (basic 900 MHz band only).
- Digital system (switching)
- SMS services is possible
- Roaming is possible
- Enhanced security
- Encrypted voice transmission
- First internet at lower data rate

Disadvantages of 2G system

- Low data rate
- Limited mobility
- Less features on mobile devices
- Limited number of users and hardware capability

2.5G and 2.75G system

In order to support higher data rate, **General Packet Radio Service (GPRS)** was introduced and successfully deployed. GPRS was capable of data rate up to 171kbps (maximum).
EDGE – Enhanced Data GSM Evolution also developed to improve data rate for GSM networks. EDGE was capable to support up to 473.6kbps (maximum).
Another popular technology **CDMA2000** was also introduced to support higher data rate for CDMA networks. This technology has the ability to provide up to 384 kbps data rate (maximum).

3G – Third generation communication system

Third generation mobile communication started with the introduction of **UMTS – Universal Mobile Terrestrial / Telecommunication Systems**. UMTS has the data rate of 384kbps, and it support video calling for the first time on mobile devices.

After the introduction of 3G mobile communication system, smart phones became popular across the globe. Specific applications were developed for smartphones which handles multimedia chat, email, video calling, games, social media and healthcare.

Key features of 3G system

- Higher data rate
- Video calling
- Enhanced security, more number of users and coverage
- Mobile app support
- Multimedia message support
- Location tracking and maps
- Better web browsing
- TV streaming
- High quality 3D games

3.5G to 3.75 Systems

In order to enhance data rate in existing 3G networks, another two technology improvements are introduced to network. HSDPA – High Speed Downlink Packet access and HSUPA – High Speed Uplink Packet Access, developed and deployed to the 3G networks. 3.5G network can support up to 2mbps data rate.

3.75 system is an improved version of 3G network with HSPA+ High Speed Packet Access plus. Later this system will evolve into more powerful 3.9G system known as LTE (Long Term Evolution).

Disadvantages of 3G systems

- Expensive spectrum licenses
- Costly infrastructure, equipment and implementation
- Higher bandwidth requirements to support higher data rate
- Costly mobile devices
- Compatibility with older generation 2G system and frequency bands

4G – Fourth generation communication system

4G systems are enhanced version of 3G networks developed by IEEE, offers higher data rate and capable to handle more advanced multimedia services. **LTE and LTE advanced wireless technology used in 4th generation systems**. Furthermore, it has compatibility with previous version thus easier deployment and upgrade of LTE and LTE advanced networks are possible.

Simultaneous transmission of voice and data is possible with LTE system which significantly improve data rate. All services including voice services can be transmitted over IP packets. Complex modulation schemes and carrier aggregation is used to multiply uplink / downlink capacity.
Wireless transmission technologies like WiMax are introduced in 4G system to enhance data rate and network performance.

Key features of 4G system

- Much higher data rate up to 1Gbps
- Enhanced security and mobility
- Reduced latency for mission critical applications
- High-definition video streaming and gaming
- Voice over LTE network VoLTE (use IP packets for voice)

Disadvantages of 4G system

- Expensive hardware and infrastructure
- Costly spectrum (most countries, frequency bands are too expensive)
- High end mobile devices compatible with 4G technology required, which is costly
- Wide deployment and upgrade is time consuming

5G – Fifth generation communication system

5G network is using advanced technologies to deliver ultra fast internet and multimedia experience for customers. Existing LTE advanced networks will transform into supercharged 5G networks in future.
In earlier deployments, **5G network will function in non standalone mode and standalone mode**. In non standalone mode both LTE spectrum and 5G-NR spectrum will be used together. Control signaling will be connected to LTE core network in non standalone mode.

There will be a dedicated 5G core network higher bandwidth 5G – NR spectrum for standalone mode.

Key features of 5G technology

- Ultra fast mobile internet up to at least 20Gbps downlink and 10Gbps uplink per mobile base station.
- Maximum latency of just 4ms (compared to 20ms for LTE).
- Total cost deduction for data.
- Higher security and reliable network.
- Supports up to 1 million devices per square kilometer, ideal for IoT (Internet of Things).
- Optimized for lower power consumption, enhancing battery life for connected devices.
- Uses technologies like small cells, beam forming to improve efficiency

Technologies behind 5G:

Millimeter Waves (mmWaves): Millimeter waves refer to radio frequency bands in the range of 24 GHz to 100 GHz. These frequencies are much higher than those used in 4G networks (typically below 6 GHz). Higher frequencies can carry **more data at faster speeds**, allowing for gigabit-level performance. However, they can't travel long distances and are easily blocked by buildings, trees, rain, and even human bodies.

Massive MIMO: MIMO uses multiple antennas at both the transmitter (e.g., base station) and the receiver (e.g., smartphone). It increases capacity by allowing multiple users to be served simultaneously and also improves spectral efficiency, meaning more data is transferred per unit of frequency.

Beamforming: Beamforming is a technique used with antenna arrays (like in Massive MIMO) to focus radio signals in a specific direction instead of broadcasting them in all directions. The system calculates the best signal path to each user and steers the beam directly toward them, like a flashlight beam instead of a bare bulb.

Generation Features	1G	2G	3G	4G	5G
Data Rates	1970-1980	1990-2001	2001-2010	2011	2015-20 Onwards
Technology	Analog Cellular Technology	Digital Cellular Technology: Digital Narrow Band Circuit Data Packet Data	Digital Broad Band: Packet Data CDMA2000 EVDO UMTS EDGE	Digital Broad Band Packet Data: WiMAX LTE Wi-Fi	www Unified IP Seamless Combination of LAN, PAN, MAN WLAN
Service	Analog Voice Service No Voice Service	Digital Voice with High Clarity SMS, MMS, High capacity Packetized Data	Enhanced Audio Video Streaming, Video Conferencing Support Web Browsing at High Speed IPTV Support	Enhanced Audio, Video Streaming IP Telephony HD Mobile TV	Dynamic Information Access, Wearable Devices with AI Capabilities
Multiplexing Switching	FDMA	TDMA, CDMA	CDMA	CDMA	CDMA
Core Network	PSTN	PSTN	Packet N/W	Internet	Internet
Standards	MTS AMTS IMTS	2G: GSM 2.5G: GPRS 2.75G: EDGE	IMT-2000 3.5G-HSDPA 3.75- HSUPA	Single unified standard LTE, WiMAX	Single Unified Standard
Web Standard		www	www (IPV4)	www (IPV4)	www (IPV6)
Hand Off	Horizontal Only	Horizontal Only	Horizontal & Vertical	Horizontal & Vertical	Horizontal & Vertical
Short falls	Low Capacity Unreliable Handoff, Poor voice links, Less Secure	Digital Signal were reliant on location & Proximity, required strong digital signal to help mobile phones	Need to accommodate Higher Network Capacity	Being Deployed	Yet to be Implemented

CELLULAR TECHNOLOGY FUNDAMENTAL TERMINOLOGIES

The design aim of early mobile wireless communication systems was to get a large number of users over a huge coverage area with a single, high-power transmitter and an antenna installed on a giant tower, transmitting a data on a single frequency spectrum.

If a single transmitter/receiver are used with only a single base station, then sufficient power may not be present at huge distance from BS (Base Station). And if we use high power transmitter for large geographic area, it **causes harm to environment**.

Also, if single transmitter was used, it was **practically not possible to reuse the same frequency** all over the system, because any effort to reuse the same frequency would result in interference.

The cellular concept was a major breakthrough in order to **solve the problems of limited user capacity and spectral congestion**.

Cellular Concept is a system-level idea in which a single high-power transmitter is replaced with multiple low- power transmitters, and small segment of the service area is being covered by each transmitter, which is **referred to as a cell**.

Each cell uses a certain number of available channels, and a group of adjacent cells together use all the available channels. Such group is called a **cluster**.

This cluster can repeat itself and hence same set of channels can be used again and again. Each cell has a low power transmitter with the coverage area equal to the area of the cell.

In brief,

Cellular Concept solves the problem of spectral congestion and user capacity (i.e., offer very high capacity in a limited spectrum)

What is a cell?

The power of the radio signals transmitted by the BS decay as the signals travel away from it. A minimum amount of signal strength (let us say, x dB) is needed in order to be detected by the MS or mobile sets which may the hand-held personal units or those installed in the vehicles.

The region over which the signal strength lies above this threshold value x dB is known as the coverage area of a BS and it must be a circular region, considering the BS to be isotropic radiator.

Such a circle, which gives this actual radio coverage, is called the **footprint of a cell**.

It might so happen that either there may be an overlap between any two such side-by-side circles or there might be a gap between the coverage areas of two adjacent circles. Such a **circular geometry**, therefore, **cannot serve as a regular shape to describe cells**.

We need a regular shape for cellular design over a territory which can be served by 3 regular polygons, namely, equilateral triangle, square and regular hexagon, which can cover the entire area without any overlap and gaps. **Along with its regularity, a cell must be designed such that it is most reliable too**, i.e., it supports even the weakest mobile with occurs at the edges of the cell. For any distance between the center and the farthest point in the cell from it, a regular hexagon covers the maximum area.
Hence, **regular hexagonal ge** **mobile communication**.

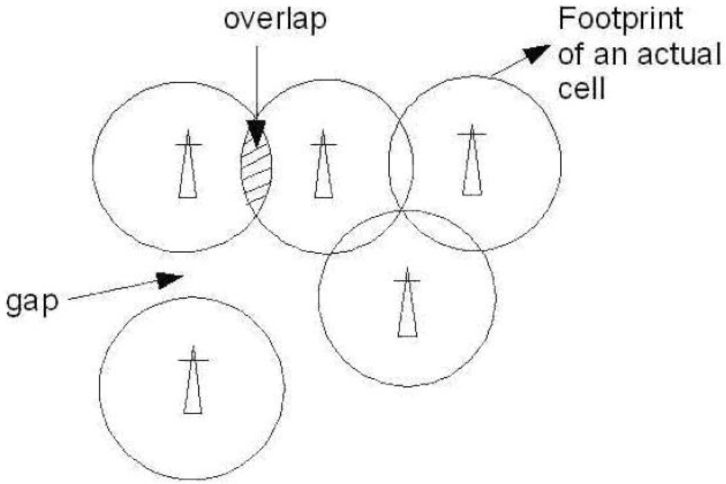


Fig: Footprints of cells showing overlaps and gaps

Hexagon is used because it is most circular in nature

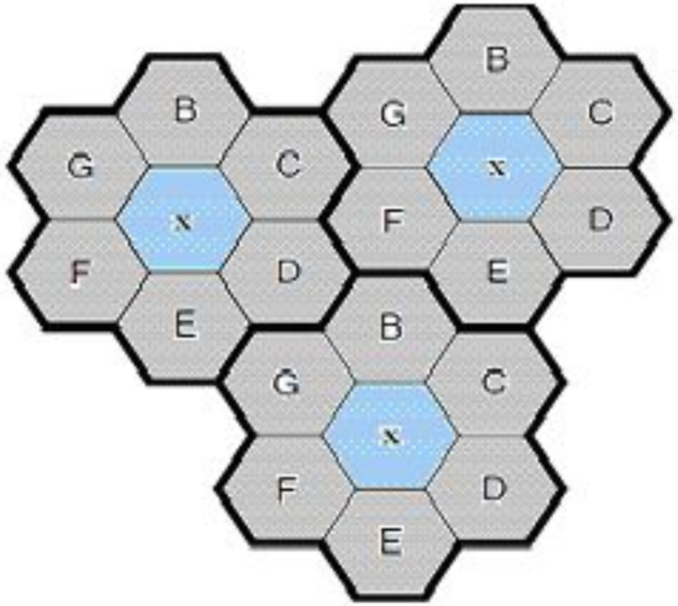


Fig: Hexagonal Cell structure and Cluster

What is Cluster?

A group of cells forms cluster when the entire available spectrum is divided equally among the cells. **Cells in a group have a disjoint set of frequencies.**

The number of cells in a cluster must be determined so that the cluster can be repeated continuously within the coverage area of a service provider. **The typical clusters contain 4,7,12 or 21 cells**.

The smaller the number of cells per cluster is, the bigger the number of channels per cell will be. The capacity of each cell will therefore be increased.

However, a **balance must be found in order to avoid interference** that could occur between neighboring clusters.

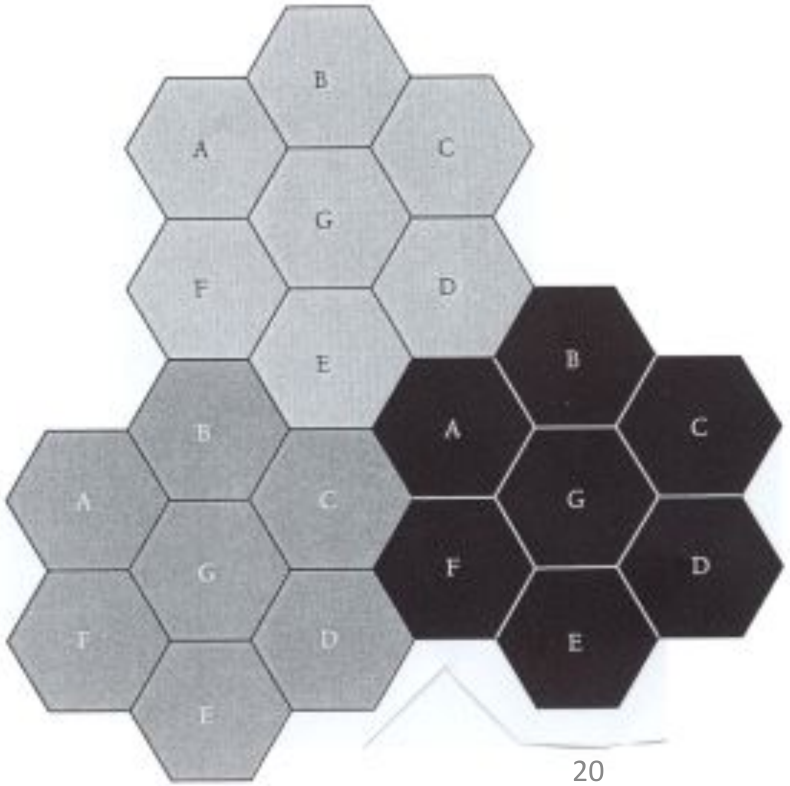
Only certain cluster sizes and cell layout are possible.

The number of cells per cluster, **N** can only have values which satisfy

$$N = i^2 + ij + j^2$$

where, I and j are non-negative integers.

Step 1: Move i number of cells along i axis
Step 2: Turn 60 degree anti-clockwise and move j number of cells



Frequency Reuse:

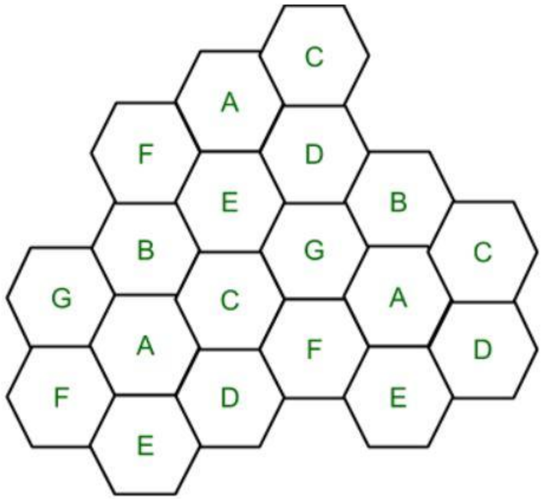
Frequency Reuse is the scheme in which **allocation and reuse of channels throughout a coverage region** is done.
Each cellular base station is allocated a group of radio channels or Frequency sub-bands to be used within a small geographic area known as a cell. The shape of the cell is Hexagonal.
The process of selecting and allocating the frequency sub-bands for all of the cellular base station within a system is called **Frequency reuse or Frequency Planning**.

Frequency reuse is one of the fundamental concepts on which commercial wireless systems are based that involve the partitioning of RF radiating area into cells.

To ensure that the mutual interference between users remains below a harmful level, adjacent cells use different frequencies. However, in cells that are separated further away, frequencies can be reused.

Silent Features of using Frequency Reuse:

- Frequency reuse improve the spectral efficiency, channel capacity and signal Quality (QoS).
- The number of times a frequency can be reused is depended on the tolerance capacity of the radio channel from the nearby transmitter that is using the same frequencies.
- In Frequency Reuse scheme, total bandwidth is divided into different sub-bands that are used by cells.
- Frequency reuse scheme allow WiMAX system operators to reuse the same frequencies at different cell sites



Cell with the same letter uses the same set of channels group or frequencies sub-band.

To find the total number of channel allocated to a cell:

S = Total number of duplex channels available to use

k = Channels allocated to each cell ($k<S$)

N = Total number of cells or Cluster Size

Then Total number of channels (S) will be,

$$\mathbf{S = kN}$$

Frequency Reuse Factor = 1/N

In the above diagram cluster size is 7 (A,B,C,D,E,F,G) thus frequency reuse factor is 1/7.

The frequency reuse distance is denoted by **“D”** and is given by:

$$\boldsymbol{D = R\sqrt{3N}}$$

Where, R = radius of the cell and N = number of cells in cluster

Size (N)	**Reuse distance (D)**
19	7.55R
12	6R
7	4.6R
4	3.46R

Interference:

Interference is one of the major factors affecting the performance of cellular radio systems.

Sources of interference consist of:

- another mobile inside the same cell
- an ongoing call in a neighboring cell
- other base stations transmitting signal in the same frequency band
- any non-cellular system which accidentally transmits energy into the cellular frequency band

Interference on voice signals could give rise to cross talk, where the caller hears interference in the background due to the presence of an unwanted transmission.

Interference on control channels gives rise to missed and blocked calls.

Interference has been accepted as a major obstruction in increasing the capacity of a system and is largely responsible for dropped calls in a network.

The two major types of interferences that are taken consideration while allocating channels to the calls are

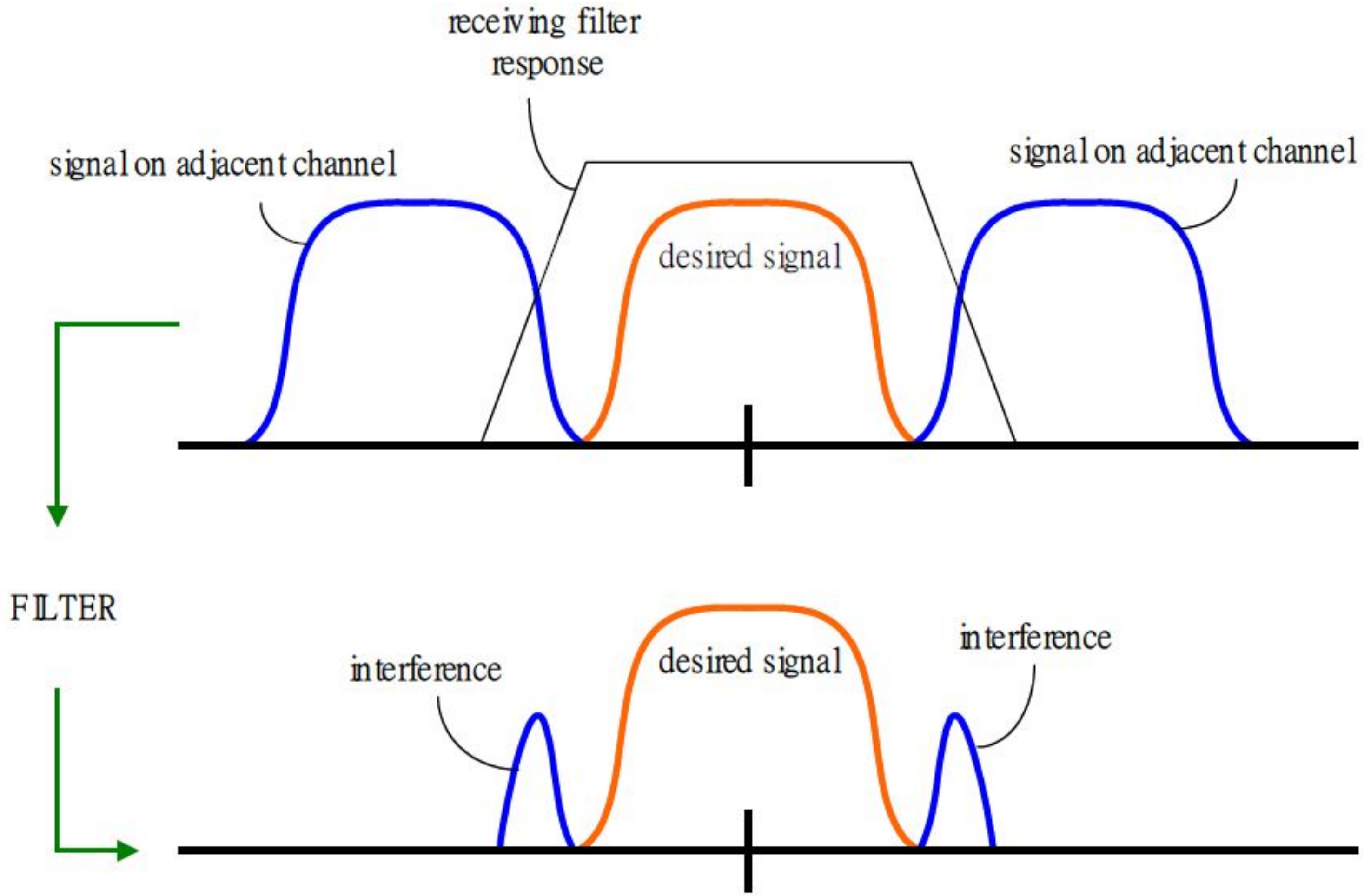
- Co-channel interference (CCI)
- Adjacent channel interference (ACI)

Co-Channel Interference (CCI): The **channel reuse approach** is very useful for increasing the efficiency of radio spectrum utilization, but it **results in co-channel interference** because the same radio channel is repeatedly used in different co-channel cells in a network. In this case, the quality of a received signal is very much affected both by the amount of radio coverage area and the co-channel interference.

The cells when the same set of frequencies is used are called co-channel cells. Co-channel interference is the cross talk between two different radio transmitters using the same radio frequency.

This type of interference is generally generated because channel sets have been allocated to two different cells that are nor far enough geographically, and their signals are strong enough to cause interference to each other.

Adjacent Channel Interference: Signals from neighboring radio channels, also called adjacent channel, leak into the particular channel, thus causing adjacent channel interference. Adjacent channel interference takes place due to the **inability of a mobile phone to separate out the signals of adjacent channels** allocated to neighboring cell sites (e.g., channel 101 in cell A, and channel 102 in cell B), where both A and B cells are present in the same reuse cluster.



Imperfect receiver filters allow nearby frequencies to leak into the passband

Adjacent channel interference can be reduced through **careful and thorough filtering** and **efficient channel allocations**.

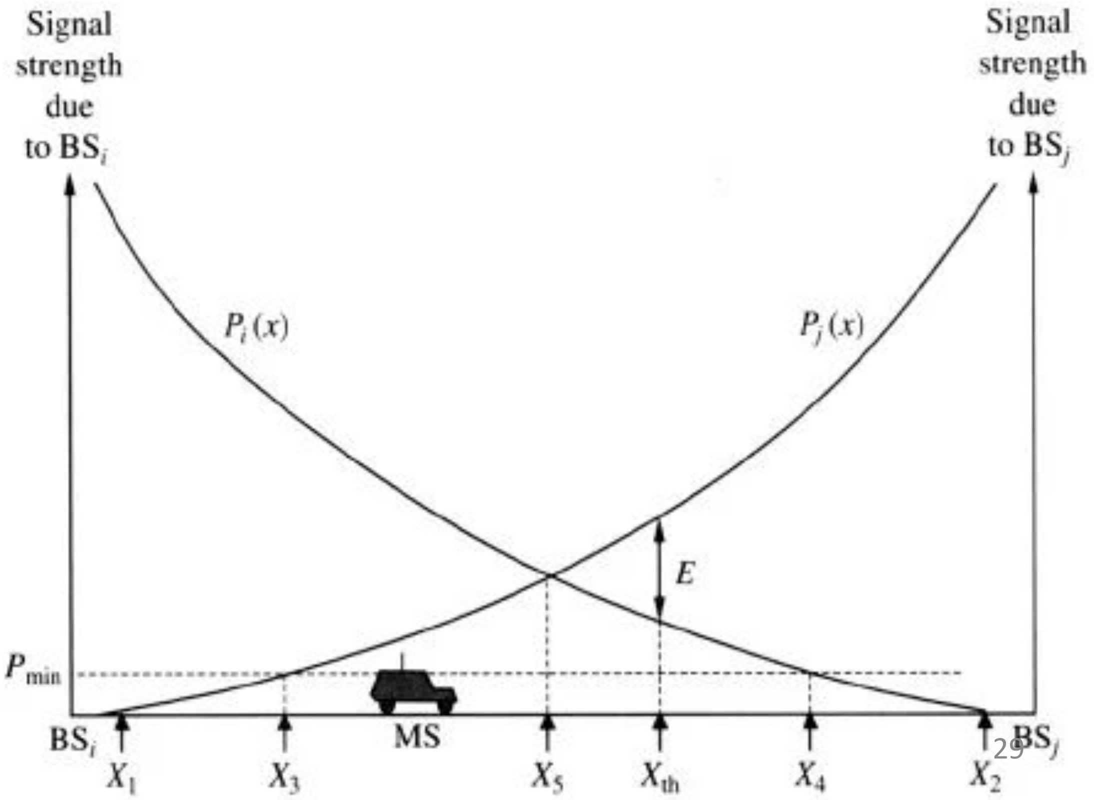
By maintaining the channel separation as large as possible in a given cell, the adjacent channel interference may well be minimized significantly.

Hence, instead of allocating contiguous band of channels to each cell, channels are allocated such a way that the frequency separation between channels in a given cell should be maximized.

Handoff strategies

In cellular telecommunications, the terms **handover or handoff** refers to the process of transferring ongoing call or data connectivity from one Base Station to other Base Station. When a mobile moves into the different cell while the conversation is in progress then the MSC (Mobile Switching Center) transfer the call to a new channel belonging to the new Base Station. Handoff is **necessary for preventing loss of interruption of service** to a caller or a data session user.

As the user (MS) moves away from the cell of one tower (BS), the signal strength of that BS reduces. However, the signal from another (now closer) BS grows, and a **handoff is imminent**.



Need of Handoff:

- One of the building blocks of cellular communication is mobility, which refers to providing users with the freedom of movement while they still are connected to the network.

- Handoffs play a major role in allowing users to move across cells without the fear of being disconnected.

- It is also to be noted that a handoff may also be triggered when the number of subscribers in a particular cell has already reached the cell's maximum limit, keeping the network safe from the threat of being congested and overloaded.

- It can be assumed to be an example of **"make before break"** as a standby connection is supposed to be present before the switch is done.

Handoff operation:

- Identifying a new base station
- Reallocating the voice and control channels with the new base station.

Handoff Threshold:

- Minimum usable signal for acceptable voice quality (-90dBm to -100dBm).
- Handoff margin cannot be too large or too small.

$$\blacktriangle = P_{r,\ handoff} - P_{r,\ minimum\ usable}$$

- If it is too large, unnecessary handoffs burden for the MSC.
- If it is too small, there may be insufficient time to complete handoff before a call is lost.

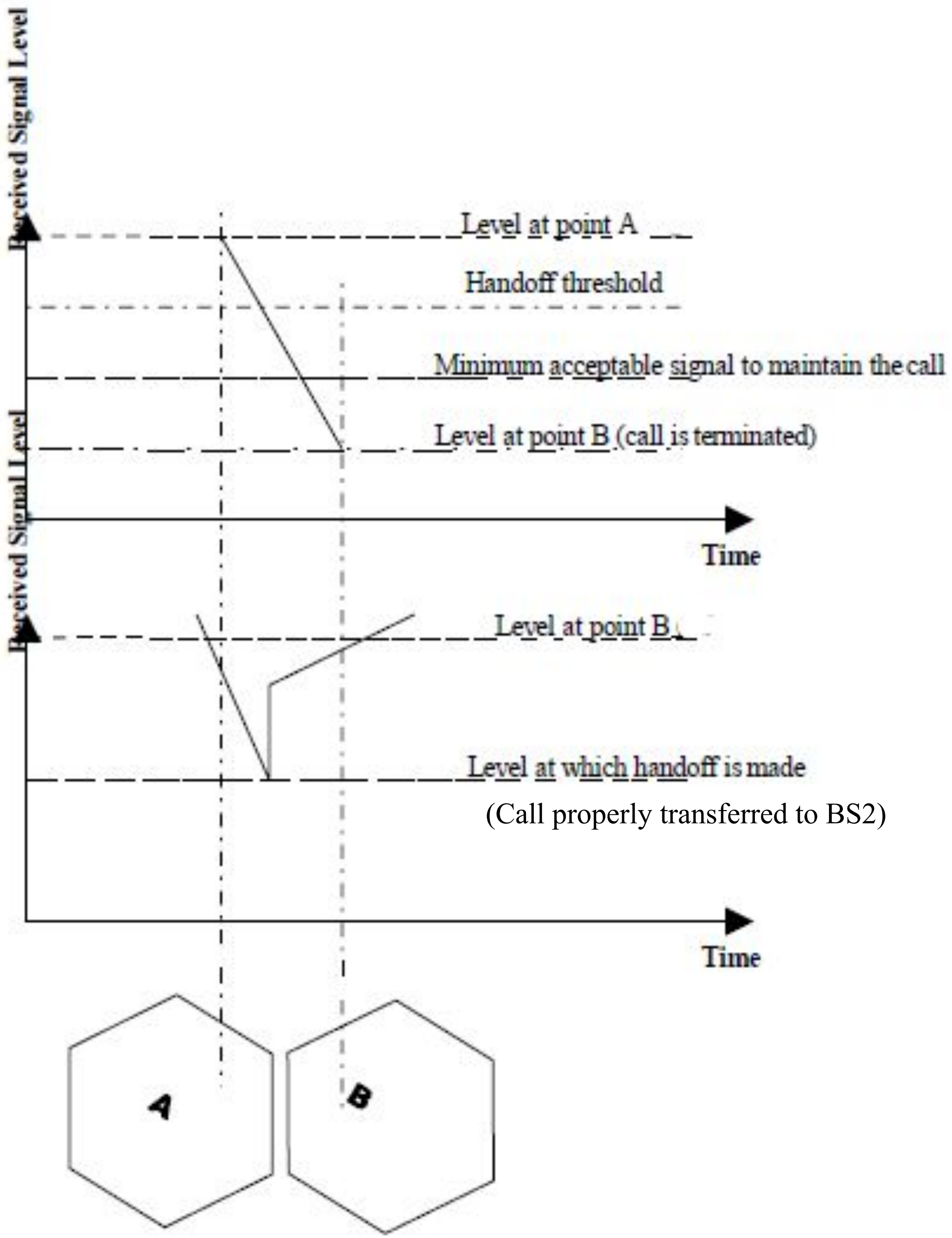


Fig: Handoff situation

This signal strength measurement must be optimized in order to avoid unwanted handoffs, while ensuring that wanted handoffs are completed before a call gets dropped.
The time required to come to a decision if a handoff is needed, depends on the speed of the vehicle at which it is moving. Information about the speed of vehicle can also be calculated from the fading signal received at the base station.

The time during which a caller remains within a cell, without any handoff to the neighboring cells, is called the **dwell time**.

The dwell time of a call depends upon a number of factors i.e.,

- Propagation
- Interference
- distance between the caller and the base station
- several other time varying factors.

Handoff measurement:

In ***first generation cellular systems***,

signal strength computations are done by the base stations and monitored by the MSC. All the base stations regularly observe the signal strengths of its reserve channels to find out the relative location of each mobile user with respect to the base station.

In addition to calculating the **radio signal strength indication (RSSI**) of ongoing calls in the cell, an extra receiver in each base station, is used to find out signal strengths of mobile users present in the neighboring cells.

The extra receiver is controlled by the MSC and is used to examine the signal strength of callers in the neighboring cells and informs RSSI to the MSC.

Based on the RSSI values received from each extra receiver, the **MSC determines whether handoff is required or not**.

In ***second generation cellular systems*** using digital TDMA technology,

handoff decisions are mobile assisted. In **mobile assisted handoff (MAHO)**, each mobile station measures the received power from the neighboring base stations and informs these results to the serving base station.
A handoff starts when the power received from the base station of a neighboring cell go above the power received from the present base station.

In MAHO scheme, the call to be handed off between different base stations at a lot faster speed than in first generation systems because the handoff computations are done by each mobile and by keeping the MSC out of these computations.

MAHO is suitable for micro-cellular network architectures where handoffs are more frequent.

- **Intersystem handoff:**

When a call is in progress, if a mobile shifts from one cellular system to another cellular system managed by a different MSC, an ***intersystem handoff*** is required.

An MSC performs an intersystem handoff when a signal goes weak in a particular cell and the MSC fails to find another cell inside its system to which it can move the ongoing call, and several issues should be addressed while intersystem handoff is implemented.

Example: a local call might automatically turn into a long-distance call when the caller shifts out of its home network and enters into a neighboring system.

Prioritizing Handoff

Various systems have different methods for dealing with hand-off requests.

Several systems **manage handoff requests in the same way as they manage new call requests**. In such systems, the possibility that a handoff call will not be served by a new base station is equivalent to the blocking probability of new calls.

However, if a call is terminated unexpectedly while in progress is more frustrating than being blocked occasionally on a new call.

Therefore, to improve the quality of service, various methods have been created to give **priority to handoff call requests over new call requests while allocating channels**.

Scheme 1:

One scheme for prioritizing handoffs call requests is called the **guard channel concept**, in which a part of the existing channels in a cell is reserved entirely for handoff call requests.

The major drawback of this scheme is that it reduces the total carried traffic, as smaller number of channels is allocated to new calls.

However, guard channels scheme present efficient spectrum utilization when dynamic channel allocation strategies are used.

Scheme 2:

Queuing of handoff calls is another way to minimize the forced call terminations due to unavailability of channels in the cell. Handoff call queuing is possible as there is a fixed time interval between the time the received signal strength falls below the handoff threshold and the time the call is terminated due to unavailability of signal strength.

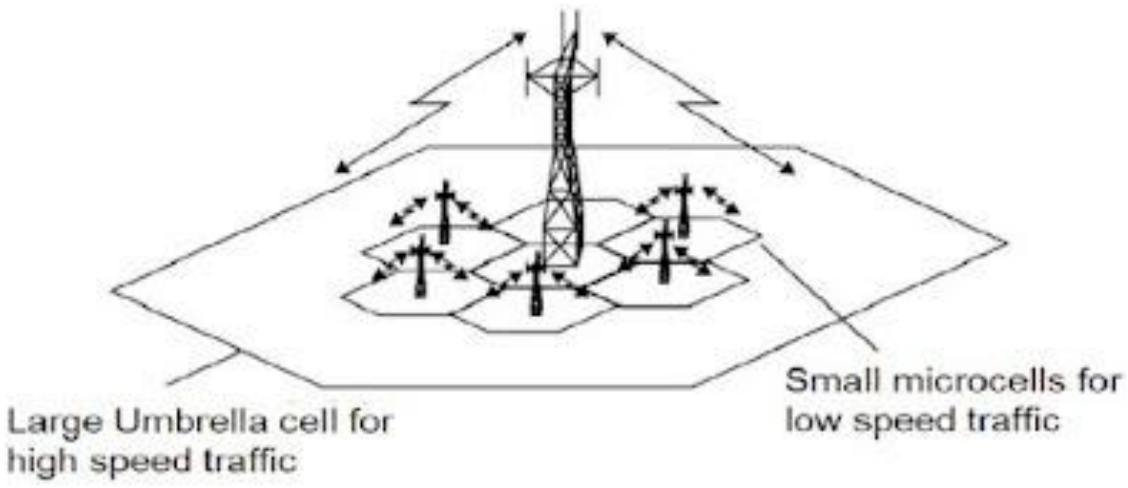
The queue size and delay time is calculated from the traffic pattern of the service area.

It should be noted that queuing of handoff calls does not promise a zero forced call terminations, because large delays will force the received signal strength to fall below the minimum level required to maintain communication and therefore, lead to forced handoff call termination.

Practical Handoff consideration:

There are different type of users in an area.

- High speed users need frequent handoff during a call.
- Low speed users may never need a handoff during a call.



The cell with low traffic speed is called as **micro-cells** and large high-speed traffic called **macro-cells**.

The MSC can become burdened if high speed users are being passed between very small cells. This burden on MSC can be solved by implementing microcell concept.

The smaller cell is grouped and assumed to be under a large cell. This method called as an **umbrella cell concept**.

- Different antenna height
- Different power level

The advantages of implementing microcell concept are:

- handoffs are minimized for high-speed users
- Handle the simultaneous traffic of high speed and low speed users.

IoT Communication

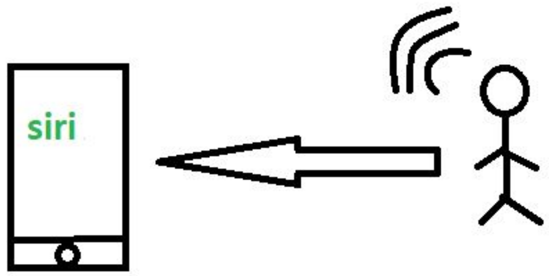
IoT (Internet of Things) communication refers to the ways **smart devices** (like sensors, appliances, wearables, etc.) **connect and exchange data** with each other, and with centralized systems like cloud platforms or edge servers.
These communications are the foundation of IoT systems, enabling **real-time monitoring**, **automation**, **data analytics**, and **remote control**.

IoT communication involves:

- **Devices** (things) with sensors and actuators
- **Communication protocols** to exchange data
- **Networks** that connect the devices (wireless/wired)
- **Platforms or servers** that process, store, or act on the data

Types of Communications in IOT:

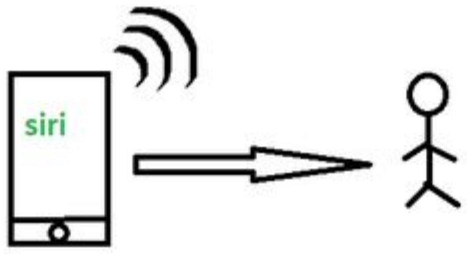
1. **Human to Machine (H2M)**: In this human gives input to IOT device i.e. as speech /text /image etc. IOT device (Machine) like sensors and actuators then understands input, analyses it and responds back to human by means of text or Visual Display. **Example:** Facial recognition, Bio-metric attendance, Speech or voice recognition.



2. **Machine to Machine (M2M):** The process of exchanging information or messages between two or more machines or devices is known as Machine to Machine (M2M) communication. It is the communication among the physical things which do not need human intervention. **Example:** Smart Washing machine sends alerts to the owners' smart devices after completion of washing or drying of clothes.

Types of Communications in IOT:

3. **Machine to Human (M2H):** In this machine interacts with Humans. Machine triggers information (text messages/images/voice/signals) respective / irrespective of any human presence. This type of communication is most commonly used where machines guide humans in their daily life. **Example:** Fire alarms, Fitness bands.



4. **Machine to Cloud (M2C)**: This type of communication allows IoT devices to send data to cloud-based applications for storage, analysis, and further action. It's essential for scenarios where cloud analytics can provide valuable insights for decision making or where remote access to the device's data is required. **Example**: Smart Temperature Sensor in a Cold Storage Warehouse.

Communication Technologies used in IOT:

1. Short-Range Communication:

Technology	Range	Use Case
Bluetooth (BLE)	~10–100 meters	Wearables, smart home
Zigbee	~10–100 meters	Home automation, sensors
Wi-Fi	~100 meters	Cameras, appliances
NFC/RFID	Few cm to meters	Contactless payments, tracking

2. Long-Range Communication:

Technology	Range	Use Case
Cellular (3G/4G/5G)	Km-level	Smart cars, asset tracking
LoRaWAN	2–15 km	Smart agriculture, remote sensors
NB-IoT / LTE-M	Km-level	Smart meters, smart cities
Satellite IoT	Global	Remote environment monitoring

Features of IoT Communication:

- **Low Power Consumption** – Optimized for battery-operated devices.
- **Low Bandwidth Usage** – Sends small data packets efficiently.
- **Scalability** – Supports millions of connected devices.
- **Reliability** – Ensures consistent and accurate data transfer.
- **Security** – Uses encryption and authentication for safe communication.
- **Interoperability** – Works across different devices and platforms.
- **Real-time Communication** – Enables instant data exchange and response.
- **Multiple Protocol Support** – Uses protocols like MQTT (Message Queuing Telemetry Transport), CoAP (Constrained Application Protocol), and HTTP.

Applications of IoT Communication:

- **Smart Homes**: Lights, thermostats, security systems
- **Healthcare**: Remote monitoring of patients
- **Industry (IIoT):** Predictive maintenance, automation
- **Agriculture**: Soil moisture sensors, livestock tracking
- **Transportation**: Fleet management, smart traffic

Application of 5G in IOT

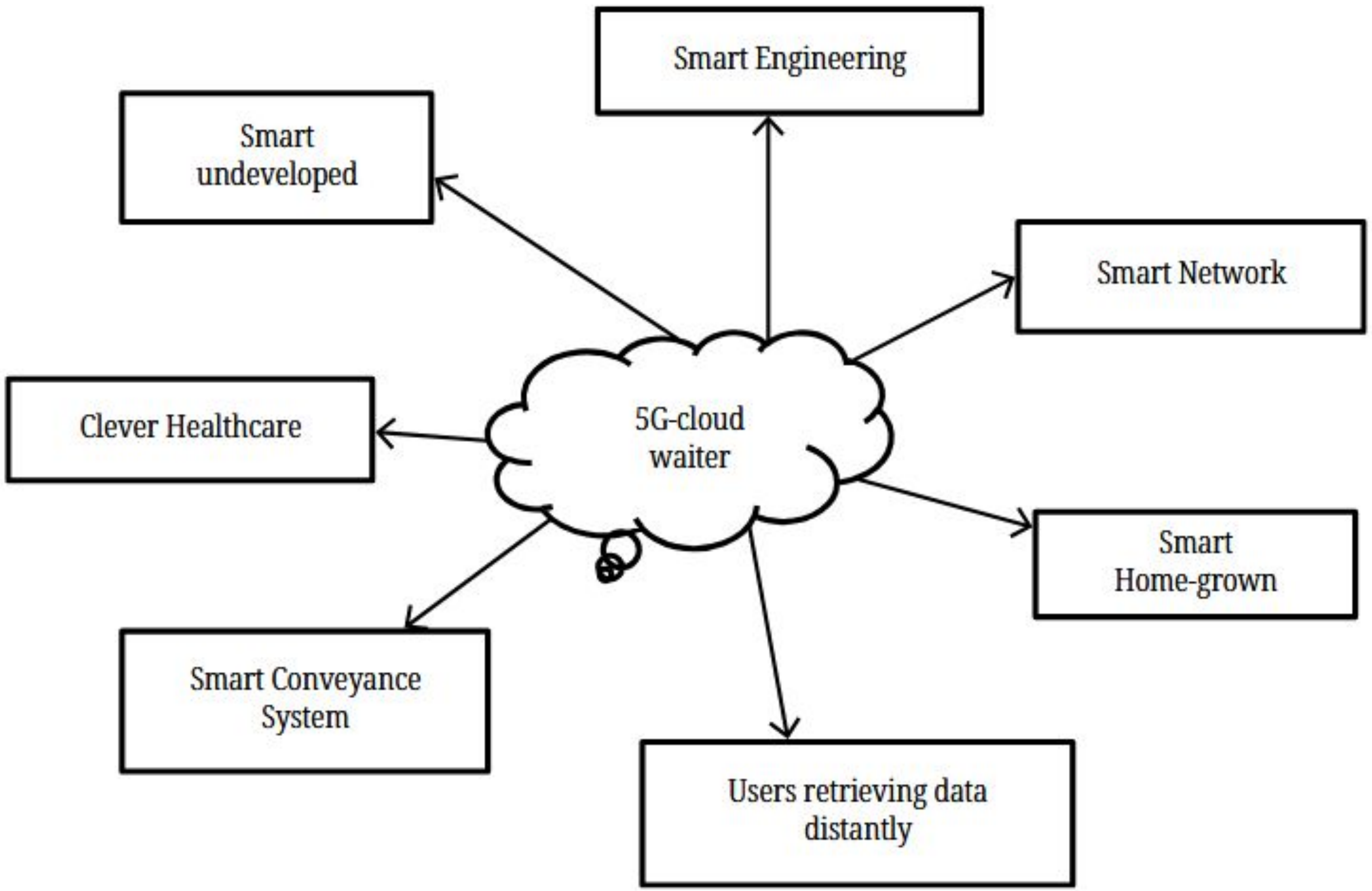


Fig. 1. 5G-enabled IoT environment network architecture

Source: https://doi.org/10.3991/ijim.v17i17.42805

Central Node (5G-Waiter/Server): Acts as the central communication and processing hub. It receives, processes, and routes data between various smart IoT components using high-speed, low-latency 5G connectivity.

Connected IoT Applications (Edge Nodes)

1. **Clever Healthcare**: Refers to smart healthcare systems using connected devices like remote patient monitoring, telemedicine, and AI-based diagnostics. 5G enables real-time medical data transmission.
2. **Smart Conveyance System**: Indicates intelligent transportation systems, such as autonomous vehicles, traffic management, and vehicle-to-infrastructure (V2I) communication.
3. **Smart undeveloped**: Indicates Smart Agriculture or Smart Rural Development, involving IoT sensors for monitoring soil, weather, and crop conditions.
4. **Smart Engineering**: Refers to **IoT in industrial engineering**, such as predictive maintenance, smart manufacturing (Industry 4.0), and automation.

5. **Smart Network**: Represents the infrastructure layer, including 5G base stations, routers, and network slices for different services. Ensures efficient data flow.
6. **Smart Home-grown**: Covers IoT-based automation in homes or farms — for example, smart appliances, lighting, irrigation, and energy management.
7. **Users retrieving data distantly**: Refers to remote access of IoT data by users — such as through mobile apps, dashboards, or cloud services. 5G makes it possible to access real-time data from anywhere.

Thank You