**NATIONAL AND KAPODISTRIAN UNIVERSITY OF ATHENS**

**SCHOOL OF SCIENCE**

**DEPARTMENT OF INFORMATICS AND TELECOMMUNICATIONS**

**THESIS PROJECT**

# The evolution of mobile communications: Moving from 1G to 5G, and from human-to-human to machine-to-machine communications

**Panagiota D. Giotopoulou**

**Supervisor:** **Merakos Lazaros, Proffesor**

**ATHENS**

**NOVEMBER 2015**

**ΕΘΝΙΚΟ ΚΑΙ ΚΑΠΟΔΙΣΤΡΙΑΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΘΗΝΩΝ**

**ΣΧΟΛΗ ΘΕΤΙΚΩΝ ΕΠΙΣΤΗΜΩΝ**

**ΤΜΗΜΑ ΠΛΗΡΟΦΟΡΙΚΗΣ ΚΑΙ ΤΗΛΕΠΙΚΟΙΝΩΝΙΩΝ**

**ΠΤΥΧΙΑΚΗ ΕΡΓΑΣΙΑ**

# Η μετάβαση από τα δίκτυα πρώτης στα δίκτυα πέμπτης γενιάς, και των επικοινωνιών από άνθρωπο σε άνθρωπο σε μηχανή προς μηχανή

**Παναγιώτα Δ. Γιωτοπούλου**

**Επιβλέπων:** **Μεράκος Λάζαρος,** Καθηγητής

**ΑΘΗΝΑ**

**ΝΟΕΜΒΡΙΟΣ 2015**

**THESIS PROJECT**

The evolution of mobile communications: Moving from 1G to 5G, and from human-to-human to machine-to-machine communications

**Panagiota D. Giotopoulou**

**A.M.:**
1115200900067

**Supervisor:** **Merakos Lazaros, Professor**

**ΠΤΥΧΙΑΚΗ ΕΡΓΑΣΙΑ**

# The evolution of mobile communications: Moving from 1G to 5G, and from human-to-human to machine-to-machine communications

**Παναγιώτα Δ. Γιωτοπούλου**

**Α.Μ.:**
1115200900067

**Επιβλέπων:** **Μεράκος Λάζαρος,** Καθηγητής

## ABSTRACT

Nowadays, where everything around us is evolving rapidly, integral part of our everyday life is communication. Technology and integration in communication systems have been operating competitively in all forms of industry, resulting in continuous improvement of end services that reach the user. One of the most important areas that will affect the configuration and provision of these services is the emergence of the Internet of Things according to which, the connection of billion devices on the Internet is expected. These devices are going to exchange information and provide services. New telecommunications technologies should therefore be created in order to enable and support the applications of IoT. One of these applications is the development of Machine-To-Machine communications. This thesis is a review and inventory of existing mobile communication systems and a study of the technologies of future communications systems. More specifically, we study the transition from existing First Generation networks to the future Fifth Generation technologies, and make an introduction and analysis of M2M applications. Although these technologies and applications are not developed or are still at the research stage, the requirements for their implementation have already been identified and will be analyzed in this thesis.



**SUBJECT AREA**: The evolution of mobile communications: Moving from 1G to 5G and from human-to-human to machine-to-machine communications.

**KEYWORDS:** Fifth Generation Networks (5G), Machine-to-Machine Communications (M2M), Internet of Things (IoT), Evolution of Mobile Networks, Telecommunication systems

# ΠΕΡΙΛΗΨΗ

Στη σημερινή εποχή, που όλα γύρω μας εξελίσσονται με ταχύτατους ρυθμούς, αναπόσπαστο κομμάτι της καθημερινότητας μας αποτελεί η επικοινωνία. Η τεχνολογία και η ενσωμάτωσή της σε συστήματα επικοινωνιών, έχει λειτουργήσει ανταγωνιστικά για κάθε μορφής βιομηχανία, με αποτέλεσμα την συνεχή βελτίωση των τελικών υπηρεσιών που φτάνουν στον χρήστη. Ένας από τους σημαντικότερους τομείς που πρόκειται να επηρεάσει την διαμόρφωση και παροχή αυτών των υπηρεσιών είναι η εμφάνιση του Διαδικτύου των Πραγμάτων (Internet of Things) σύμφωνα με το οποίο αναμένεται η σύνδεση δισεκατομμυρίων συσκευών στο διαδίκτυο. Οι συσκευές αυτές πρόκειται να μοιράζονται πληροφορίες και να παρέχουν υπηρεσίες. Θα πρέπει λοιπόν να δημιουργηθούν νέες τηλεπικοινωνιακές τεχνολογίες οι οποίες θα επιτρέπουν και θα υποστηρίζουν τις εφαρμογές του IoT. Μία από αυτές τις εφαρμογές είναι και η ανάπτυξη των Machine-To-Machine επικοινωνιών. Στην εργασία αυτή γίνεται μία ανασκόπηση και καταγραφή των ήδη υπαρχόντων συστημάτων κινητών επικοινωνιών αλλά και μία μελέτη των τεχνολογιών των μελλοντικών συστημάτων επικοινωνιών. Πιο συγκεκριμένα, μελετάται η μετάβαση από τα υφιστάμενα δίκτυα Πρώτης Γενιάς στα μελλοντικά δίκτυα Πέμπτης Γενιάς αλλά και η εισαγωγή και ανάλυση των M2M εφαρμογών. Αν και ακόμη αυτές οι τεχνολογίες και εφαρμογές είτε δεν έχουν υλοποιηθεί, είτε βρίσκονται σε ερευνητικό στάδιο, οι απαιτήσεις για την υλοποίηση τους έχουν ήδη προσδιοριστεί και πρόκειται να αναλυθούν στα πλαίσια αυτής της πτυχιακής εργασίας.

**ΘΕΜΑΤΙΚΗ ΠΕΡΙΟΧΗ:** Η εξέλιξη των κινητών επικοινωνιών: Η μετάβαση από τα δίκτυα πρώτης στα δίκτυα πέμπτης γενιάς, και των επικοινωνιών από άνθρωπο σε άνθρωπο σε μηχανή προς μηχανή

**ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ:** Δίκτυα πέμπτης γενιάς, Διαδίκτυο των Πραγμάτων, επικοινωνία μεταξύ μηχανών, εξέλιξη κινητών επικοινωνιών, Τηλεπικοινωνιακά συστήματα

# ΕΥΧΑΡΙΣΤΙΕΣ

Για την ολοκλήρωση αυτής της πτυχιακής εργασίας θα ήθελα αρχικά να ευχαριστήσω τον καθηγητή μου, κύριο Μεράκο Λάζαρο που ανέλαβε και στήριξε την πρωτοβουλία μου για την ενασχόλησή μου με το συγκεκριμένο αντικείμενο ενώ παράλληλα συνέβαλλε στο να διευρύνω τις γνώσεις μου στον τομέα των κινητών δικτύων και να εντείνω το ενδιαφέρον μου σε συναφή επιστημονικά πεδία

Στην συνέχεια, θα ήθελα να εκφράσω τις ιδιαίτερες ευχαριστίες μου στην υποψήφια διδάκτωρ Λιώτου Ειρήνη για την πολύτιμη και ουσιαστική καθοδήγηση που μου προσέφερε καθ’ όλη την διάρκεια εκπόνησης της πτυχιακής μου εργασίας. Η συμβολή της κρίθηκε καταλυτική για την πραγματοποίηση της παρούσας εργασίας.

Τέλος, θα ήθελα να ευχαριστήσω την οικογένεια μου αλλά και τους πολύ καλούς μου φίλους Παπανάγνου Κατερίνα και Πετρόπουλο Κωνσταντίνο για την υπομονή και την κατανόηση που έδειξαν όλα αυτά τα χρόνια μέχρι τώρα, για την ολοκλήρωση των σπουδών μου.

# CONTENTS

## LIST OF FIGURES

# PREFACE

The scope of this thesis project is to study the evolution of telecommunication system technologies, from First Generation to future Fifth Generation Networks, and to present a comprehensive description of Machine-to-Machine use cases.

This thesis project was realized from March 2015 to September 2015 under the supervision of Professor Merakos Lazaros and under the guidance of PhD. Candidate Liotou Eirini.

This document comprises of three chapters; Evolution of Mobile Networks, Fifth Generation Systems and Machine–to-Machine Communications.

The first chapter describes the network evolution from First (1G) to Fourth Generation advanced (LTE-A) systems. To be more specific it contains an extensive description of each system, the technologies used for air and core access parts and the network standards that were developed in order to make them efficient.

The second chapter describes the technologies and use cases that are envisioned to be deployed in Fifth Generation networks. In particular, it contains a comprehensive description of 5G use cases, network requirements, standardization methods, and radio access and core part technologies.

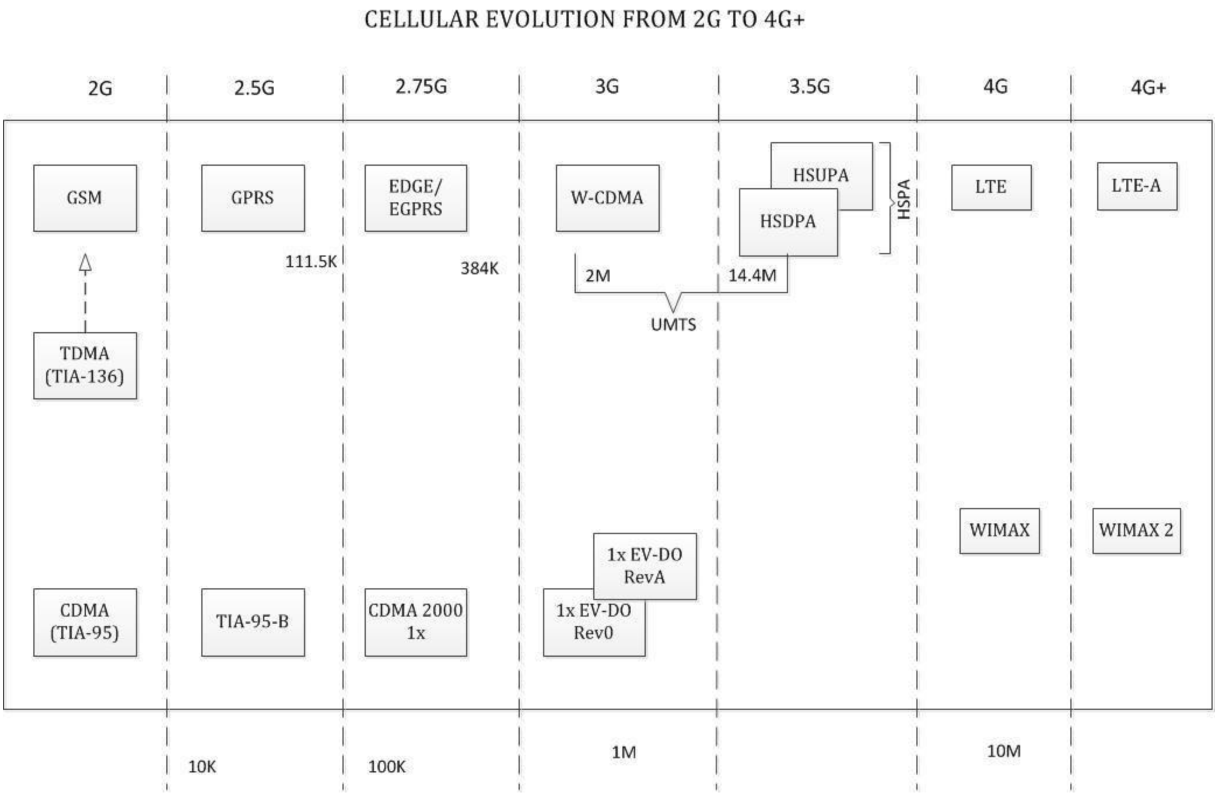
Finally, the third chapter focuses on the Machine-to-Machine use cases, network requirements and technologies and M2M suggested architectures.

*Panagiota Giotopoulou,*

*November, 2015*

# 1. EVOLUTION OF MOBILE COMMUNICATIONS

Mobile communications systems revolutionized the way people communicate. First Generation (1G) of telecommunications technologies were originally introduced in the early 1980's and fulfilled the basic mobile voice using analogue access transmission (FDMA). A decade later, Second Generation (2G) systems followed, introducing digital multiple access technologies (such as TDMA and CDMA) which improved the quality of the existing voice services and added new ones as Short and Multimedia Message Services. This is followed by the third generation (3G), which targets for data at higher speeds to open the gates for truly "mobile broadband".




*Graphic 1.1: This graphic illustrates the evolution in network standards from second to fourth generation of mobile networks.*

The Fourth Generation (4G) provides access to wide range of telecommunication services, including advanced mobile services, supported by mobile and fixed networks, which are increasingly packet based, along with a support for low to high mobility applications and wide range of data rates, in accordance with service demands in multiuser environment. Fifth Generation should be more intelligent technology that interconnects the entire world.

## 1.1 First Generation Technology

### 1.1.1 Analogue Cellular Networks

First Generation or 1G telephony technology was introduced in the 1980s as the first mobile telecommunication system. Those circuit-switched systems were based on analogue transmission techniques and were designed to carry low quality voice traffic. However, First Generation Technology compares unfavourably to its successors as it has low capacity, poor voice links and no security at all since voice calls were played back in radio towers, making these calls susceptible to unwanted eavesdropping by third parties.

### 1.1.2 Network Standards

1G or First Generation of wireless telecommunication technology consists of various standards among which most popular were Advance Mobile Phone Service (AMPS), Nordic Mobile Telephone (NMT), Total Access Communication System (TACS). All of the standards in 1G use frequency modulation techniques for voice signals and all the handover decisions were taken at the Base Stations. The spectrum within cell was divided into number of channels and every call is allotted a dedicated pair of channels.

- NMT –NORDIC MOBILE TELEPHONY

NMT mobile phone network was created on 1981 as a response to the increasing congestion and heavy requirements of ARP (auto radio puhelin or car radio phone). NMT was based on analogue technology and was developed in two versions; NMT 450 and NMT 900. The numbers indicate the frequency bands used. This standard specified billing and roaming but its specifications lacked in security as the traffic was not encrypted. This omission made communications vulnerable to eavesdropping as this could be achieved by tuning a scanner in the correct frequency. Later versions of NMT specifications defined optional analogue encryption which was based on two-band audio frequency inversion. The cell sizes in an NMT network range from 2 km to 30 km. NMT used full duplex transmission, allowing for simultaneous reception and transmission of voice. Signalling between the base station and the mobile station was implemented using the same RF channel that was used for audio, and using the 1200 bps FFSK modem. This caused the periodic short noise bursts that were uniquely characteristic of NMT sound.

- AMPS- ADVANCE MOBILE PHONE SERVICEA

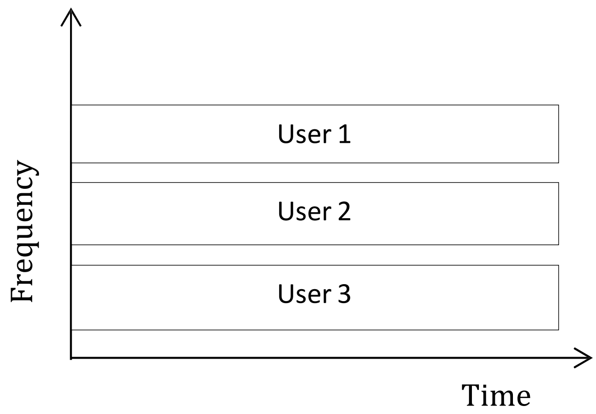
AMPS was based on the FDMA (frequency division multiple access) technology, which allowed multiple users in a cell or cell sector. Initially, cell size was not fixed and an eight mile radius was used in urban areas and a twenty-five mile radius in rural areas. However, as the number of users began to increase, new cells were added. With the addition of every new cell, the frequency plan was to be re-done to be able to avoid interference related problems. Except for the limited capacity there were security problems too. For example if someone was able to get hold of another person's serial code, it would be possible to make illegal calls. Although efforts were made to address these problems, especially the ones related to capacity, the results were not sufficient and the industry started to look into other options, such as the next generation digital systems. [1]

- TACS- TOTAL ACCESS COMMUNICATION SYSTEM

The *TACS* was similar to the AMPS and operated in the 900 MHz frequency range.

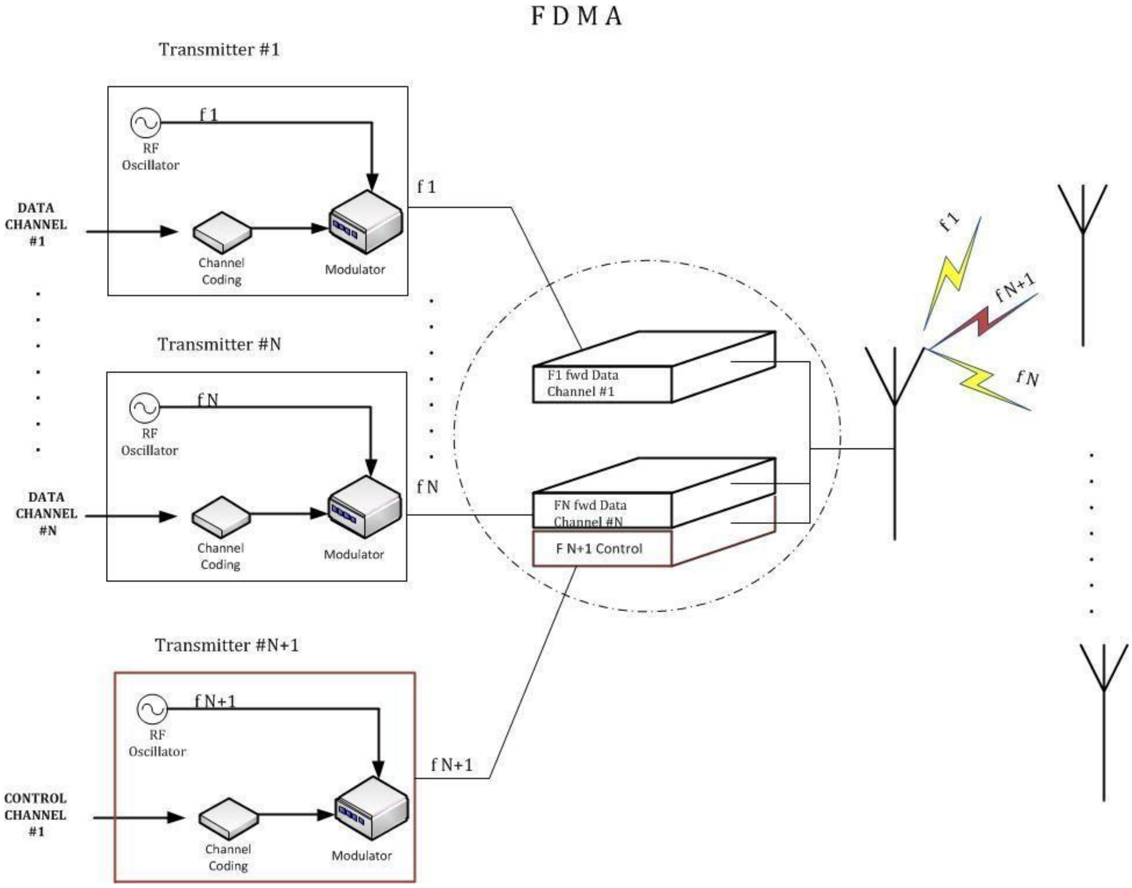
### 1.1.3 Access Technology

All wireless communication technologies rely on multiple access methods designed to support multiple users sharing a common physical communication resource. Different channelization protocols have been developed in order to provide this support. In this case this is done by using Frequency Division Multiple Access (FDMA) technique which allows a number of users to share the available frequency by segmenting the frequency block into smaller subcarriers, and allocating those subcarriers on a per-user basis. According to FDMA, each phone call is assigned to a specific uplink frequency channel, and other downlink frequency channel. The channel therefore is closed to other conversations until the initial call is finished, or until it is handed-off to a different channel.




*Graphic 1.2: This graphic illustrates how FDMA would allocate a subcarrier to a particular user in a 1G wireless system.*

FDMA techniques though, are the least efficient systems for multiple access as they depend on the transmission of analogue signals. In particular as the speech converts into electrical signal and then back to sound, inevitably an amount of noise is produced affecting user's call quality. Secondly as the adoption of cellular phones grew, analogue channels created limited capacity issues due to the fact that each channel can only be allocated to one user at any given time, and cannot be "reassigned." This means that, even if the call is silent, the channel is closed to other conversations until the initial call is finished, or until it is handed-off to a different channel and cannot be re-used for a different user.




*Graphic 1.3: This graphic illustrates the FDMA technique.*

According to the FDMA technique, described in graphic 1.3, the banwidth is divided, slicing up the frequencies and defining a data channel for each frequency. For instance, the data for user N are going through the encoding where redundancy to the datastream is added, then goes through the modulation technique where are transformed into waveforms and finally are transmitted on the frequency with number N. In this case, frequency N+1 is dedicated for the control traffic, mostly things related to signal traffic. All of this control comes through the control channel. So what comes out is multiple frequencies for the antenna system.

## 1.2 Second Generation Technology Systems

### 1.2.1 Digital Cellular Networks

Second Generation or 2G technology was introduced in the early 1990s' as the first generation of digital radio technologies. Those circuit-switched data services were developed as a replacement for 1G analogue cellular networks as they could offer more benefits for the subscribers. In particular, through digital systems the voice is taken through the handset and passes from an analogue to digital converter so that what comes out is a series of bits (bitstream). That means that the sound of the speaker's voice is processed in a way that imitated a human mouth through techniques such as sampling and filtering, which comparing to 1G brings better voice quality even in low bit rates. This made it possible for many more mobile users to be accommodated in the radio spectrum. Additionally, Second Generation technologies introduced data services such as SMS (Short Message Services) and MMS (Multimedia Message Services). These services are also digitally encrypted which means that only the intended receiver can receive and read the transferred data. [1]

### 1.2.2 Network Standards

Second Generation technologies were mainly developed on four standards: GSM, D-AMPS, cdmaOne and PDC. Those standards were based on digital communications, both in radio path and between network entities. The processes implemented for 2G standardization were aimed at making the notion of global roaming more realistic, as in 1G it was limited to national standards and could not offer such services beyond national boundaries.

- GSM - GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS (ORIGINALLY GROUPE SPÉCIAL MOBILE)

GSM is a standard developed by European Telecommunications Standards Institute (ETSI) in order to describe Second Generation network protocols. In 1991 GSM was the world's first commercially operated digital cellular system and it was designed to provide services such as voice mail, text messaging, international roaming, prepaid calling, SMS and many other low cost alternatives of communication which enhance its popularity till today. The early GSM systems used a 25MHz frequency spectrum in a 900MHz band. This spectrum is then divided into 124 carrier frequencies of 200 KHz each. A single 200 KHz channel was shared between eight users by allocating a unique time slot to each one of them. GSM operates at various radio frequencies, with most of them operating at 900 MHz and/or 1800 MHz. The cell radius in the GSM network varies depending upon the antenna height, antenna gains, propagation conditions, etc. These factors vary the cell size from a couple of hundred metres to a few kilometres. Due to this cell, sizes are classified into four kinds in GSM networks; macro, micro, pico and umbrella, with macro cells being the biggest and pico and umbrella cells are being the smallest. [2]

- D-AMPS – DIGITAL ADVANCED MOBILE PHONE SYSTEM

D-AMPS, also known as Us- TDMA is a digital version of first generation AMPS technology popular in North America. It is also backward-compatible to AMPS which is among the popular 1G mobile technologies.

- CdmaOne

CdmaOne or IS-95 is a technology popular in Korea and the United States, which offered a tough competition to GSM technology. Unlike other standards which are based on TDMA or FDMA techniques CdmaOne is based on Code Division Multiple Access technology (CDMA).

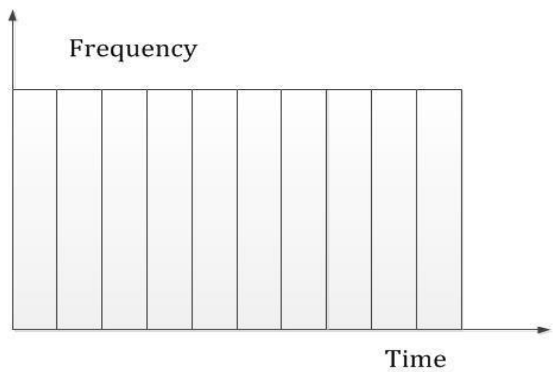
- PDC- PERSONAL DIGITAL COMMUNICATION

PDC is a standard which became popular in Japan and operated between 800 MHz and 1500 MHz frequencies.

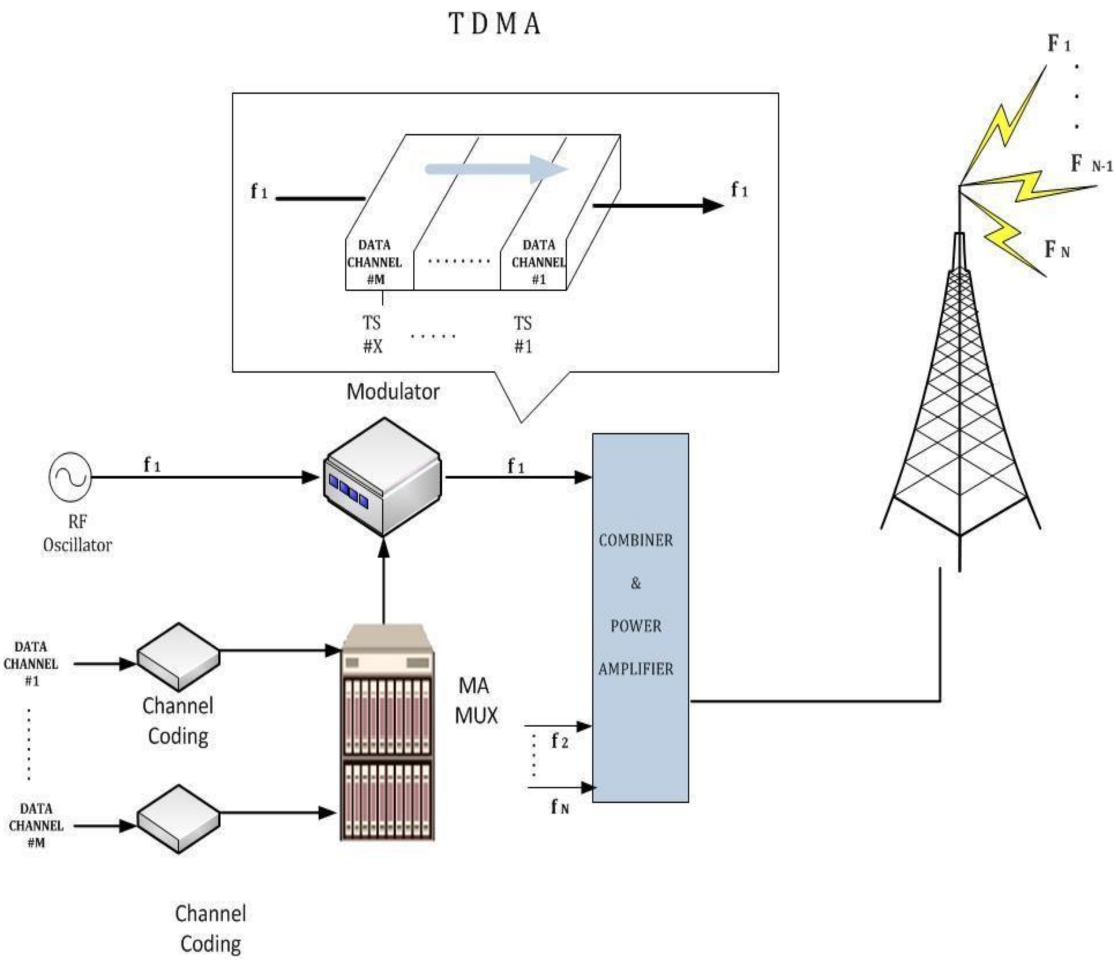
### 1.2.3 Access Technology

One of the major challenges that Second Generation Systems had to overcome was the increase of the network capacity. In particular such an increase would mean the simultaneous support of active users within the region serviced by a radio tower. This is achieved by the use of TDMA and CDMA techniques which are both Multiple Access Technologies.

- TDMA or Time Division Multiple Access Technology is a method that is designed to support many users simultaneously by dividing the signal into different time slots. This is achieved by dividing the frequency first and then slicing each one of them up in time. In that way one frequency can be shared among different users, literally though they take turns.



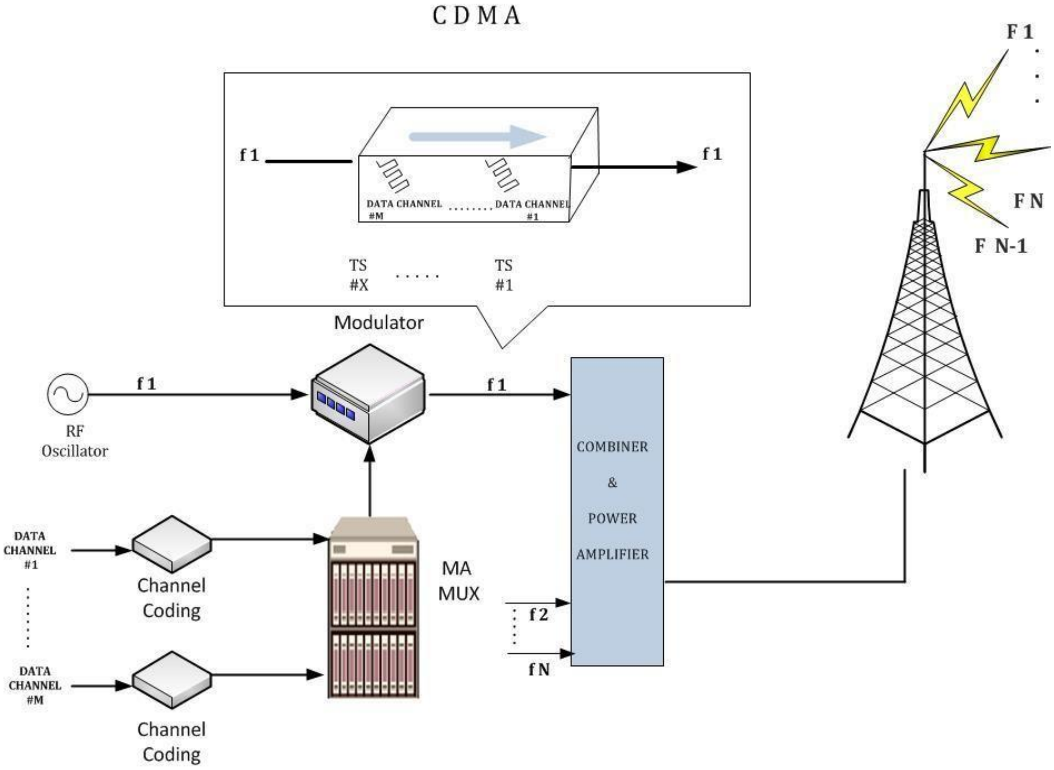

*Graphic 1.4: This figure illustrates how TDMA would allocate a timeslot to a particular subscriber in a 2G wireless system.*




*Graphic 1.5: This graphic illustrates how a channel is divided in the frequency domain among multiple users in TDMA.*

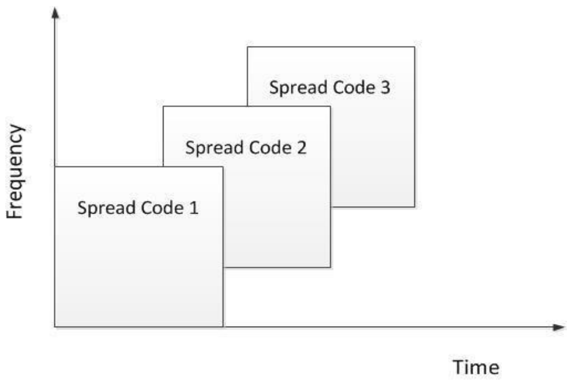
In TDMA technique, according to the graphic 1.5, the frequency is divided in X timeslots and each one of them is dedicated to a specific user. In particular, each data channel is going through the encoding process, the data for multiple users are going to be combined and multiplexed together and then transmitted over the modulator. So each frequency is transmitted over the air through the antenna system.

- CDMA or Code Division Multiple Access is based on “spread” spectrum technology. Since it is suitable for encrypted transmissions, it has long been used for military purposes. CDMA increases spectrum capacity by allowing all users to occupy all channels at the same time. Transmissions are spread over the whole radio band, and each voice or data call are assigned a unique code to differentiate from the other calls carried over the same spectrum. CDMA allows for a “soft hand-off”, which means that terminals can communicate with several base stations at the same time.



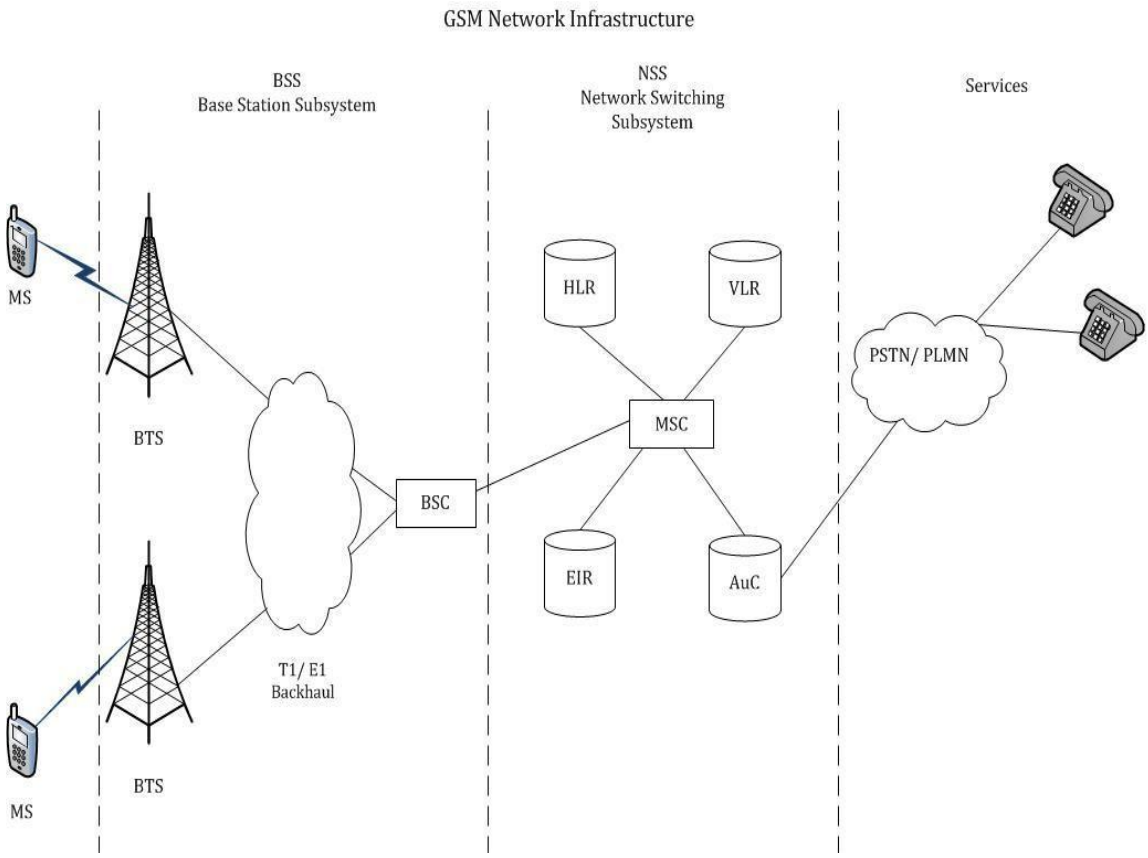

*Graphic 1.6: This graphic illustrates how several transmitters can send information simultaneously over a single communication channel.*

Unlike the other two techniques, FDMA and TDMA, in CDMA there is no frequency division or timeslots. There are different data channels, which as before, go through the encoding process where redundancy is added to the data stream. Then multiplexing process takes place and different signals from different channels are multiplied and combined together. A modulator is again created, in this case in frequency 1, but now the signal has been spread across a much wider band before being transmitted over the air. In case there are multiple frequency carriers, multiple CDMA systems might operate independently and transmit through an antenna system. This technique is preferred as it is more spectrally efficient and offers bigger capacity.




*Graphic 1.7: This graphic illustrates the CDMA technique*

### 1.2.4 Network Infrastructure




*Graphic 1.8: This graphic illustrates the GSM system*

A network mobile system has two major components: the fixed installed infrastructure (network) and the mobile subscribers, who use the services of the network. The fixed installed network can again be subdivided into three subnetworks: radio networks, mobile switching network and management network. These subnetworks are called subsystems. The respective three subsystems are:

- Base Station Subsystems (BSS);
- Switching and Management Subsystem (SMSS);
- Operation and Management Subsystems (OMSS).

According to graphic 1.8 the 2G system can be divided into three parts; the BSS (Base Station Subsystem or the radio network), the NSS which is the Network Station Subsystem and finally the part of Services.

### 1. Base Station Subsystem or Radio Network

This comprises the Base Station Controller (BSC) and the Base Transceiver Station (BTS). Base station Subsystem is responsible for handling traffic and signalling between the mobile system (MS) and the network switching subsystem (NSS). It also carries out transcoding out of speech, allocation of radio channels to mobile phones, paging, transmission and reception over the radio network. To be more specific;

- *BTS or Base Transceiver Station* contains the equipment which is responsible for receiving and transmitting radio signals, the antennas, and equipment for encrypting and decrypting communications. A BTS is controlled by a parent BSC.

- BSC or Base Station Controller handles allocation of radio channels, receives measurements from the mobile phones, and controls handovers from BTS to BTS. A key function of the BSC is to act as a concentrator where many different low capacity connections to BTSs (with relatively low utilisation) become reduced to a smaller number of connections towards the mobile switching center (MSC) (with a high level of utilisation). Overall, this means that networks are often structured to have many BSCs distributed into regions near their BTSs which are then connected to large centralised MSC sites. [3]

### 2. Network Station Subsystem or Core Network

The Network Switching Subsystem of GSM is responsible for carrying out call switching and mobility management functions for mobile phone roaming on the network of base stations. It is owned and deployed by mobile phone operators and allows mobile devices to communicate with each other and telephones in the wider public switched telephone network (PSTN). The architecture contains specific features and functions which are needed because the phones are not fixed in one location. In particular it consists of the HLR, VLR, EIR and AuC databases and the MSC switch.

- HLR or Home Location Register is the central database which provides information about the mobile phone subscribers who are authorized to use GSM network. The primary key to this database is the field that contains IMSI which stands for International Mobile Subscriber Identity and is the unique identifier of every SIM card. Another field that is also a primary key and is necessary for identifying each user is MSISDN (Mobile Station International Subscriber Directory Number) which is the telephone number of each user, used by the mobile phones for making and receiving calls. [4]

Other data which are stored in HLR database are GSM services that the subscriber has requested or been given, current location information and call divert services.

- *VLR or Visitor Location Register* is the database which provides information about the mobile phone subscribers who are using roaming services. The data which are stored in the VLR are either received from the HLR or collected from the MS (Mobile Station). Some other fields of this database are IMSI, authentication data, MSISDN, GSM services and HLR address. Whenever an MSC detects a new mobile station in the GSM, apart from creating a new field in the VLR it also updates the HLR.

In general, there is one central HLR per public land mobile network (PLMN) and one VLR for each MSC.

- *AuC or Authentication Center* is the database in which the authorization of user takes place. In particular it provides the functions by which each SIM card is authenticated. If the authentication is successful then the HLR is allowed to manage the services above, otherwise the subscriber can't have access to these services.

- *EIR or Equipment Identity Register* is a database of which primary key is the IMEI that identifies the mobile phones to be banned or monitored. This is designed to allow tracking of stolen mobile phones, however in most countries it is not in operation.

- *MSC or Mobile Switching Center* is the primary service delivery node for GSM and is responsible for routing all the voice or message services. It also sets up all end to end connections, handles the mobility and handover during a call, contains all the charging and policy rules and takes care of real time pre-paid account monitoring.

### 1.2.5 Technology Limitations

Though the 2G systems brought a major change in the way mobile networks were built, they had some limitations. Some of which are as follows:

- Low transfer rates. The 2G networks are primarily designed to offer voice services to the subscribers. Thus the transfer rates offered by these networks are low. Though the rates vary across technologies, the average rate is of the order of 10Kb/s.
- Low efficiency for packet switched services. There is a demand for Internet access, not just at home or the office but also while roaming. Wireless Internet access with the 2G networks is not efficiently implemented.
- Multiple standards. With a multitude of competing standards in place, a user can roam in only those networks that support the same standard. This allows the user only limited roaming. Therefore the 2G network technology was semi-global in this respect.

### 1.2.6 Evolved 2G Systems and Enhancements

Introduction of 2.5 Generation Systems

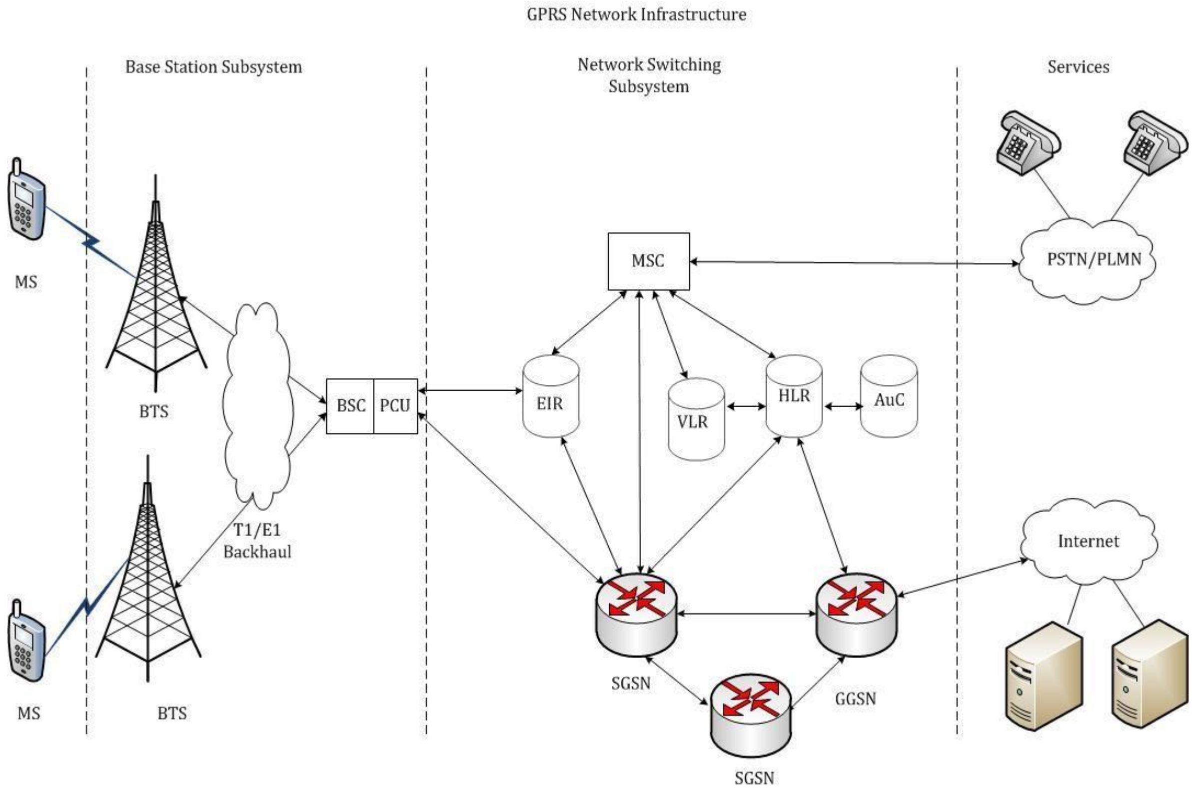
The lack of efficiency and capacity in Second Generation Network forced Telecommunication Operators to find ways to enhance these systems by making changes in the existing network architecture. The outcome was 2.5G networks which differentiated from their predecessors as they could support packet data services in addition to the circuit switched data services that 2G used to support. 2.5 Generation systems introduced some new changes in the air interface as evolution of the already existing GSM standard, which was the most commonly used. However there cannot be any improvement in the air interface without enhancing the core network. The major changes that 2.5G brought are described below:

- Introduction of *General Packet Radio Service* into the GSM specifications. GPRS provides faster data rates by aggregating several time slots into a single bearer. To be more specific GPRS takes all eight timeslots from GSM (which is a TDMA system) in a 200 KHz bandwidth giving a theoretical data rate of 8 x14,4=115Kbit/s. In practice though it supports up to 56Kbit/s and up to 4 timeslots. Most operators do not offer such high rates, because obviously if a slot is being used for a GPRS bearer, it is not available for other traffic. Also, not all mobiles are able to aggregate all combinations of slots.

- *Enhanced Data Rates for Global Evolution or EDGE i*s the technology for the Enhanced GPRS or EGPRS and could increase GSM and GPRS data rates up to 3 times. This could be done by using different modulation techniques which can provide data rates up to 384Kbit/s. It is a relatively straight forward evolution of the GPRS radio modulation to higher data rates within the same 200 KHz bandwidth used by GSM and GPRS. It also adds the capability of 8-PSK modulation to transmit 3bits per waveform (using 1 of 8 phrases) compared to only 1bit per waveform using GMSK modulation as used in GSM and GPRS.

- *High-Speed Circuit-Switched Data or HSDC* is introduced in order to provide higher data rates comparing to those provided by GSM. This is achieved by using multiple time slots instead of one. Given that a GSM channel provides speeds between 9,6Kbps and 14,4Kbps, HSDC is able to obtain up to 57Kbps by using up to four channels. The advantage of using this scheme is the fact that it requires minimum changes in the network architecture as it uses circuit switching, which is inefficient though in terms of resource usage.

### 1.2.7 GPRS Network Infrastructure




*Graphic 1.9: This graphic illustrates the GPRS network architecture*

Two major new core network elements are introduced with GPRS: the SGSN and the GGSN.

- The SGSN monitors the state of the mobile station and tracks its movements within a given geographical area. It is also responsible for establishing and managing the data connections between the mobile user and the destination network.

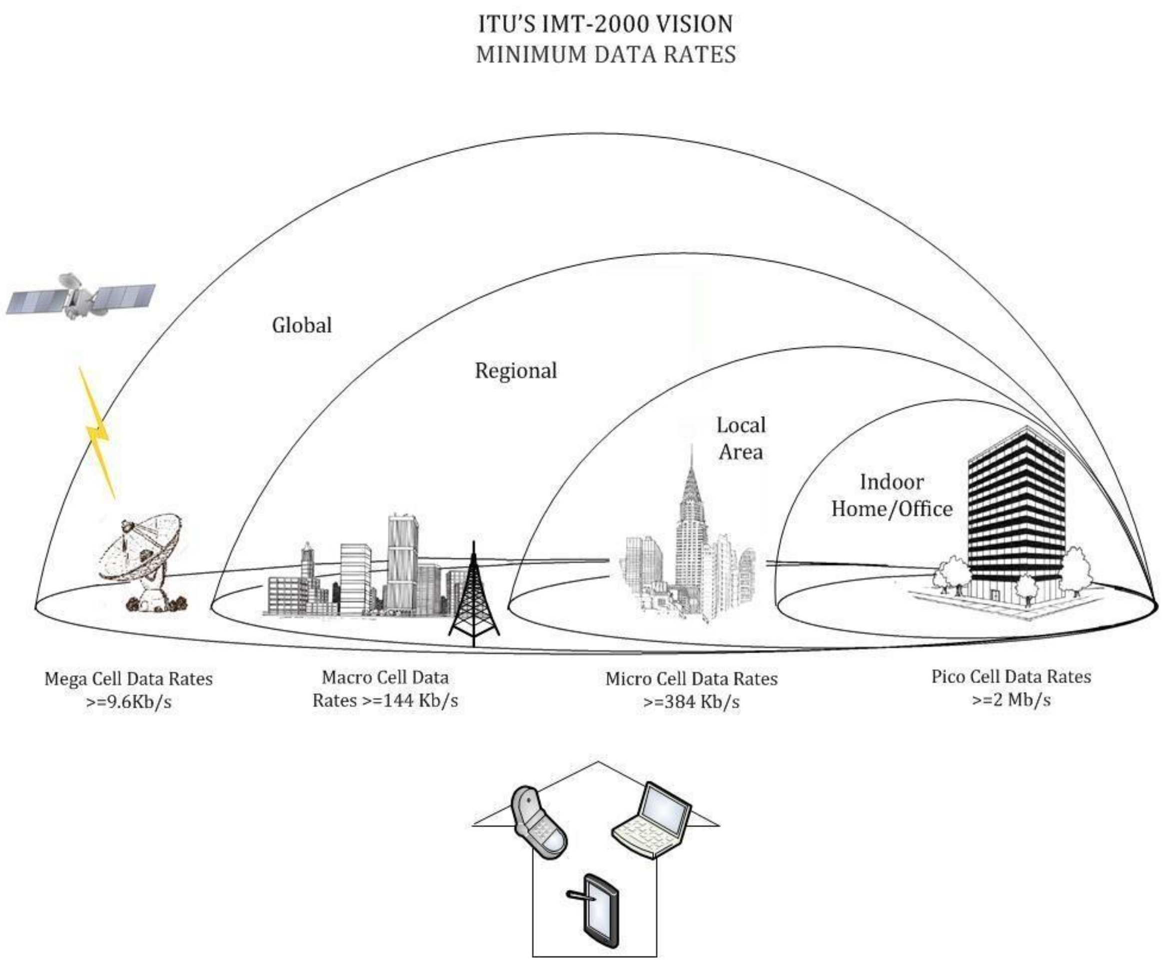
- The GGSN provides the point of attachment between the GPRS domain and external data networks, such as the Internet and corporate Intranets. Each external network is given a unique Access Point Name (APN) which is used by the mobile user to establish the connection to the required destination network.

The GSM has been adapted to support the GPRS connectionless packet mode of operation. A new functional node called the Packet Control Unit has been introduced to control and manage the allocation of GPRS radio resources to mobile users.

## 1.3 Third Generation Technology Systems

The ever-growing needs of subscribers and the several technological advances that existed in the early 2000s made Second Generation Systems obsolete. That led the Market to the development of the third generation technology which focused on the improvement of voice services with some data capabilities. Those systems were developed with the aim of offering high speed data and multimedia connectivity to subscribers. The International Telecommunication Union (also known as ITU) has defined 3G systems as being capable of supporting high speed data ranges of 144 kbps to greater than 2 Mbps. A few technologies are able to fulfil the International Mobile Telecommunications standards, such as CDMA, UMTS and some variation of GSM such as EDGE.

### 1.3.1 ITU'S requirements for third generation technology




*Graphic 1.10: This graphic illustrates the ITU'S vision for the minimum data rates that third generation systems should support.*

As illustrated in the graphic above, ITU's requirements for the 3rd generation systems were mostly related to capacity improvements. In particular:

- For the large cells or macro cells, which are the most commonly used in urban areas (and suburban) the distance from the base station must be considered. The radius in those areas would be one to five miles but in rural areas could be up to five. So third generation systems should be capable of supporting at least 144Kb/s.

- For the smaller cells or micro cells, where antennas are typically bellow rooftops the ITU didn't focus on the vehicular high speed but more on pedestrian's connectivity. So third generation systems should support at least 384Kb/s.

- For the smallest cells or pico cells which are thought to be indoors and the user is close to an antenna or a hub, even walking slowly third generation systems should be capable of at least 2Mb/s. That would approach Wireless Local Area amounts of capability but in the late 1990's there was not Wi-Fi so it seemed like a good idea.

### 1.3.2 Network Standards

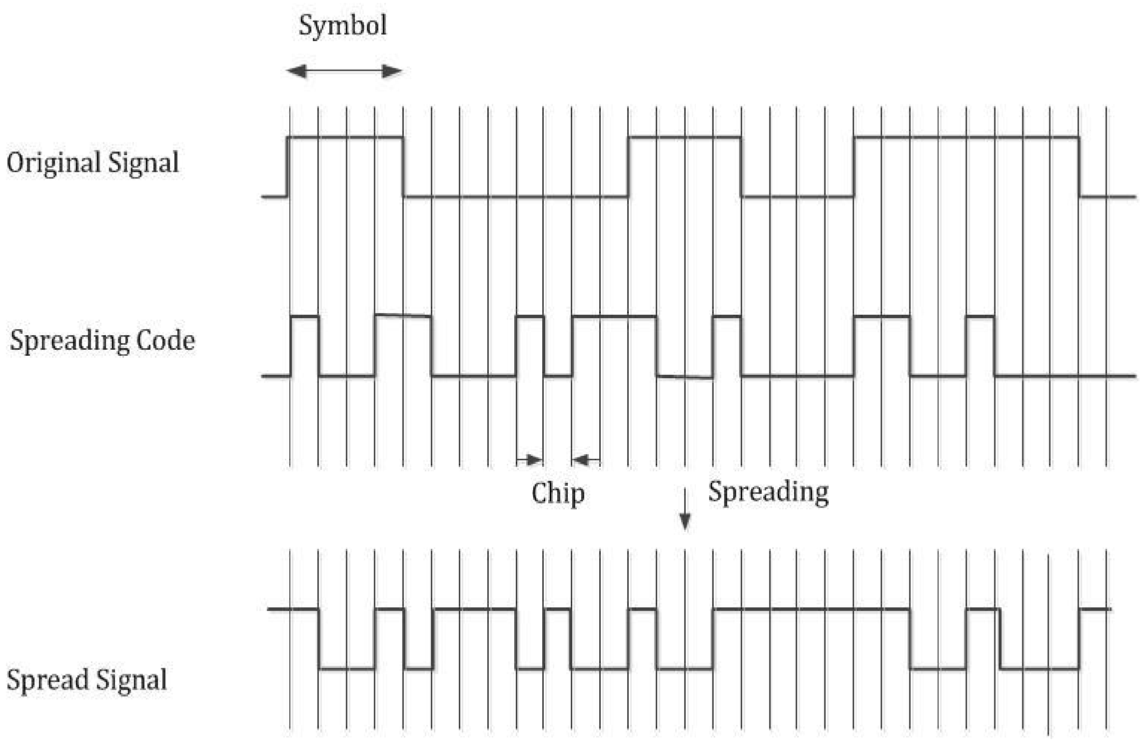
Third Generation of digital technologies debuted after the 2000s and focused on the improvement of voice services, higher bandwidths and the support of multimedia services. In order to provide these capabilities 3rd Generation systems were developed mainly on two technologies: UMTS and CDMA 2000.

- *UMTS or Universal Mobile Telecommunication System* community decided to evolve from GSM, GPRS and EDGE to W-CDMA system in addition to those three pre-existing radio access technologies in order to meet the 2 Mb/s requirement. UMTS uses W-CDMA as the underlying standard offering greater spectral efficiency and higher bandwidth than GSM. It also uses a pair of 5 MHz channels, one in the 1900 MHz range for uplink and one in the 2100 MHz range for downlink. The specific frequency bands originally defined by the UMTS standard are 1885–2025 MHz for uplink and 2110–2200 MHz for downlink.

- *CDMA 2000 also known as IMT Multi-Carrier (IMT-MC)* is a family of 3G mobile technology standards for sending voice, data, and signaling data between mobile phones and cell sites. It is developed by 3GPP2 as a backwards-compatible successor to 2nd generation cdmaOne (IS-95) set of standards and used especially in North America and South Korea. The name CDMA2000 denotes a family of standards that represent the successive, evolutionary stages of the underlying technology. These are Voice (CDMA2000 1xRTT, 1X Advanced) and Data (CDMA2000 1xEV-DO/ Release 0, Revision A, Revision B, ) [5]

### 1.3.3 Access Technology

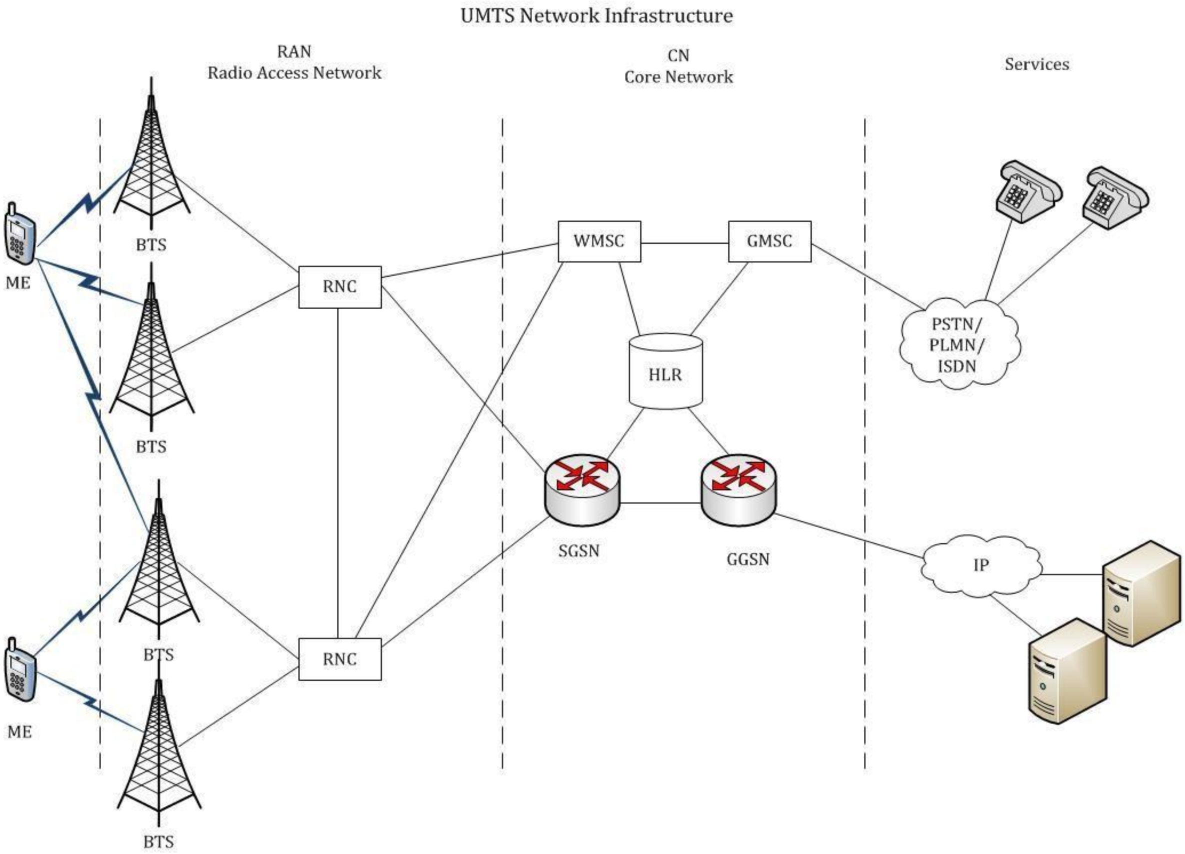
*W-CDMA* stands for wideband-CDMA and it is a technology that was specified by 3GPP for the radio access network part of UMTS. This CDMA based standard provides higher data transmission rates in GSM systems. In particular W-CDMA is a spread-spectrum modulation technique which uses data channels whose bandwidth is greater than the ones to be transmitted. Every data channel is going through the encoding process where it's encoded in a way that a decoder (knowing the code) can pick out the wanted signal, from other signals with the same band which simply appear as so much noise. W-CDMA transmits on a pair of 5MHz wide radio channels and provides a different balance of trade-offs among cost, capacity and performance. It also supports conventional cellular-voice, text and multimedia services.




*Graphic 1.11: This graphic illustrates how the incoming signal is transformed and spread through W-CDMA technique.*

According to the graphic above, W-CDMA is a spread-spectrum technique by which the original user's signal is transformed into a signal form that is spread over a larger bandwidth than required for the initial signal. The codes which are used for this transformation are called spreading codes. Through this method the user's signal is going through the transformation process where is multiplied with bits in a spreading code. A unique spreading code is dedicated to each user. The bits in the spreading code are termed as "chips" while the ones in the user's signal are termed as "symbols".

### 1.3.4 UMTS Network Infrastructure




*Graphic 1.12: This graphic illustrates the UMTS network architecture.*

A UMTS network consists of three parts: the ME or mobile equipment, the UTRAN which stands for the UMTS Terrestrial Radio Access Network and the CN which is the Core Network.

1. *The UE (User Equipment) or ME (Mobile Equipment)* contains the mobile phone and the SIM (Subscriber Identity Module) card called USIM (Universal SIM) which contains member specific data and enables the authenticated entry of the subscriber into the network. This UMTS UE is capable of working in three modes: CS (circuit switched) mode, PS (packet switched) mode and CS/PS mode. In the CS mode the UE is connected only to the core network. In the PS mode, the UE is connected only to the PS domain (though CS services like VoIP (Voice over Internet Protocol) can still be offered), while in the CS/PS mode, the mobile is capable of working simultaneously to offer both CS and PS services.

2. The components of *the Radio Access Network (RAN)* are :
   - *Base Stations or Node B* of which major functions are closed loop power control, physical channel coding, modulation and demodulation, air interface transmissions and reception and error handling.

   - *Radio Network Controller or RNC* of which main functions are radio resource control and management, power control, channel allocation, admission control, ciphering, segmentation and reassembly.

3. The main function of the Core Network (CN) is to provide switching, routing and transit for user traffic. The CN also contains the databases and network management functions. The basic CN architecture for UMTS is based on the GSM network with GPRS. All equipment has to be modified for UMTS operation and services. The CN is divided into the CS and PS domains. The components of the Core Network are:

   - *GMSC or Gateway Mobile Services Switching Centre* which is a Circuit Switched element and is used to route calls outside the mobile network. In particular whenever a call for a mobile subscriber comes from outside the mobile network or the subscriber wants to make a call to somebody outside the mobile network the call is routed through the GMSC.

   - *VLR or Visitor Location Register,* which is also a circuit switched element, contains information about the subscribers roaming within a mobile switching centre's (MSC) location area. The primary role of the VLR is to minimize the number of queries that MSCs have to make to the home location register (HLR), which holds permanent data regarding the cellular network's subscribers.

   - *SGSN or Serving GPRS Support Node* which is a packet switched element mediates access to network resources on behalf of mobile subscribers and implements the packet scheduling policy between different QoS classes. It is responsible for establishing the Packet Data Protocol (PDP) context with the GGSN (gateway GPRS support node) upon activation.

   - GGSN or Gateway GPRS Support Node which is also a packet switched element is responsible for the interworking between the GPRS network and external packet switched networks .From the external networks' point of view, the GGSN is a router to a sub-network, because the GGSN ‘hides’ the GPRS infrastructure from the external network. When the GGSN receives data addressed to a specific user, it checks if the user is active. If it is, the GGSN forwards the data to the SGSN serving the mobile user, but if the mobile user is inactive, the data are discarded. On the other hand, mobile-originated packets are routed to the right network by the GGSN. To do all this, the GGSN keeps a record of active mobile users while SGSN on the mobile users attached to. It allocates IP addresses to mobile users and last but not least, the GGSN is responsible for the billing.

- Network elements like EIR, HLR, VLR and AUC are shared by both domains. The Asynchronous Transfer Mode (ATM) is defined for UMTS core transmission.

UMTS cell sites continue to retain GSM, GPRS and EDGE transceivers in order to serve the users who haven’t upgraded their user devices according to W-CDMA standards. Except for it, UMTS continues to use, with a few changes though, the infrastructure of GSM and GPRS. This is done by including MSCs or Mobile Switching Centres, GPRS routers (SGSNs) and GGSNs.

### 1.3.5 Third Generation Technology Limitations

As the third generation technology was the first one to introduce high speed data services along with good quality of voice services there are still some major limitations in 3G networks. These limitations are related to coverage, security and system complexity. To be more specific:

- With WCDMA based 3G, as the data speed increases the coverage area of the cell become smaller and smaller.
- There has been some improvement with HSPDA, but still it is impossible to connect these by wireless links in cellular technology.
- Using WCDMA cells, with increase in data rate, the speed of movement of user terminal also becomes less and less.
- Wireless Systems consume a lot of power and therefore have a limited time battery life.
- Wireless systems are more complex due to the need to support mobility and to make use of the channel effectively. By adding more complexity to systems, potentially new security vulnerabilities can be introduced.

### 1.3.6 Evolved Third Generation Network Enhancements

INTRODUCTION OF 3.5 GENERATION SYSTEMS

With the convergence of Internet and Wireless Communications, mobile network services are undergoing tremendous growth. However, even Third Generation Systems failed to meet user's expectations as there were limitations mainly on access speed. That led the industry to find ways to update the already existing air interface standards and replace them with improved and higher data versions. This was done with the deployment of the updated versions of W-CDMA and CDMA 2000, HSPA and 1xEV-DO.

*HSPA or High Speed Packet Access* which is the evolved version of W-CDMA is the actual technology for 3.5 Network Generation. HSPA consists of two individual standards, HSDPA and HSUPA which stand for High Speed Downlink and Uplink Packet Access respectively. To be more specific:

- *HSDPA or High Speed Downlink Packet Access*, as illustrated in graphic 1, provides up to 14Mbit/s with significantly reduced latency. It also provides around three times the capacity of the 3G UMTS technology defined in Release 99 of the 3GPP UMTS standard. HSDPA improves on W-CDMA by using different techniques for modulation and coding. It creates a new channel within W-CDMA called HS-DSCH, or high-speed downlink shared channel. That channel performs differently than other channels and allows for faster downlink speeds. It is important to note that the channel is only used for downlink. That means that data are sent from the source to the phone. It isn't possible to send data from the phone to a source using HSDPA. The channel is shared between all users which lets the radio signals to be used most effectively for the fastest downloads. In a few words, HSDPA offers higher capacity, higher data rates, shortest response time, better quality of service and channel sharing.

- *HSUPA or High Speed Uplink Packet Access* increases the uplink from 2Mbit/s to 5,76Mbit/s. It also increases the capacity and reduces the latency. The enhanced uplink features several improvements similar to those of HSDPA, including multi-code transmission, short Transmission Time Interval (TTI), fast scheduling and fast Hybrid Automatic Repeat request (HARQ). Enhancements to achieve HSUPA were added according to Enhanced Dedicated Channel or E-DCH.

As for the evolved cdma2000 version, 1x EV-DO can provide customers with peak data rates of 2.4 Mbit/s. In particular 1x EV stands for 1x Evolution using 1x or 1,25Mhz carrier while DO stands for data only. There were two versions introduced, 1x EV-DO Rev A and 1x EV-DO Rev 0. To be more specific:

- 1x EV-DO Rev A offers a number of benefits and advantages over previous iterations of CDMA technology. In particular, it provides:
  - Improved broadband speeds which are three to four times greater than W-CDMA
  - Higher Spectral efficiency allowing the support of more users per cell site sector
  - Better quality of service as it allows wireless carriers to offer differentiated services to users based on performance criteria
  - Reduced latency to an average of between 150 and 256m/s²
  - Advanced Services. EV-DO Rev A's improved bandwidth capabilities allow users to share large data files more quickly and efficiently, which allows wireless carriers to provide more advanced services in the future. Such services include VoIP, video telephony, media streaming, enhanced backup and redundancy capabilities, and more. EV-DO Rev. A technology is leading to higher adoption rates of enterprise applications among wireless business users. Increased bandwidth and capacity is making the use of enterprise applications, such as enterprise resource planning or customer relationship management, more feasible through wireless devices. In addition, this feasibility makes it possible for wireless carriers to offer advanced services beyond email and voice. [6]

- 1x EV-DO Rev 0 supports high-speed broadband downlink data speeds up to 2.4MBPS in a 1.25MHz radio channel. It also provides:
  - Broadband Data: as it supports a peak data rate of up to 2.4 Mbps in the forward link and 153 kbps in the reverse link within a single 1.25 MHz FDD channel
  - Spectral Efficiency of 0.630 bit/sec/MHz in downlink and 0.180 bit/s/MHz uplink over a 5 MHz FDD channel
  - Average Latency: of 110 msec node-to-node ping
  - User Experience as it offers an "always on" user experience and data rates comparable to DSL networks
  - Ip Connectivity: as it leverages the existing suite of Internet Protocols and supports the already existing IP-based applications and services
  - Applications: as it supports broadband data applications, such as broadband Internet or VPN access etc. [7]

## 1.4 Fourth Generation Technology Systems

4G or Fourth Generation is IP-based and packet-switching evolution of 3G systems. A 4G system in addition to voice, data and the other services Third Generation Systems support, provides mobile broadband internet access.

### 1.4.1 Network Standards

Like 3G, there is no single 4G standard. Instead, different cellular providers use different technologies that conform to the 4G requirements. The technologies considered to be 4G standards include Long Term Evolution, Ultra Mobile Broadband and the IEEE 802.16 standard. To be more specific:

- *LTE or Long Term Evolution* is considered to be a 4G or a Fourth Generation Technology. It has the potential to offer significantly faster mobile broadband services that were possible with legacy 3G or 2G network Technologies. LTE is described in a set of open specifications published by 3GPP (3rd Generation Partnership Project). It belongs to the GSM family of cellular technologies and it can offer data rates greater than 100Mb/s.

  LTE can offer a number of key capabilities among which the most significant ones are:

  - Interworking: As LTE is developed by 3GPP, the body also responsible for 2G GSM and 3G UMTS, an LTE capable device should be able to “fall back” onto legacy network coverage when no LTE service is available ensuring that global roaming continues to benefit users.

  - All-IP: As the LTE is an All-IP based environment it can support a variety of IP and Internet-based services. Services such as VoIP (Voice over IP) therefore operate using the same technologies employed by the Internet and other Ip-based networks.

  - Fast Data: An LTE cell is capable of providing data connections that run over 100Mb/s, which is 50 times faster than average home fixed broadband service.

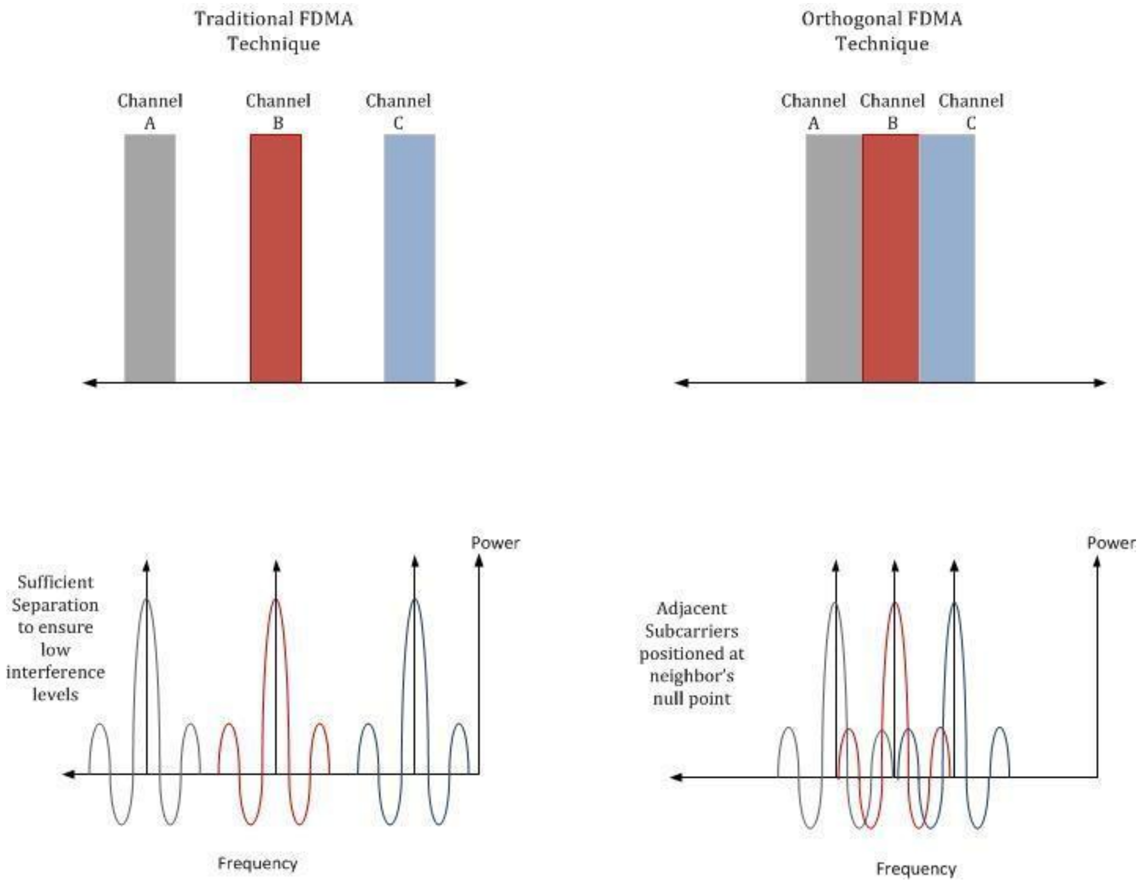
  - High Capacity: LTE’s radio capacity can be used either to supply a small number of users with very fast data connections or medium speed connections to many users.

- *IEEE 802.16 or WiMAX* is a technology designed to provide 30-40Mbit/s data rates. It is also capable of offering fast data services but it’s facing some disadvantages as it offers poor voice services, limited roaming potential and it can be supported by a limited range of services.

- *Ultra-Mobile Broadband or UMB* is the name for the next evolution for the cdma2000 cellular telecommunications system which is run under the auspices of 3GPP2. The UMB cellular system promises to provide very much faster data transfer speeds, and enables the system to compete with other mobile broadband systems including WiMAX and Wi-Fi. It wasn't deployed though due to lack of operator interest.

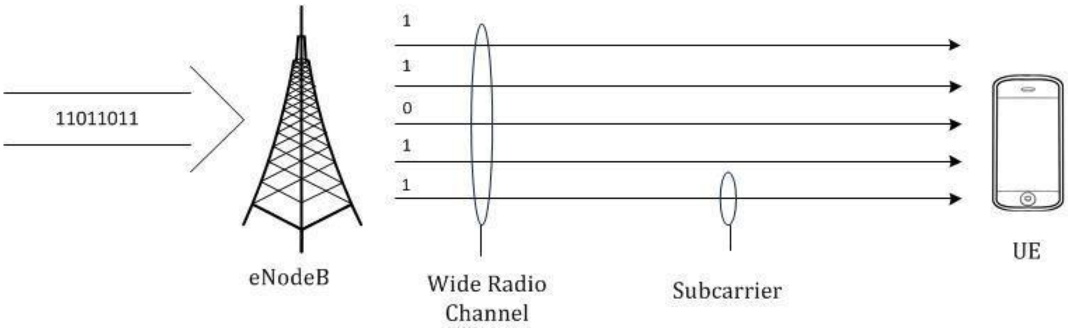
### 1.4.2 Access Technology

LTE interface employs two main technologies -OFDMA for downlink and SC-FDMA for uplink- which are based on parallel transmission. Traditional FDMA systems employ multiple radio channels and assign different users to each. The channels used are spaced sufficiently far apart to ensure that each causes as little interference to its neighbours as possible. Orthogonal FDMA systems adapt this concept by defining closely spaced adjacent subcarriers, each of which is positioned at the 'null' point, where its neighbour causes no interference. Closely spaced subcarriers lead to high-capacity radio channels and allow OFDMA to achieve high data rates.



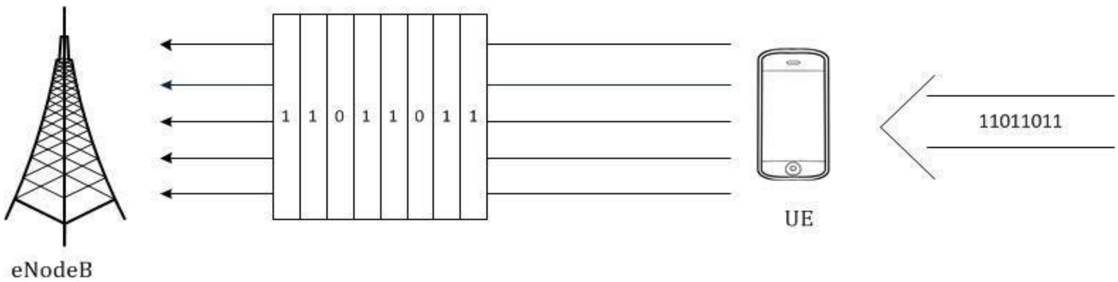

*Graphic 1.13: This graphic illustrates the difference between the traditional and the orthogonal FDMA technique*

According to OFDMA technique radio channels are created by binding together multiple "subcarriers" that allow data to be sent in parallel. This method provides high capacity-speed data to a few users by supporting simultaneously many users. In particular every radio channel is divided into a set of individual subcarriers. Serial input data is separated into parallel output streams prior to transmission. Each stream is assigned to travel across a different subcarrier. OFDMA systems operate on the principle of appearing to transmit data in multiple separate subcarriers spread across a wide radio channel.



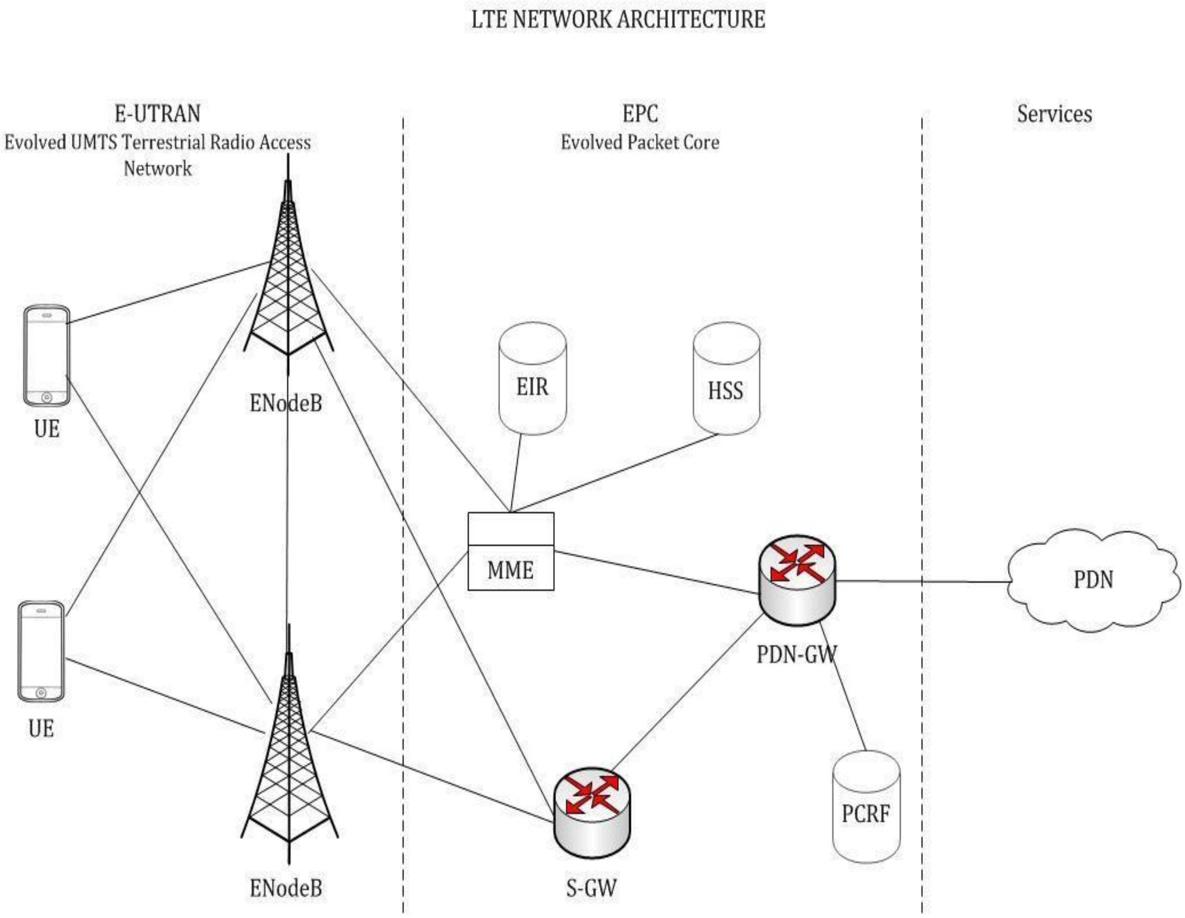

*Graphic 1.14: This graphic illustrates how the incoming data is separated and transferred across different subcarriers through the OFDMA technique.*

LTE uplink channels employ an adaptation of OFDMA known as SC-FDMA. This technology employs the same orthogonally spaced subcarriers and Fourier transforms as OFDMA, but encodes data onto the subcarriers using a different technique. The SC-FDMA based uplink offers roughly 50% of the capacity that is available on the downlink, with a 20 MHz wide LTE channel being able to carry around 50 Mbit/s of user traffic.




*Graphic 1.15: This graphic illustrates how the incoming data is separated and transferred across different subcarriers through the SC-FDMA technique.*

### 1.4.3 LTE Network Infrastructure




*Graphic 1.16: This graphic illustrates the 4th Generation Network Architecture*

The LTE Network Infrastructure consists of three parts: the E-UTRAN which stands for the evolved UMTS Terrestrial Radio Access Network, the EPC or Evolved Packet Core and the part of Services. In particular:

1. *E-UTRAN or Evolved UMTS Terrestrial Radio Access Network* is the air interface of the Fourth Generation Network System and it is the replacement of UMTS and HSPA technologies that were specified in 3GPP networks. It consists of UEs or User Equipment which is the devices through which the user is connected to network and the EnodeBs which are the Evolved versions of NodeBs.
2. *The EPC or Evolved Packet Core* which is responsible for providing “always-on” connectivity, handover support and the transport of the voice packets.
3. *The Services* part which is responsible for providing the internet services to the subscribers.

ENodeB Functionality

- E-NodeB is an evolution of 3G Node B with 3G radio Network Controller Functionality. The combination of these two components brings latency reduce as the signalling between the eNodeB and the Radio Access Network is now eliminated.
- Contains the radio transmitters and receivers which do the modulation and demodulation of radio signals, does the forward error correction Coding and all the other processing required when creating and receiving the radio signal.
- Supports Radio Network Controller functionality. In particular it manages the radio resources so that it would determine which radio signals should be assigned and which configuration in order to support the desired service. It schedules them, providing access to User Equipment and determines when to transmit certain packets to the user in order to meet the quality of service requirements, through the dynamic allocation of the radio channels in both the downlink and the uplink.
- Supports Router Functionality including user data to the user gateway S-GW and signalling to the Mobility Management Entity (MME), e.g. for location updating, operations, etc..
- Supports signalling directly to another eNodeB to prepare the handover operation. During handover the data will be anchored at the S-GW so that it will be routed first to one eNodeB and then to another but with an anchor point at S-GW that is provided so that both eNodeBs are served by the same S-GW.
- Compresses and encrypts the header of the data across the radio interface to the user equipment in order to provide security and better efficiency of operation by compressing these large IP headers.

PDN Gateway (PDN-GW) Functionality

- It provides gateway access to PDN, e.g. the Internet.
- It queries the HSS to find where the user is actually located at this particular time, because in case he is roaming in a different network the PDN-GW will need to forward that packet somewhere else.
- It is responsible for IP allocation to the User Equipment (or UE).
- It is responsible for per-user-packet filtering using “deep packet inspection”. This is done by looking at the layers above IP, e.g. UDP ports, TCP port addresses, as well as the upper layers to ensure that the UE is using authorized channels to connect to authorised services.
- Connects to PCRF (Policy and Charging Rules Function) where it gets information on the Quality of Service and the general services

that are approved for this user. This information is used along with the packet-filtering and the deep-packet-inspection so that the P-GW is able to actually enforce those rules and collect the data needed for charging for those particular services.

- It is responsible for transport level packet making using the differentiated services code points for IP packets in the downlink. In this case downlink comes from an external network. Also some of the downlink packets is S-GW comes from within the UMTS or the EPC.

Mobility Management Entity (MME) Functionality

- It is responsible for signalling and control. One of the objectives of SAE was to improve system scalability by separating control from transport.
- It can serve a number of S-GWs and P-GWs.
- It deals with signalling from UE directly to MME (independent signalling) used in RAN. It is called Upper Layer 3 signalling or Non-Access Stratum signalling because it does not depend on radio technology used in access network.
- It keeps track of where the UE is actually located at the moment so that it knows how to direct incoming calls or data sessions.
- It is responsible for paging idle UEs for incoming call/sessions.
- It is responsible for UE authentication.
- It controls the signalling with S-GW to set up transport paths for calls.

Serving Gateway (S-GW) Functionality

- It does the packet filtering for user data.
- It marks the packets on uplink or downlink by inserting the correct differentiated service code point so that those packets can be given the appropriate treatment in order to guarantee the Quality of Service.
- It is an anchor to eNodeB mobility or handovers that go from the one eNodeB to another.

Policy and Charging Rules Functions (PCRF) Functionality

- Takes charging enforcement decisions on its behalf.
- Provides policy control and flow based charging control decisions.
- Supports service data flow detection.
- Manages policies to manage and control Quality of Service.

Home Subscriber Server (HSS) Functionality

- HSS is an authentication server that stores authentication parameters applied for the users.
- Contains the user profiles which include information about the media types that the users are authorized to use and about the services that are to be applied for the users.

EIR or Equipment Identity Register Functionality

- Is a database that contains the IMEI or the blacklisted handsets. This enables the operators to prevent the use of stolen handsets in their network.

### 1.4.4 Fourth Generation Technology Limitations

No technology is complete in itself and this is also the case with 4G. Although fourth generation of technologies compares favourably to its predecessor ones, there are still limitations to be addressed. These are mostly related to wireless network performance and quality of service. [1] To be more specific these limitations are:

- Mobile station: For a large variety of services and wireless networks in 4G systems the multimode user terminals are essential for adapting to the different wireless networks, thereby eliminating the need for separate multiple terminals. The most promising approach is that of the software radio. Unfortunately, the current software radio technology is not completely feasible for all wireless networks.

- Wireless network: With the support of 4G user terminals, it is possible to choose any available wireless network for each particular communication session. The correct network selection can ensure the QoS required by each session. However, it is complicated to select a suitable network for each communication session, since network availability changes from time to time.

- Quality of service: Supporting Quality of Service (also known as QoS) in 4G networks will be a major challenge due to varying bit rates, channel characteristics, bandwidth allocation, fault-tolerance levels and hand-off support among heterogeneous wireless networks. QoS support can occur at packet, transaction, circuit, user and network levels.

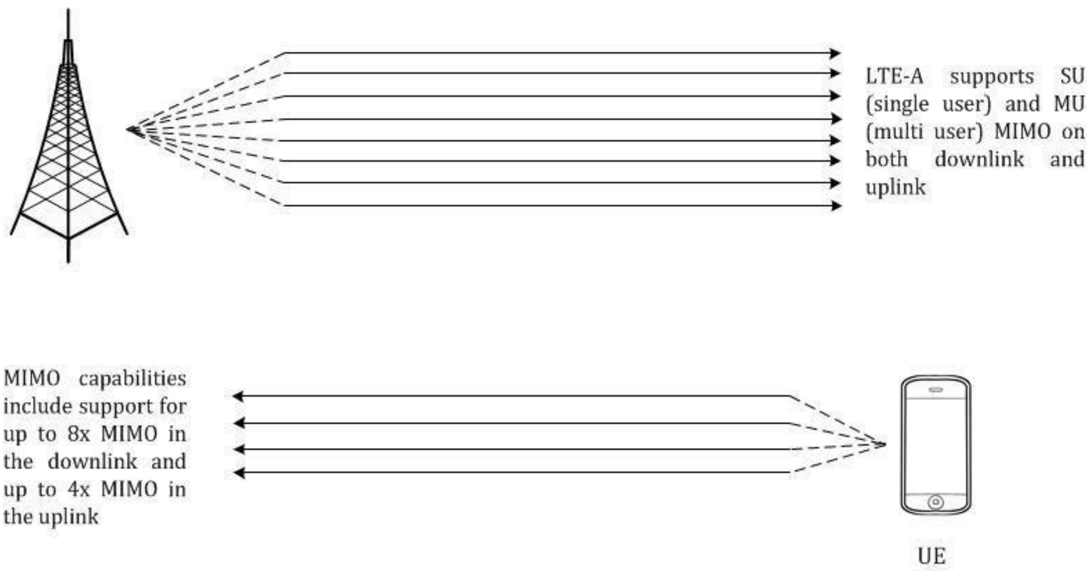
### 1.4.5 Evolved 4G Systems and Enhancements

LTE ADVANCED

LTE advanced is 3GPP’s response to IMT-advanced and was first described in 3GPP Release 10. The main features of this technology (4G+) are Carrier Aggregation, enhanced MIMO features and the use of LTE relays. LTE was originally allocated the 2600 MHz band but additional frequency bands were quickly defined for various regions. Separate band definitions have been for LTE’s FDD and TDD variant. Carrier Aggregation is the most prominent feature of LTE Advanced. It offers an inverse multiplexing flexibility that allows a UE to substantially increase the overall data rate it can achieve by allowing eNB to schedule capacity for it on multiple cells or carriers simultaneously.

### 1.4.6 Access Technology

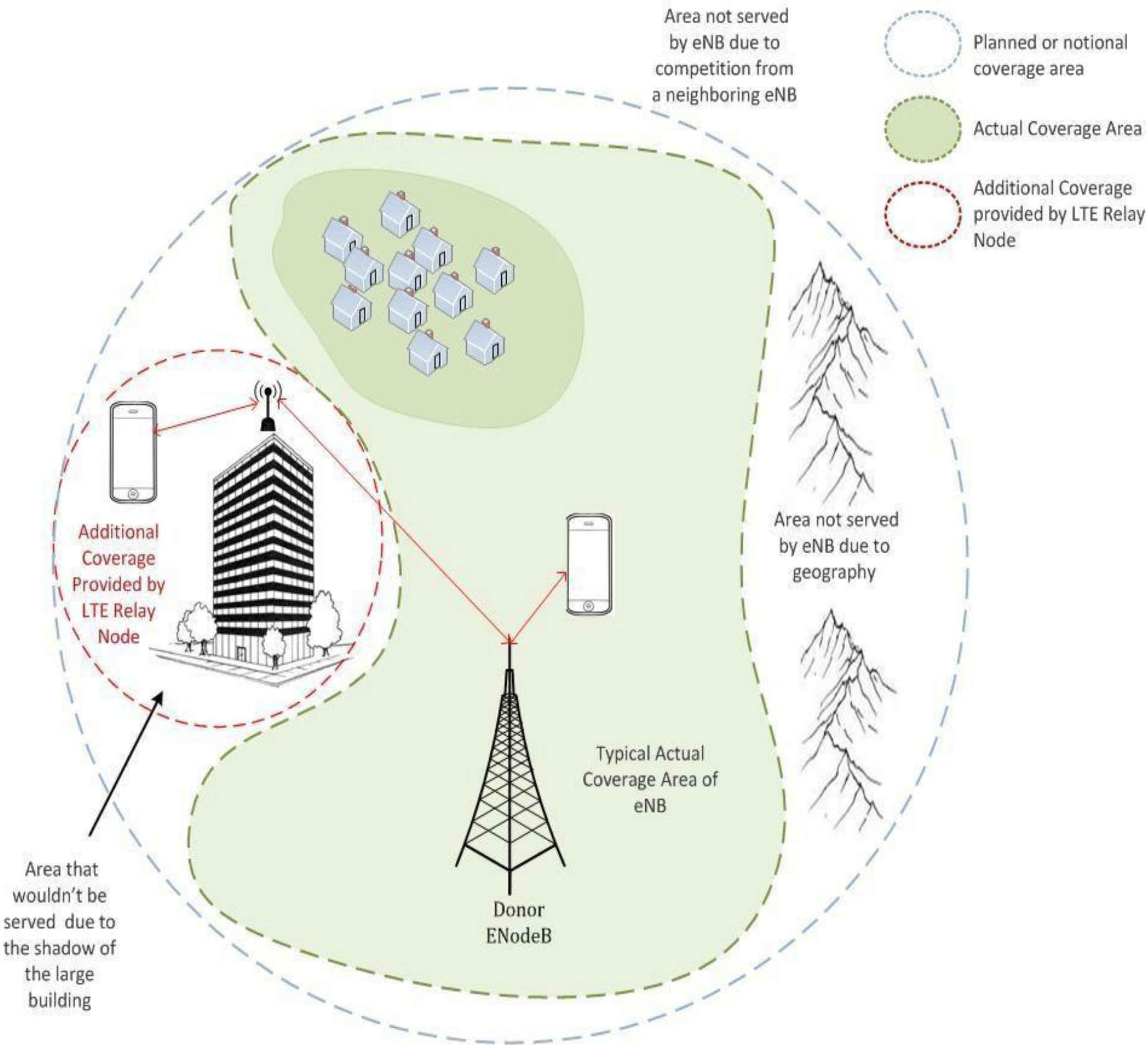
LTE supports capability expansion methods based on spatial multiplexing or multi-antenna techniques. These techniques employ multiple, spatially-diverse antennas to create separate streams of transmitted signals that all occupy the same frequency domain or radio channel. There are several ways in which these techniques may be configured, but the method employed in LTE is known as Multiple Input –Multiple Output or MIMO. [8]




*Graphic 1.17: This graphic illustrates how data are transmitted in both uplink and downlink, through MIMO technique.*

### 1.4.7 Relay Nodes

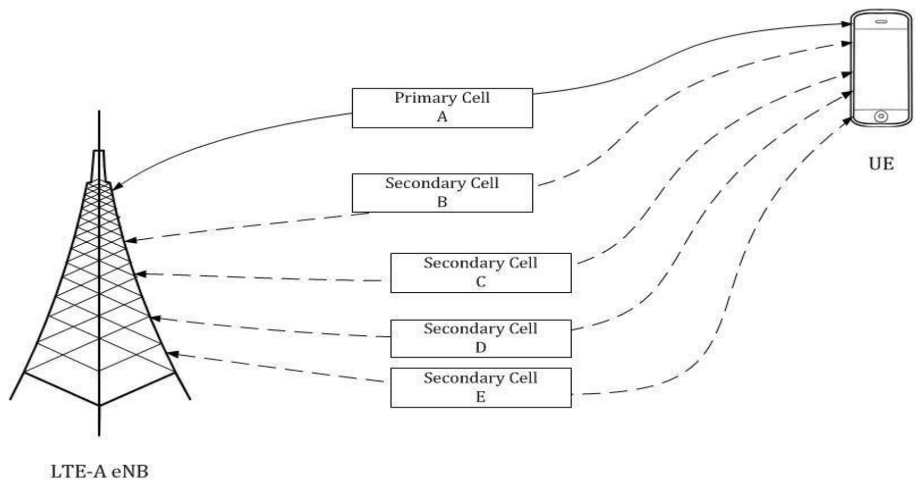
An LTE Relay Node is able to relay or repeat the signal from an eNode B into areas that might previously have been difficult to penetrate, including areas where signals from an eNode B were blocked by large buildings, hills or other obstructions. LTE relays operate using two LTE air interface instances: One instance is projected towards UEs and provides standard LTE coverage; the other instance maintains a link back to the controlling or "donor" eNB and is used for backhaul. This Controlling eNB is known as a "donor" device as it provides or donates the radio channels that will be used by Relay Node.




*Graphic 1.18: This graphic illustrates how actual coverage is increased by the use of an LTE Relay Node.*

### 1.4.8 Carrier Aggregation

Carrier Aggregation is the most prominent feature of LTE Advanced. It offers an inverse multiplexing flexibility that allows a UE to substantially increase the overall data rate it can achieve by allowing eNB to schedule capacity for it on multiple cells or carriers simultaneously. UEs that support the feature are capable of maintaining connections with multiple cells. In each UE's aggregation set there will be one Primary Cell (or Pcell) and up to four Secondary Cells (or SCells). RRC and NAS signaling and other administrative functions are handled by the SCell. Scells simply provide additional user capacity.

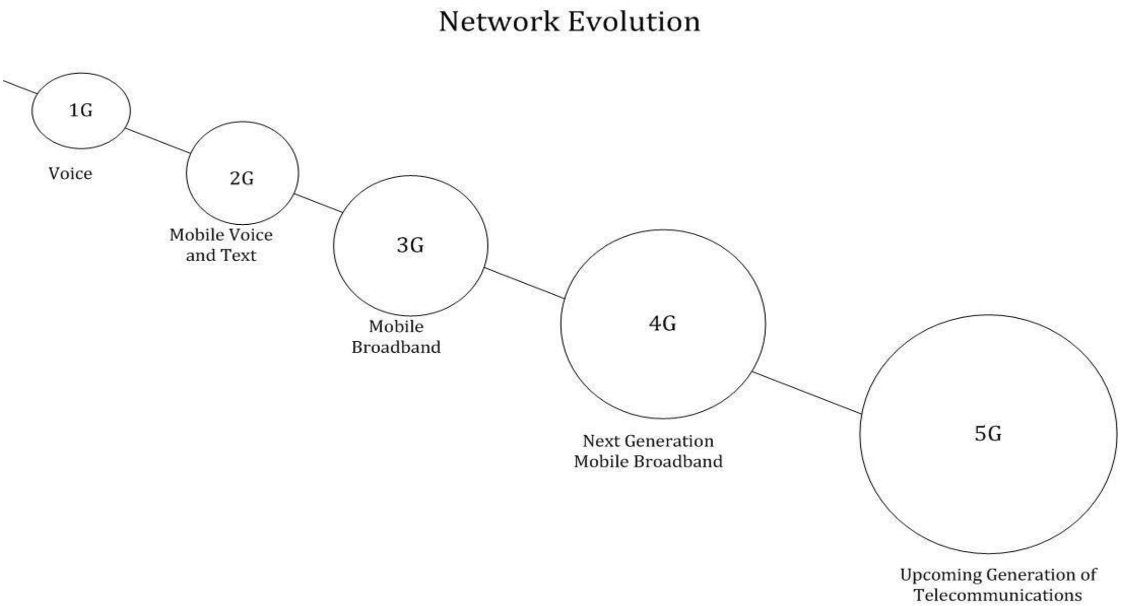



*Graphic 1.19: This graphic illustrates how an eNodeB can assign capacity to a UE on multiple cells simultaneously.*

# 2. FIFTH GENERATION SYSTEMS

## 2.1 Introduction

Once a decade a new generation of mobile telecommunication technology comes along: the analogue-based communications in 1980s, voice and text services in 1990s, mobile broadband followed at the turn of the century and Long Term Evolution systems were introduced at 2010. As the demand for mobile data and high speed services grows, the need of developing a new generation of telecommunication systems is now urgent. So it seems quite likely that 2020 will be the year that Fifth Generation technology will make its entrance in the global telecommunication market.




*Graphic 2.1: This graphic illustrates the network evolution from First to Fifth Generation of Networks.*

Every generation of telecommunications introduces new services or improves the already existing ones. Unlike predecessor systems, which focused on providing voice and data services, operators' research for 5G focuses on users and their needs. So Fifth Generation technology, except for increasing data speed and improving quality of service, is going to bring tremendous changes in the way that network is used till today. Due to the emergence of technological innovations such as Internet of Things Technologies (IoT) it is expected that by 2020 the number of devices connected to the network will be a thousand times bigger. User equipment will no longer be limited to smartphones or tablets but there will be smart devices such as wearables, home appliances, vehicles etc. These devices will extend their capabilities to various applications such as cloud gaming, proof of identity, sensors and supporting smart life in general.

## 2.2 Fifth Generation Use Cases

As 5th Generation Technologies are not developed or implemented yet the services they are going to support or provide and the way the network is going to be designed could only be assumed. Industries' and operators' research is still in an exploratory phase, however general requirements and visions for 5G are already under discussion and biggest focus is given on services, spectrum, capacity and core design. Fifth Generation of telecommunications, apart from network enhancements brings new services and use cases that are envisioned to be the driver for the technology. These services are expected to go beyond the basic mobile internet access and cover interactive work, smart applications, cloud storage, real time gaming, etc.

### 2.2.1 Mobile Broadband

Mobile Broadband is one of the key use cases which are driving the requirements for 5G. Biggest focus is given on providing access to broadband services everywhere. These services are mostly cloud applications or streaming services which require availability and always-on connectivity. In particular:

- *Cloud Storage* is driving the growth of uplink data rates as everything is uploaded and stored online, so higher data rates are required.

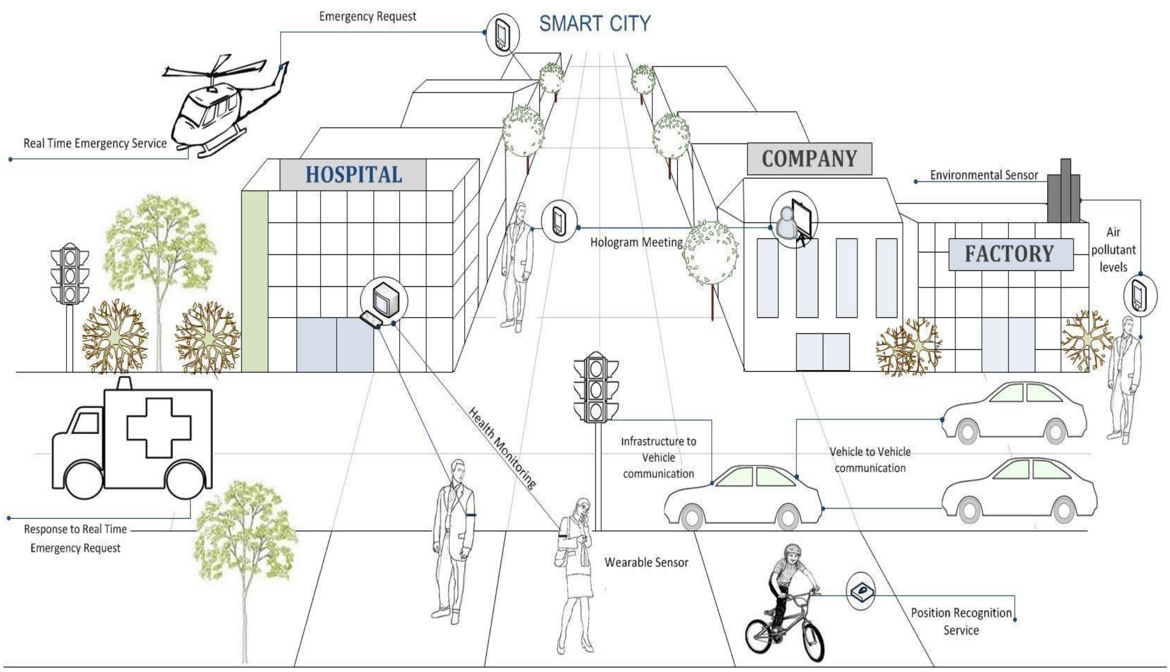
- *Cloud applications*, such as real-time gaming or streaming are use cases that are mostly related to entertainment which is very essential for the users. So higher mobile broadband capacity is required again.

- *Virtual Reality* is another demanding use case which is expected to be a common service among network users for entertainment and information retrieval. This type of application would require both high bandwidth and low latency beyond the capabilities of LTE, and therefore has the potential to be a key business model for 5G networks.

- *Broadband Access Everywhere* is a very challenging use case in terms of coverage and connectivity. The mobile connected society will need broadband access to be available everywhere so a minimum user data rate should be specified.

### 2.2.2 Smart City With Internet Of Things

A smart city is a place where digital technologies are used in order to provide more efficient services to its citizens. These services could reduce costs and energy consumption, and benefit sectors such as health care, resource use, transportation systems and public safety. The concept of smart city aims to provide a more responsive and interactive administration and a better way of living to its cohabitants. This could be achieved by setting up intelligent sensor networks which could also identify conditions for cost and energy-efficient maintenance of the city or home. Moreover it is expected that between 2020 and 2030 the number of the devices connected to the network will grow up to a thousand-fold due to the emergence of Internet of Things (also known as IoT) technologies. These technologies will play a significant role in user's experience improving his everyday life.




*Graphic 2.2: This graphic illustrates the use cases that 5th Generation Systems could provide among users in a "smart city".*

- *Automotive* is expected to be a very promising sector for users as it allows the real-time interaction between users and vehicles. Services such as real-time gaming, video streaming and generally entertainment for passengers should be supported everywhere even in high speeds, providing that way better user experience. So both high availability and mobility are required. Another use case that is also very interesting and demanding too is vehicle- to- vehicle communication (also known as V2V). It is expected that every vehicle will be connected to the network, providing location, traffic, road conditions, car accidents and other useful information to other vehicles, increasing in that way traffic safety. Vehicle-to-Infrastructure communication is also a use case that is expected to contribute in road traffic optimization. This could be achieved by the real-time interaction of traffic lights with other vehicles, providing information such as road traffic reducing in this way travel delays.

Finally, the next phase is expected to be remotely controlled or self-driven vehicles. This would be a very demanding use case as it requires fast communication between other self-driven vehicles. However, automotive use case adds a very large amount of connected equipment to the network so higher bandwidth capacity, very low latency and hyper-reliability are required.

- *Health* is another sector that could also benefit from mobile telecommunications. In particular, applications of remote health monitoring, treatment or medicine could be available to users. These services require the connection of devices such as wearable sensors which can provide parameters such as heart rate, blood pressure and temperature. As these applications could be life critical, the system must be capable of providing high availability and reliability.

- *Smart Wearables* such as clothing and wearable sensors will be widely used in the future. These sensors will be able to measure and occasionally transmit various health or environmental data such as blood pressure, body temperature, air pollutant levels etc. The implementation of this use case is challenging as it requires higher capacity, always-on connectivity and reliability.

- *Sensor Networks* is a very interesting use case as it will be implemented in many sectors such as vehicle communication, traffic lights management, environment monitoring, metering and other services which require ultra-reliable communications.

- *Logistics* is a sector which would also benefit from the mobile telecommunications. Tracking of inventory and packages could be enabled by sensor devices or location based information systems. The implementation of this use case requires wide coverage and reliable location information.

- *Smart Grid* concept was created in order to control the energy consumption. This is done by setting up wireless sensor networks which interconnect and gather information about behaviours of suppliers and users, improving this way efficiency, reliability and economics of the production.

- *Smart Antenna* is a concept that was created in order to provide better network efficiency to users. This will be done by using techniques such as signalling processing, track and scan which make it possible to alter the beam direction and to enable more direct communications limiting interference and increasing overall cell capacity.

- *Public Safety* is a use case that is needed to be considered in the design of fifth generation technology. Some of the safety needs that could be possibly included require the deployment of wireless sensors and tracking devices. These could be used for intrusion detection, bio and air pollution monitoring and emergency personnel tracking. Real time request and response emergency services that allow the direct communication between the user and the local public safety group (such as local police) could also be included. The implementation of this use case requires availability, zero latency and reliable location information.

## 2.3. Fifth Generation Design Principles

Although the need for deploying a new network system is not pressing for the time being, industries and universities have already started the research for the development of the upcoming generation of telecommunications. Fifth Generation networks face significant design challenges in order to meet all the service requirements that are described above. These requirements are already specified between operators and are mostly related to the enhancement of user experience, system performance, network operation and the services provided. To be more specific the requirements for each sector are:

### User Experience

One of the major challenges of 5th Generation Telecommunication Systems is the improvement of User Experience. 5G systems should be able to provide a consistent user experience over time with minimum latency, high data rates and seamless mobility.

- *Reduced Latency (<1ms)*

  The reduction of latency plays a significant role not only in the improvement of user experience but also in the support of tactile internet, augmented reality and other use cases. In particular reducing latency to 1ms could conduce to achieving high data rates and fast procedure response times but could also introduce new use cases such as remote control of machines, etc.

- *Higher User Mobility*

  By 2020, the year that is expected that 5G will be commercially provided, there will be a growing demand for mobile services in vehicles. Some of these services are going to be the natural evolution of the already existing ones such as navigation and entertainment, but there are also going to be completely new ones such as autonomous driving, vehicle-to-vehicle communications, traffic safety and other services. So there is a pressing need for higher user mobility regardless of the cell types in the environment.

- *Higher Data Rates (10Gbps)*

  It has been projected that in the next decade, services such as real-time gaming, augmented reality, remote controlled vehicles, cloud services and machine to machine communications will be common among users. In order to meet these service requirements Fifth Generation systems have to achieve a 10Gbps data rate.

- *Per User Data Rate (1Gbps)*

  It is estimated that by 2020, there will be a new class of data-rate-hungry services such as augmented reality, tactile internet, etc. In order to meet this requirement Fifth Generation Systems should provide a minimum per-user data rate of 1Gbps delivering in this way an enhanced user experience to the subscribers.

- *Low Battery Consumption*

  A key requirement for the deployment of 5G networks is the reduction of energy consumption in devices. The new use cases that will be brought by the time that 5G will be commercially available require an uninterrupted operation of devices. Such use cases could be remote health services, automotive, virtual reality etc. So an extended battery life for 5G devices is required; at least three days for a mobile phone and up to fifteen years for a sensor device.

- *Robustness and Resiliency*

In the near future, 5G networks should be able to support new use cases such as emergency services, machine type communications and all type of use cases that require always on connectivity and high reliability. It is also forecasted that Fifth Generation Systems are going to replace all the existing networks such as PSTN, and be the primary source of communication guaranteeing the ability to defend against security attacks especially in mission-critical applications such as public safety, smart grids and health monitoring. Therefore 5G systems need to ensure robustness and resiliency in order to provide better quality of services and more reliable applications.

### 2.3.2 System Performance

5G systems should provide a better network performing which would be able to support the connection of a greater number and variety of devices. A better system performance is needed to satisfy the variability of users and use cases.

- *Higher System Capacity (x1000)*

  As mentioned before, 5G systems will bring new use cases such as sensor networks, automotive and other services that require the connection of more devices. As a result the network has to expand in order to support billions of connected devices. This expansion is already specified to a thousand times higher wireless area capacity.

- *Massive Device Connectivity (x100)*

  It is estimated that by 2020 the number of the devices and appliances connected to the network will grow up to a hundred-fold. 5G systems should be capable of supporting that number of connections. The implementation of massive device connectivity systems is then required.

- *Spectrum Efficiency*

  A better spectral efficiency needs to be achieved to extend traffic capacity and support higher data rates. In order for operators to meet this requirement a new range of frequencies is expected to be used for mobile communications, providing additional system capacity and wider bandwidths.

### 2.3.3 Network Deployment

Fifth Generation Networks need to be deployed in a way that could benefit economically industries and users.

- *Cost Reduction for devices*

  A very challenging requirement that industries have to overcome is the cost reduction in the devices that connect to the network. The emergence of Internet of Things brings new use cases that require the connection of billions devices such as home appliances, sensors, wearables etc. In order to enable this vision industries need to reduce the cost of these devices and services, providing affordable solutions to all users.

- *Cost Efficiency*

  With an expected increase in the total network traffic, and the need to stay competitive, the next generation of mobile networks should provide a significant cost benefit over the current generation. The cost improvement should be at least as good as or possibly much better than what we experienced while going from 3G to 4G. [10]

- *Scalability*

  One of the most significant challenges that have to be met in 5G deployment is the system scalability. In particular, as it is already forecasted, the number of the connected devices is going to increase on the order of hundreds of times, primarily due to the emergence of Internet of Things Technologies. Therefore 5G networks should be able to scale up gracefully to handle this growth as well as the data transmissions from large number of devices. Moreover 5G networks should be able to support both high-data-rate and low-latency conventional services alongside M2M applications that require much lower bandwidths. Similarly, many devices in 5G networks will be stationary or nomadic and require no mobility support or only occasional mobility support. 5G network designs therefore should not assume mobility support for all devices and services but rather provide mobility on demand only to those devices and services that need it [10].

### 2.3.4 Enhanced Services

5G systems should provide services that will be enhanced with security, higher connectivity, availability and reliability.

- *Higher Connectivity and Availability*

  Fifth Generation of Networks is going to bring new use cases such as vehicle-to-vehicle communications, remote driving and health monitoring sensor networks. As these services can be critical always-on connectivity and availability are required.

- *Reliability*

  The 5G technology should allow high reliability rates of 99.999%, or higher for the use cases that demand it, in particular those under the ultra-high reliability and ultra-low latency use cases category. For use cases for which reliability may be less an issue, the reliability rate may be 99% or even lower depending on the associated trade-off needs.

- *Security*

  5G systems should be able to provide all the security functions needed in order to offer secure and protected services to users. Applications such as smart grids, telemedicine, industrial control, public safety and automotive, have strict security requirements to defend against intrusions and to ensure uninterrupted operations. This requirement is quite challenging though as operators have to keep the cost low in devices and services.

## 2.4 Fifth Generation Radio Access Network

One of the key drivers for the development of Fifth Generation telecommunication systems is the continuing growth in demand for greater capacity and higher data rates. It is expected that wireless data traffic will grow up to a thousand-fold until 2020 driven by the emergence of Internet of Things technologies enabling this way more subscribers, machines and objects to use the same network cell simultaneously. To meet this demand, operators need to focus on the Radio Access Network deployment. There are three ways to improve the radio access transmission; by adding more spectrum, by improving spectral efficiency, or adding more infrastructure. Key technology components include new standardization for the access technology that will be used, new waveforms and other potential technologies.

### 2.4.1 RAN Transmission

### 2.4.2 Spectrum

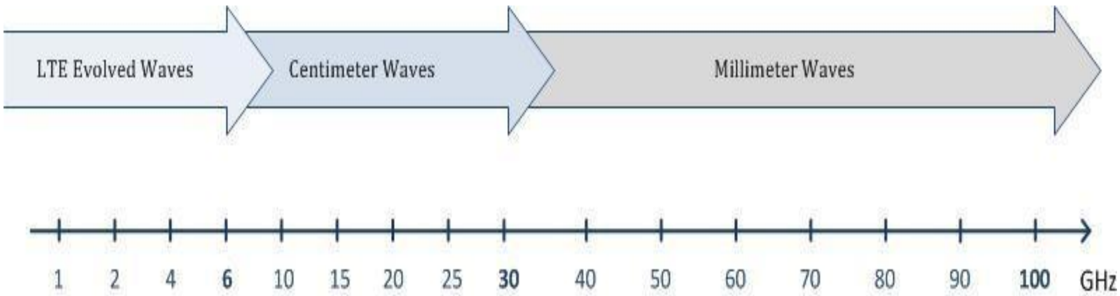
Estimates, which are based on existing technologies, confirmed that during the next decade there will be a thousand – fold increase in network capacity along with a hundred fold increase on connected devices. Such an increase would require the use of higher spectrum bands in order to achieve a greater spectral efficiency. There has already been a research on several techniques by which this demand could be met such as the use of higher frequencies and spectrum sharing. Both the application of advanced technology and the use of appropriate higher spectrum bands with larger channel bandwidth are anticipated from a data rate perspective to provide support for the large factor increase projected for 5G system traffic. From a capacity viewpoint, the use of higher spectrum bands may also support new architecture models promoting increased effectiveness of the systems.

### 2.4.3 New Frequency Bands

By the time that Fifth Generation Systems will be commercially available, they should be able to support higher data rates and greater system traffic. A good solution in order to achieve this requirement would be the extension in the range of frequencies used for mobile communication. Until now, all the mobile network systems have operated in frequencies bellow 6GHz. Recent research has shown that frequencies between 10GHz and 100GHz could provide higher capacity and data rates. However they could only serve as a complement, providing additional system capacity and wider transmission bandwidths in dense areas. This range could be split in two parts; the centimetre and the millimetre waves.

### 2.4.4 Centimetre waves and Millimetre waves

In order to achieve higher data rates and increase spectrum availability, operators focused on the utilization of higher frequencies. As illustrated in the graphic these frequencies range from 6 GHz to 100 GHz with centimeter frequencies ranging from 6 GHz to 30 GHz and millimeter frequencies from 30 GHz to 100 GHz. Centimetre waveforms are closer to the currently used frequencies as they behave similarly to traditional cellular bands. On the other hand millimetre waves, the wavelengths of which range from ten to one millimetre, provide ten times more bandwidth than the cellular bands used in predecessor technologies, supporting in this way higher data rates, as required for the next generation communications. However, they can only operate in dense networks as frequencies up to 30 GHz suffer from atmospheric attenuation. To be more specific, wireless conditions such as rainfalls, snowfalls and fogs have to be carefully considered due to path loss. This could be reduced though by using more advanced antenna configurations such as high directional antennas (centralized, distributed, regular array, etc.). [16]



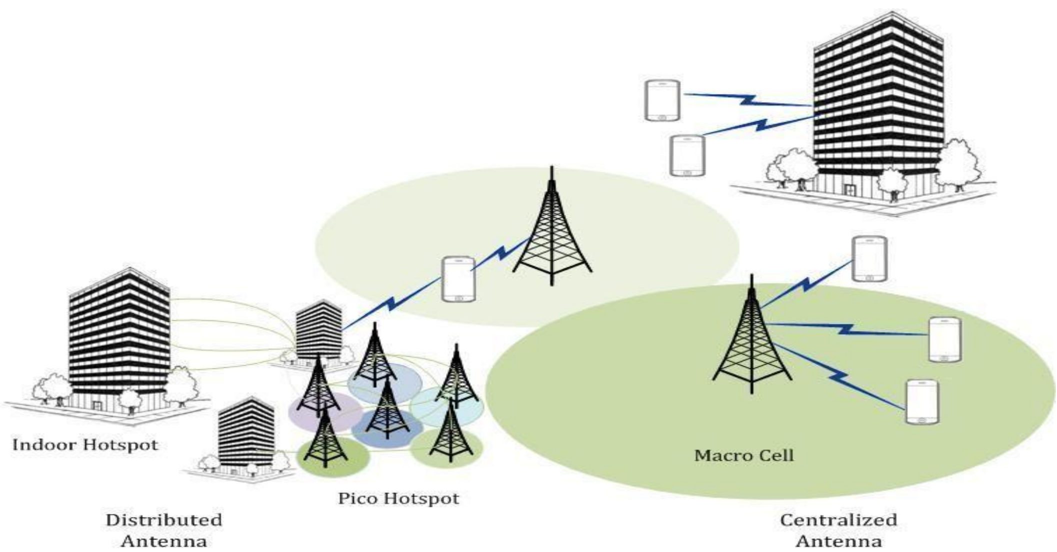

*Graphic 2.3: This graphic illustrates the frequency bands that are expected to operate in Fifth Generation Systems.*

### 2.4.5 High Frequency Communications

As mentioned before, the utilization of higher frequency bands is going to open up a huge amount of bandwidth and alleviate concerns about wireless traffic congestion. In addition, whereas 4G supports hundreds of megabits-per-second data rates, 5G is promising data rates in the gigabits-per-second range. It may not support those higher rates at all times in all places, but it will lower latency rates overall. However, there are some major challenges in the deployment of high frequency communications. Generally, as you move to higher frequencies, transmission range gets shorter—hundreds of meters rather than kilometres. And signals are unable to penetrate walls easily. Some hardware components, such as analogue-to-digital converters, might also be expensive. Another challenge is the atmospheric absorption loss due to weather effects such as rainfalls, fogs, H2O and O2. In order to overcome these challenges operators focused on developing new technologies that are better suited for transmission over relatively short ranges such as small cells and pico cells. High-frequency signals can also be reused across short distances by different cells in a network, meaning the available spectrum is used more efficiently. In addition, antenna size is inversely proportional to frequency size, so higher-frequency signals would require smaller antennas. You could pack more antennas into devices. That enables directional transmissions—you could actually steer the signal in a particular direction. This could overcome the loss of some of the signal transmission strength. More than one antenna operating in the same frequency range can also send multiple streams of data, increasing the data rate. [13]

### 2.4.6 Advanced MIMO

Massive MIMO is a promising technology that could improve spectrum efficiency and provide higher data rates. To be more specific this technology envisages a scenario where both receiver and transmitter have a large number of antenna elements within one antenna panel or location. Each antenna element can enable advanced beamforming. Massive MIMO base stations allocate antenna arrays at existing macro base stations, which can accurately concentrate transmitted energy to the mobile users. Small cells offload traffic from base stations by overlaying a layer of small cell access points, which actually decreases the average distance between transmitters and users. With the combination of massive MIMO and millimetre waves the very narrow beam could facilitate management of inter-cell interference. This could also enable the simultaneous use of a large number of connected users, lower propagation losses, higher data rates and better energy efficiency. It should be noted that Massive MIMO does not significantly increase the peak rate to a single user as it inherently needs multiple users to be served simultaneously to achieve the high spectral efficiency.




*Graphic 2.4: This graphic illustrates the Massive MIMO scenarios.*

### 2.4.7 Advanced Multi-Carrier Transmission

Every Generation of Telecommunication networks brings a new radio access technology that responds to current's system needs. Due to the significant growth in the number of devices, a candidate technology for 5G could be a multi-carrier transmission method such as OFDM, which is the one used in LTE systems. However, several other or modified multi-carrier methods are also under consideration for 5G networks as they could provide a more confined spectrum while being able to support spectrum sharing scenarios. Such techniques could be Filter-Bank Multi-Carrier (FBMC) transmission, Universal Filtered Multi-Carrier (UFMC) transmission and Generalized Frequency-Division Multiplexing (GFDM). The more confined spectrum is also assumed to make the above transmission schemes less reliant on-time synchronization to retain orthogonality between different transmissions. This may be valuable especially for UL transmission with requirements on very low access latency as the need for time-consuming synchronization procedures may be relaxed or even avoided. [10]

### 2.4.8 Non-Orthogonal Transmission

4G radio access is based on orthogonal transmission for both Downlink and Uplink. Orthogonal transmission avoids interference and leads to high system capacity. However, for rapid access of small payloads, the procedure to assign orthogonal resources to different users may require extensive signalling and lead to additional latency. Thus, support for non-orthogonal access, as a complement to orthogonal access, is being considered for 5G. [10]

### 2.4.9 Heterogeneous Networks

Fifth Generation of Telecommunications, apart from new use cases and technologies, brings unprecedented challenges for the operators. These challenges include the need for a massive increase in capacity and greater network flexibility in order to support various types of heterogeneous devices and applications. Therefore, industries are all moving toward heterogeneous networks due to their capability to support high speed connections, flexibility of resource management, and integration of distinct access technologies. In particular HetNet (also known as Heterogeneous Network) is a new technology which enables the network operation through a combination of different cell types and access technologies. By integrating a number of diverse technologies depending on the topology of the coverage area, operators can potentially provide a more consistent customer experience compared to what could be achieved with a homogenous network. Small cell deployments are a key feature of the HetNet approach as they allow considerable flexibility as to where they are positioned, however, the use of more cells brings implications in terms of power supply and backhaul, especially when they are located in remote areas. Wi-fi can also play a significant role in HetNets, both in terms of data offload and roaming. [17]

### 2.4.10 Full Duplex

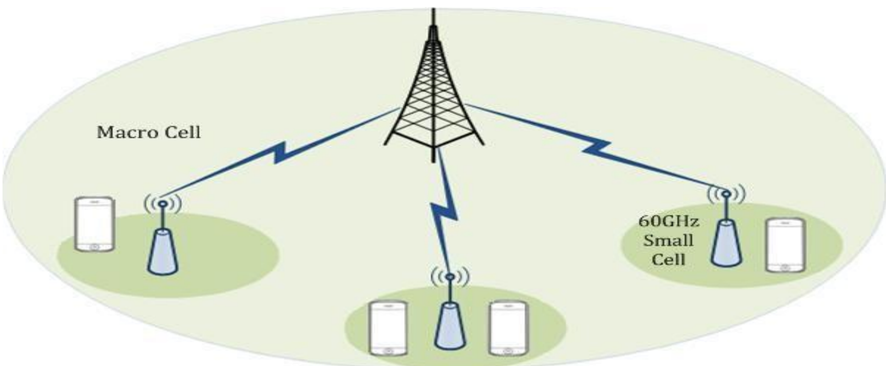
Full Duplex is a technique which enables simultaneous signalling transmission and reception at the same frequency. Moreover, it could also be used in order to support access on non-licenced spectrum. There are three basic scenarios for full duplex:

1. Point-to-Point Communications, such as D2D.
2. Point- to-Multi-Point communications, where a full duplex BS communicates with two half-duplex users with one DL and another UL.
3. Networking, where all or several cells will work with full duplex all time or sometime.

However there are few challenges in full duplex deployment including Self-Interference cancellation, inter-user interference avoidance and inter-cell interference coordination for networking. [13]

### 2.4.11 Advanced Small Cell

The need for higher data rates and more mobile data is expected to grow significantly in the next few years due to the emergence of IoT (Internet of Things). As mentioned before it is estimated that the number of wireless connected devices will exceed 50 billion in 2020 demanding this way more bandwidth. The growth in bandwidth demand is not only about smartphones and tablets but other computing gadgets too such as wearables, sensors, appliances, etc. As an increase in density (Gbps/km2) of the radio networks is foreseen, the operators need to examine new ways in order to find a solution that is going to improve coverage and to offload traffic from their current base station networks.

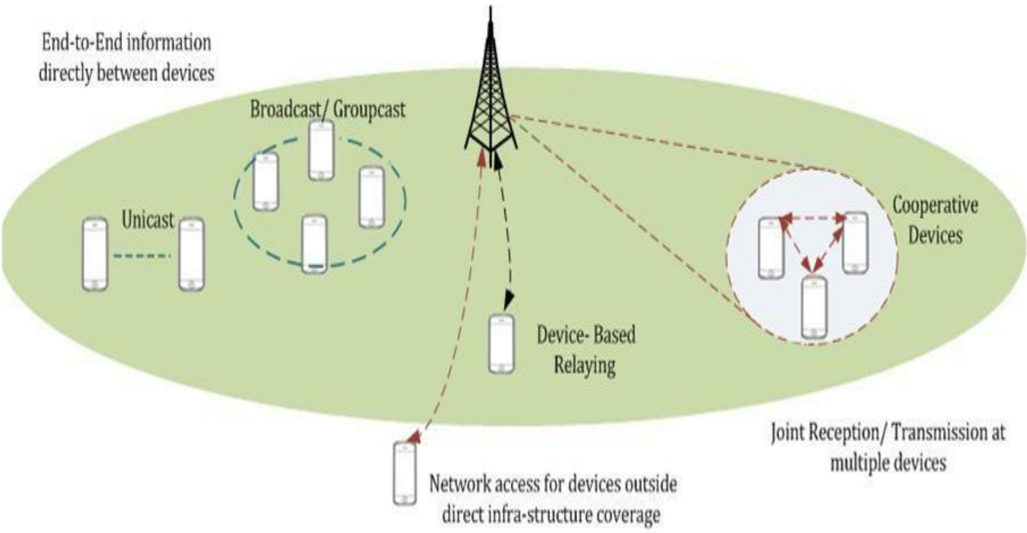



*Graphic 2.5: This graphic illustrates the small cell solution.*

Small cells could be a very good solution as they could be used in order to eliminate capacity problems and increase data speed, especially combined with technologies such as millimetre waves. In particular, small cells offload traffic from base stations by overlaying a layer of small cell access points, which actually decreases the average distance between transmitters and users, resulting in lower propagation losses and higher data rates and energy efficiency. [4] The deployment of small cells in realistic environments faces several technical challenges though, that need to be addressed at various network layers. Such challenges are the support and parallelization of different coverage sizes of cells that need to be achieved in the network architecture.

### 2.4.12 Advanced Device – To-Device Communication

Fifth generation technologies are expected to bring about abundance of new services and novelties. Except for communication between users, there is also going to be machine – to – machine and device – to – device communications. In particular direct D2D (Device- to- Device) could be considered as a more general tool that is a well-integrated part of the overall wireless-access solution. This includes peer-to-peer user-data communication directly between devices but also, for example, the use of mobile devices as relays to extend network coverage. Service providers could take advantage of D2D functionality as they could take some load off the network in areas such as companies, stadiums, buildings. In advanced D2D communication, a single radio resource can be reused among multiple groups which want to communicate with each other if the interference incurred between groups is tolerable. D2D could also be carried out in licenced or unlicensed spectrum under network control.

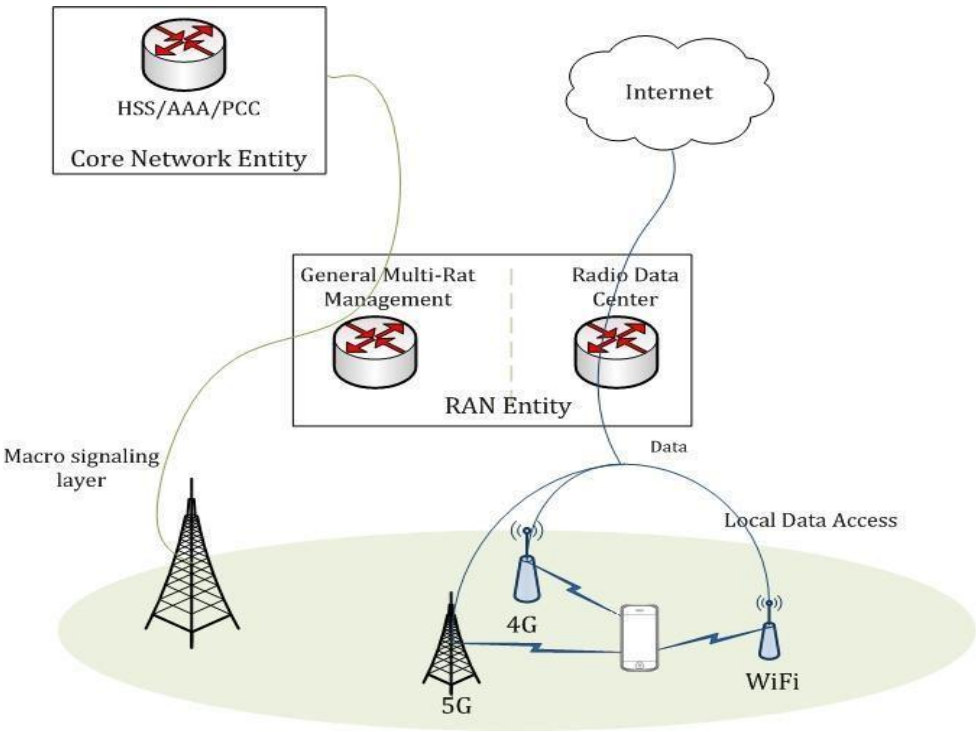



*Graphic 2.6: This graphic illustrates the wireless access solution*

Also in that case, an overlaid network, operating in the same or other spectrum, can be used to control/assist the D2D communication for enhanced efficiency and performance. However, D2D communication should also be possible in scenarios where there is no network coverage available, in which case the D2D link has to be possible to be established without network control/assistance. There are many challenges ahead for the implementation of D2D scenarios including efficient interference management scheme, signaling design, reference signals and transmit schemes design. [2],[5]

### 2.4.13 Multi - Rat Integration

It is forecasted that the demand for mobile data and higher data rates will grow significantly in the next few years. In order to meet this demand operators have already found efficient methods of cell deployment and spectrum management. In particular, the utilization of a larger amount of system bandwidth could lead to additional increase in capacity by allocating more frequency resources to each user in the system. Therefore 5G is likely to be a system integrating multi-radio technologies over various spectrum segments through a software-defined architecture. 5G radio access will be built upon new RAT(s), along with evolved existing wireless technologies such as LTE, HSPA, GSM and Wi-Fi to achieve a seamless integration, to bring a new user experience and enable the introduction of a host of new services.

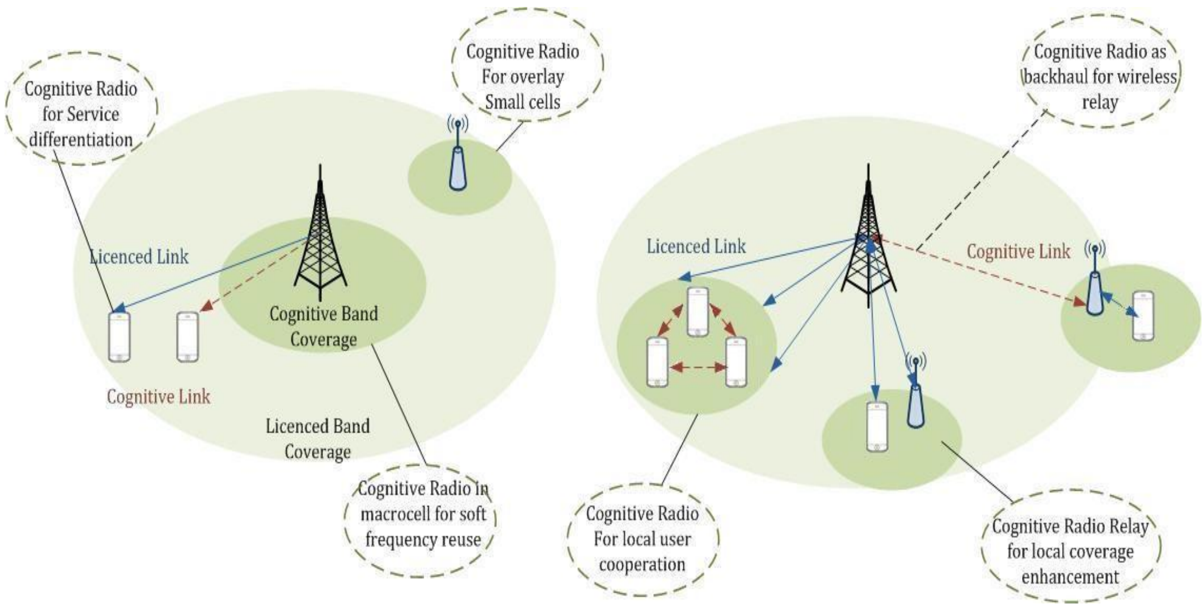



*Graphic 2.7: This graphic illustrates the Multi-RAT solution*

Multi-Rat and multi-spectrum deployment are some of the new techniques that are going to be deployed in order to achieve significant gains in radio links and better energy efficiency. An efficient mapping of devices and services to the right RAT needs to be investigated, where RAT selection may depend on the warning capacity, load, future traffic, QoE and energy providing status of these RAT(s) by introducing context awareness. [13]

### 2.4.14 Cognitive Radio

The ever-growing demand for ubiquitous mobile broadband combined with the multi-fold increase in network devices are some of the most significant factors that need to be considered in 5G deployment. Since, the mobile data demand will increase on the order of hundreds of times during the next decade, there is an urgent need to accommodate the exploding traffic. Moreover 5G systems, as described previously, should meet the requirements of massive connectivity, zero latency, huge capacity and high reliability. Therefore, network operators should focus on finding new techniques in order to benefit from currently underutilized spectral resources, increasing this way the overall capacity. However one of the most significant challenges in 5G deployment is that mobile data are becoming increasingly random and diverse. In particular, mobile traffic is distributed unevenly across space and time affecting in this way the traffic ratio per user. This traffic variation causes an obvious dilemma in the planning of network infrastructure: the capacity is either insufficient for peak traffic or overabundant and therefore cost-ineffective. Moreover the mobile data demand for 5G high-quality services is excessive and cannot be provided by the conventional cellular networks which are built on expensive licensed bands.

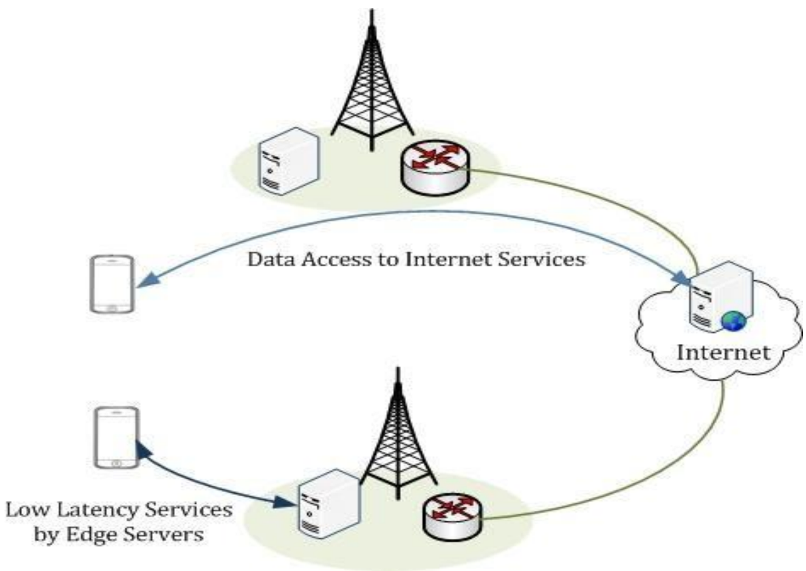



*Graphic 2.8: This graphic illustrates the architecture and usage scenarios of cognitive cellular networks.*

However it has been revealed that while the cellular bands are heavily capitalized and exploited, some frequency bands which are licensed to other incumbents are significantly underutilized. Cognitive Radio, with the capability to be aware of radio environments and flexibly adjust its transceiver parameters, has been proposed as an enabling technique to dynamically access the underutilized spectral resources. To be more specific, based on the demand for mobile cognitive radio could dynamically lease the underutilized frequency bands without causing harmful interference to the incumbents. This could benefit companies, as the cost of leasing the spectrum is much lower than the cost of purchasing a licensed band. Cognitive networks are cellular networks that employ cognitive radio to lease additional spectrum outside the licensed cellular bands and could be also used to mitigate the interference issues from space, frequency and time domains with a very dynamic manner. [14]

### 2.4.15 Latency

When considering latency requirements, no standard is available; however the industry has a fair goal on what it must deliver. The metrics considered are End-to-End latency of less than 5 milliseconds and Over-the-Air latency of less than 1 millisecond. For that to occur, a new way of thinking about how networks are structured must be introduced, and will likely prove to be a significant undertaking. Despite the inevitable developments in processor speeds and network latency in the forthcoming years, the speeds at which signals can travel through the air are finite. Subsequently services requiring a delay time of less than 1 millisecond must introduce novel topologies including application servers placed closer to the network edge.




*Graphic 2.9: This graphic illustrates the flat network architecture.*

Industry estimates suggest that this distance may be less than 1 kilometer, which means that any service requiring such a low latency will have to be served using content located very close to the customer, possibly stored or processed at the base station, radio network controller, or similar. Another factor that should be taken into account is the transmission method followed. Currently, 4G radio access is based on orthogonal transmission for both downlink and uplink. Orthogonal transmission avoids interference and leads to high system capacity. However, for rapid access of small payloads, the procedure to assign orthogonal resources to different users may require extensive signaling and lead to additional latency. Thus, support for non-orthogonal access, without any switching point restrictions so that any slot can be either uplink or downlink and in addition, serve a direct device-to-device link or provide self-backhauling, is being considered as a complement to orthogonal access.

#### 2.4.16 Standardization

Unlike predecessor technologies, which focused on providing universal service facilities to users, Fifth Generation systems evolve from single-purpose wireless systems (mobile broadband) to a broader range of use cases and requirements. It is also necessary to consider how the various technologies will coexist and share access to spectrum when operating on a licence-exempt basis and to address this in standards. For that reason, there should be many different co-existent standardization methods, rather than one standard that fits all of these use cases and scenarios. In order to achieve the required target performance 5G should utilize a wider range of frequencies. Although most 5G requirements will be addressed to LTE enhanced systems, there is an urgent need for the development of a new radio access technology that will operate in bands which are not included in Fourth Generation technologies. There are many challenges ahead for the standardization of 5G systems which are determined by the complexity of the new usage scenarios. As mentioned before, these new usage scenarios will not only be supported by smartphones or tablets but machines, devices, appliances, etc. Network operators need to find ways to develop standardization methods which will allow 5G systems to operate in an ever-growing number of heterogeneous network devices that can communicate with each other. At the same time, the network standards they will develop must be capable of minimizing the complexity while keeping the cost of interfaces low.

#### 2.4.17 Advanced Modulation and Coding

The deployment of 5G systems requires several breakthroughs mostly in radio access technologies. To be more specific, advanced modulation and coding algorithms are essential for the achievement of higher spectral efficiency, especially when combined with multiple access and advanced waveform technologies. The existing telecommunication systems, such as 3G and 4G, use Turbo coding and Quadrature Amplitude Modulation (QAM) techniques. However, 5G technologies require more advanced modulation and coding methods like Frequency and Quadrature Amplitude Modulation (FQAM) which can provide a significant improvement in the cell edge performance. Moreover, when combined with higher density deployments and multi-BS cooperation this method could deliver higher Quality of Experience. With FQAM, the statistical distribution of ICI is likely to be non-Gaussian, especially for cell-edge users. As a result, the transmission rates for the cell-edge users can be significantly improved.

### 2.4.18 Sparsity exploitation

Sparsity exploitation design mainly relied on Shannon/Nyquist sampling theory. The work of Harry Nyquist (1928) and proof by Claude Shannon (1949) was the basis upon which signal processing in telecommunications was applied, as it involves few samples and reconstructs the signal with high fidelity. However, for 5G networks with the peak data rate as high as 100 Gbps, the corresponding Nyquist rate is too high that makes the hardware/processing cost too expensive or even unaffordable in practice. In addition, in 5G networks with the connection density up to 1 million connections/km2, we may face the situation of not being able to collect enough measurements to meet the Nyquist rate. Fortunately, around 2004, Emmanuel Candès, Terence Tao and David Donoho proved that given knowledge about a signal's sparsity, the signal may be reconstructed with even fewer samples than the sampling theorem requires, ultimately introducing compressive sensing technique. At the core of compressive sensing (CS) lays the discovery, that salient information of a signal can be preserved in a relatively small number of linear projections, hence it is possible to reconstruct a sparse signal exactly from an underdetermined linear system of equations. This can be done in a computationally efficient manner via convex programming. As more and more experimental evidence suggests that many kinds of signals in wireless applications are sparse or compressible in some transform domain, sparsity exploitation design under the framework of CS has the potential to revolutionize certain traditional design concepts in 5G wireless communications and, furthermore, to play significant role in the fields like wireless channel estimation, signal detection, data gathering, network monitoring, and so on. [18], [19], [20]

### 2.4.19 Information Centric Networking

The information and communication challenges being put over the existing networking fabric of today’s Internet by the myriad of online services and mobile applications have manifested the technical inadequacies and complexities of its base architecture. Therefore there has been an urgent need for the deployment of new architectures the design of which should be based on mobility, security and content caching criteria. Information Centric

Networking (ICN) concept, is the leading architecture that can meet such design criteria. To be more specific, ICN is a network that separates content from terminal location and provides named content and name-based content routing, and the support of enhanced mechanisms that changes the way security and mobility is realized. In particular, Information Centric Networking focuses on the support of new communication models that focus on the distribution of information rather than the communication of data packets between endpoints. ICN enhances the role of the networking layer replacing its task from simply providing a pair-wise packet-delivery channel between communicating hosts to delivering named-information to an endpoint that expresses an interest in it without explicit direction as to where that content is stored. Everything in an ICN is called information that can be interconnected and labelled by name. By naming information at the network layer, ICN facilitates the deployment of in-network caching (and storage in general), simplifies multicast and enables a security model where content itself is secured rather than the channel over which the content is conveyed. Expressions of interest, implemented via a request-response mechanism, support mobility and congestion control/avoidance mechanisms implicitly so the need for an overlay to support mobility may be avoided. The strategy mechanism provides a flexible mechanism to realize intelligent, context-aware control of content storage and delivery. [11]

### 2.4.20 Energy Efficiency

Unlike previous technologies, higher energy efficiency with 5G will be achieved through infrastructure-oriented arrangements. The prospect of a different mobile architecture, the ultra-dense networks, which allows the separation of the network’s control plane and data plane, changes the way the radio access networks will be deployed. Instead of few macro, energy costly, cells, a plethora of smaller cells, lower in energy cost, will be introduced, that due to the overall number of units activated, would seemingly increase the overall energy consumption. However, and there lies the distinguishing difference, such modifications in the system architecture, induce scope for beneficial adjustments to take place. In particular, the idea of energy consumption depending on current traffic conditions is induced. According to which, smaller cell layers, would be partially turned off, during low traffic situations, and turned on again when needed, while the anchor is left intact. That could be, for instance, the low hot spot requirements of a business district at night. Such dormancy periods could result to significant energy savings. Furthermore, for the implementation of this idea, appropriate air interface design must be adopted. Dynamic TDD appears to be convenient from this point of view, as it is an interface that does not require constant transmissions on all carriers, hence allows transmitters and receivers to deactivate during those zero traffic situations.

### 2.4.21 Moving Networks

A challenging requirement that has to be met in Fifth Generation communications deployment is the support of network connectivity even in moving devices. 5G systems need to ensure that they will operate in high speed scenarios which include V2V (Vehicle – to – Vehicle) or V2I (Vehicle-to – Infrastructure) communications and network mobility will extend in very high speeds in order to support more use cases and services. Therefore, the concept of a cell becomes blurred in favour of a more general concept of connectivity, where the network follows the movement of the user rather than the opposite. The management of nomadic and moving cells presents a number of issues – such as activation/deactivation of cells, trajectory prediction and handover optimization – because users will rapidly traverse multiple cells in a very short time. Additionally, the Doppler shift caused by very high relative movement between transmitter and receiver can challenge the use of millimetre waves. [10]

### 2.4.22 System Integration

Ultra-dense networks of the future will be designed to provide connectivity to devices using a variety of different services. According to current traffic situation and the requirements each application premises, appropriate adjustments need to be programmed, for the effectual operation of the network system. Hence, the flexible adaptation of the small cells to the demands of each node, as well as the integration of the different frequency layers inside the system is necessary. Normally, in a heterogeneous environment, consisting of wide area layers, micro cellular layers and indoor capacity layer for example, one device would connect to one layer at the time, according to coverage availability or the needs of the service used. However, in the case of constant latency need, such connectivity would be insufficient. Instead, an integrated system, in which the wide area layer would act as coordination layer, scheduling smaller cells to connect with the device, could optimize performance. Such structure, of a fixed anchor and the succession of smaller cell layers, improves performance in terms of reliability and mobility.

## 2.5 Fifth Generation Core Network

Since research in Fifth Generation Networks is still in its early stages, the system design can only be assumed. However, basic concepts and use cases, mainly concerning radio access technologies and requirements, are already being defined and analysed. In order to meet all those requirements and support user expectations, the system design should move away from the previous telecommunication systems technologies which are optimized for mobile broadband only. Besides, there can't be any substantial change in radio access technologies without the appropriate changes in core network. Core network evolution will revolve around how to enable more flexibility for the creation of new services and new applications. Moreover, in order to support multi-RAT scenarios, 5G core networks should be equipped so that they can seamlessly integrate with predecessor core networks, such as 3G and 4G. Cloud computing will become the foundation of core networks, and will open the network to allow the leveraging of innovations as they are developed.

### 2.5.1 Core Design Principles

As 5G vision and requirements have already been explicit, there is an urgent need to define the network design principles, which will be able to support all the use cases scenarios. 5G core network needs to support low latency, large capacity and high rate of all kinds of services and offer a more efficient way to realize differential service requirements on-demand orchestration. Therefore, network functions in core network should be based on Evolved Packet Core in order to offer efficient and flexible network control and forwarding function. [7] These principles include:

### 2.5.2 Software Defined Networking (SDN)

In the SDN architecture, the control plane and the data plane are decoupled, then the extracted control functions can be integrated into a centralized control plane, and the underlying network infrastructure is abstracted from applications and network services. SDN adoption can improve network manageability, scalability, programmability, agility and rapid innovation ability.

### 2.5.3 Network Function Virtualization (NFV)

Network Function Virtualization is a fundamental technology to 5G design as it provides network flexibility by separating dedicated hardware from software. NFV implements network functions in software that can run on standard hardware, located in the network as required, without the installation of new equipment. This could lead to power and cost consumption. According to NFV technique, the control plane can be reconstructed by softwarized network function component. Therefore, reconstructed control function can be deployed in every place of the common hardware-based platform. The introduction and development of NFV and SDN in mobile network will promote the innovation of 5G network architecture, SDN and NFV are mutually beneficial but not dependent on each other. NFV is highly complementary to SDN, but can be implemented without an SDN being required and vice-versa. Approaches relying on the separation of the control and data forwarding planes as proposed by SDN can enhance performance, simplify compatibility with existing deployments, and facilitate operation and maintenance procedures. NFV is able to support SDN by providing the infrastructure upon which the SDN software can be run. Furthermore, NFV aligns closely with the SDN objectives to use standard hardware. The two concepts and solutions can be combined and potentially greater value accrued.

### 2.5.4 Separation of Control and Access plane

5G new network architecture includes access, control and forwarding plane. Control plane and forwarding plane of existing functions (like S-GW and P-GW) should be further separated. That contributes to the centralization of control plane of network functions, the distribution of data plane functions to localize data traffic and more flexible steering of data traffic according to operator policies. Control plane is primarily responsible for generating global control strategy. Access and forwarding planes are responsible for the implementation of strategy. [21] To be more specific:

- ♦ *Access Plane*: In order to accommodate various service requirements and use cases, the access plane needs to enhance the coordination among different base stations, and improve the capability of flexible wireless resource scheduling and sharing. Through the comprehensive utilization of distributed and centralized networking mode, inter-cell radio interference can be reduced effectively, and mobility management becomes much easier. With perception to users and services, the access plane defines network topology and protocol stack on-demand, to provide guaranteed services performance. The access plane has ability to support new networking technologies such as wireless mesh, dynamic self-organizing network and unified multi RAT convergence.
- ♦ *Control plane*: The function of control plane includes control logic, on-demand orchestration and exposure of network capabilities. In the aspect of control logic, based on separation and reconstruction of network control function, it will create access control, mobility management, connection management and other functional elements independently. Different functional elements can

be assembled flexibly, to meet various scenarios and service requirements. With the help of virtualized platform, control plane can do agile network resource orchestration. By the network slicing technology, control plane has ability to construct special and isolated logical network for different services that will promote the flexibility and elasticity of whole network. Control plane will have an exposure layer of network capabilities. Through the Open APIs and ignoring technology detail of lower layers, network capabilities are abstracted and open to the third party friendly, including infrastructure, pipeline capacity and value-added services, etc.

♦ *Forwarding plane*: On the forwarding plane, gateway's control function will be separated completely, and gateway's deployment will be distributed and localized. Data forwarding is scheduled by the control plane. Based on flexible gateway anchor, E2E various requirements of extreme broadband, ultra-low latency, and ultra-high reliability and load balance can be achieved. The efficiency of packet data transmission and user experience also can be promoted.

### 2.5.5 Multi-Rat Interworking

5G architecture should support connectivity and service continuity regardless of the Radio Access Technologies in environments where different types of cells and relay nodes are mixed. [21] Moreover it should guarantee seamless mobility in spite of the bandwidth deficiency in a wireless access.

- Intelligent access control and management: according to current network state, wireless environment, UE capability, and combining the technology of smart service sensing to map each service to the most appropriate access technology, to improve the user experience and network efficiency.
- Multi-RAT wireless resource management: according to service types, network loads, interference levels etc., to achieve joint management and optimization of the multiple networks radio resources, which realizes the interference coordination among multiple RATs, and it achieves resource complete sharing and allocation.
- Protocol and signal optimization: enhance the interfaces between access network nodes, construct more flexible network interface relationships, and support the dynamic network function distribution. Multiple modes and multiple connections technology: UE may access to multiple nodes of different RAT at the same time, which allows transmit parallel flows.

# 3. MACHINE-TO-MACHINE TO COMMUNICATIONS

## 3.1 Introduction

It is estimated that the number of wireless device connections will reach 50 billion by 2020. This will lead to an unprecedented increase in the data traffic involving the existing types of communications and new ones such as machine type communications. Such projections entice the industry to explore and tap a wide range of opportunities that the M2M (Machine-to-Machine) communication concept offers, enabling novel business cases, enhanced workflow efficiency and improved quality of life. The abbreviation M2M denotes various concepts, namely: Man-to-Machine, Machine-to-Man (meaning communication between a human operated device and a machine), Machine-to-Mobile and Mobile-to-Machine. However, the most common meaning is Machine-to-Machine, which will be described in this chapter. M2M refers to solutions allowing communication between sensors (which record temperature, pressure and humidity, among other things), assets (such as cars, smart meters, vending machines and consumer electronics) and information systems without, or with only limited, human intervention. Integration of sensors and information systems also allows automatic execution of processes based on data collection, data analysis and remote interaction. [22][23]

## 3.2 Market Motivation

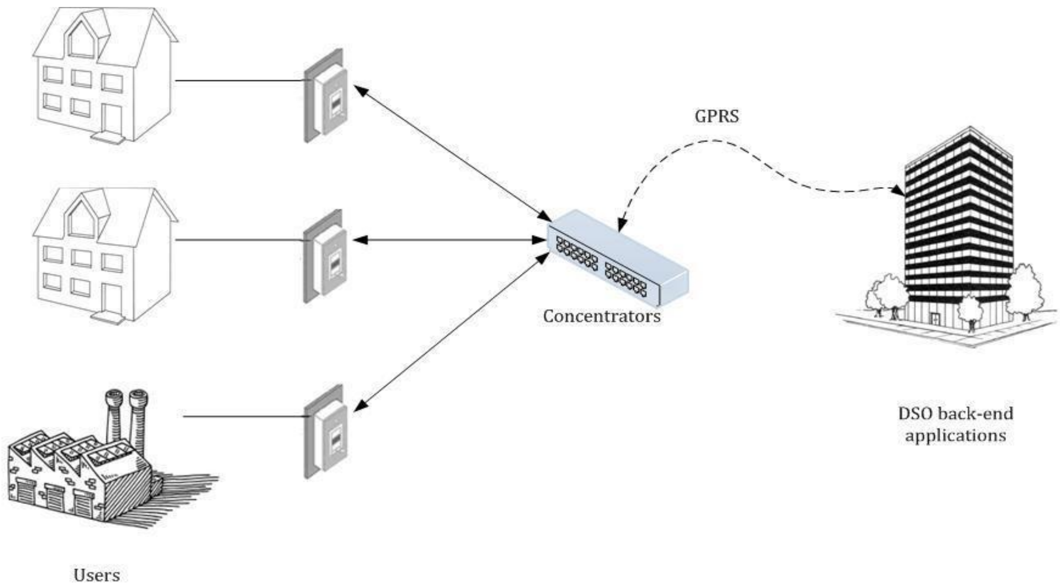
The use of M2M is shifting the market from one, where users have a relatively limited number of devices to tens of, or in the case of business users to hundreds of devices. As a result there will be a tremendous growth in the market for connected devices. M2M industry is comprised of a plethora of opportunities and use cases such as smart city, health, automotive, security etc. Currently, successful implementations of Machine-to-Machine communications exist for cell towers, vending machines, security systems and more. These implementations are yielding significant results. Although the use cases are quite different, all these areas have in common that they require not only connected devices able to communicate over a variety of network connections, but these devices also require remote configuration and control capabilities. Moreover, the millions of connected devices that make up M2M systems and are part of the Internet of Things need to be switched on, configured, provisioned for services, maintained, updated with software, possibly switched off and on again, recovered from error conditions, monitored, queried for data, repaired, their applications managed and finally the devices taken off their network connections at the end of their lifetime. And ideally, all this happens remotely. Today the picture of the M2M market is one of a highly fragmented landscape with margins that could be much better. It is also obvious that the lack of industry standards in certain areas is hindering the growth of the M2M market. However, if the market aims to introduce millions of M2M devices, there will be a need for stakeholders to assess the costs and benefits of existing business models and finally there may also be a need to develop new business models. [24]

### 3.3 Use Cases

Machine-to-Machine communications are considered as an integrated part of Internet of Things (IoT) and their deployment could bring several benefits to industry and business. The introduction of the Internet, wireless devices and cloud computing have greatly expanded the possible uses of M2M technologies and as a result a wider range of applications and use cases is provided. These use cases include automated city, healthcare, smart metering, automotive and other scenarios which will be described further.

#### 3.3.1 Smart Telemetry

Smart telemetry applications, such as smart grid and metering are being deployed by the energy sector in order to achieve better usage efficiency and higher reliability. Utility applications typically interact with smart meters deployed at customer premises and a variety of other sensors or M2M devices that allow for the provision of a grid-wide monitoring infrastructure, the collection of consumption information and the sending of information about tariffs of incentives. Smart meters and smart grid will be connected via a variety of wireless and wired technologies such as PLC , cellular access, etc. These provide network connectivity between smart meters, sensors or M2M devices and the utility's back-end applications, databases and management systems.




*Graphic 3.1: This graphic illustrates a smart metering deployment scenario*

According to the graphic, a combined connectivity model is emerging where PLC is used from the electricity meter to the data concentrators located at the distribution service operator (DSO) network, and then cellular connectivity is used from the concentrators to utilize back-end applications. [25]

- SMART METERING

An interest playground where citizen identities and industrial infrastructure are quickly converging is that of smart metering. Smart metering is a concept which was created in order to provide information to customers about their energy consumption and allow timely adaptation in their demands. To be more specific these objects are in charge for measuring the energy consumption of the citizens and, in some cases for measuring the energy production. Therefore, the establishment of smart meters could contribute to the achievement of better energy efficiency and to the mitigation of greenhouse-gas emissions. Smart meters are utility meters (gas, water, electricity, heat) which eliminate the need for estimated bills and human meter readings as they provide customers, energy distributors, and suppliers with accurate and timely information on the amount of the consumable utility being used. The meter can transmit real time information on energy use, which the consumer can access in their own home and which the energy company can use to manage the network. This is achieved by installing concentrators which collect usage data and distribute control data to and from consumers in a limited geographical area and then transmitting it back to the utility's data centre. However, there are several requirements that have to be met in order to support such services. The main challenge is to provide a framework that will be able to manage the identities of different objects and ensure the protection of citizen's information and data.

- SMART GRID

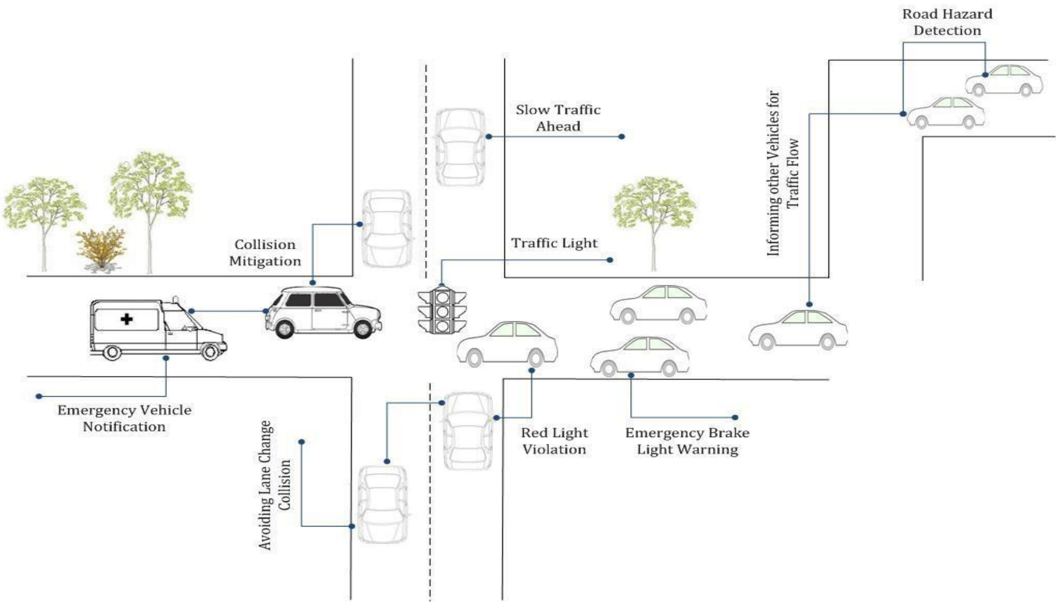
Smart metering is one of the first steps in a smart grid. The development of smart grid is expected to implement a new concept of transmission network which is able to efficiently route the energy which is produced from both concentrators and distributed plants to the final user with high security and quality. In particular, a Smart Grid is an electricity network that can efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety. Therefore, smart grid is expected to be the implementation of the concept where energy packets are managed similarly to the data packets, in order to eliminate energy wasting. Though elements of smartness also exist in many parts of existing grids, the difference between a today's grid and a smart grid of the future is mainly the grid's capability to handle more complexity than today in an efficient and effective way.

### 3.3.2 Automotive

Automotive is expected to be a very promising sector for users and companies as it allows real time interaction between users and vehicles. Automobiles have been the focus of many M2M initiatives to improve its use and usefulness to users and owners, or as a way to realise a public goal. Automotive applications cover a wide range of use cases that include V2V (Vehicle-to-Vehicle), V2I (Vehicle-to-Infrastructure) communications, etc. These use cases will be analysed further.

- VEHICLE- TO-VEHICLE COMMUNICATIONS

Vehicle–to–Vehicle communication is part of the growing trend towards pervasive computing, a concept known as the Internet of Things (IoT) and is considered to be the first step towards the development of intelligent transportation systems. In particular, V2V Communication concept envisages a scenario where, for the first time, the roadway and the vehicle would actually be connected. According to this scenario, vehicles will be able to collect and make sense of data from a huge array of sources. This data will include information about traffic conditions, warnings, potential collisions and other useful info for drivers. The main goal of V2V communications is to prevent accidents by allowing vehicles in transit to exchange this data in order to make highway driving efficient, safe, and predictable. Moreover, these communications could contribute to the improvement of traffic management and optimization.

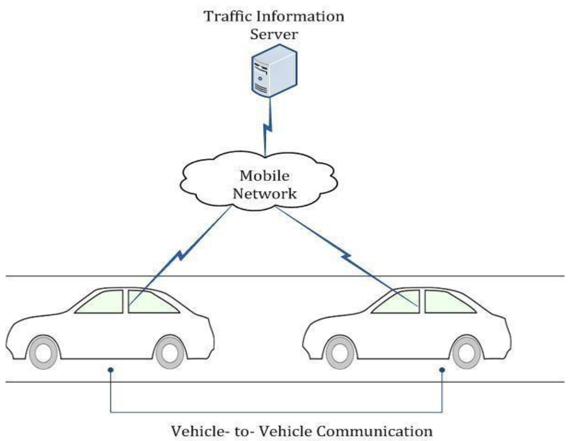



*Graphic 3.2: This graphic illustrates the vehicle-to-vehicle communication scenario.*

Therefore, the communication system must provide increased data throughput, high levels of reliability such as high message reception probabilities and zero latency in order to offer the driver sufficient time to take action. Although Third Generation systems (3G) provide low latency and high capacity, they lack in effective ways to support V2V local broadcasts, which are essential to most hard safety applications. On the contrary Fourth Generation systems provide significantly lower communication delay, higher capacity, and enhanced broadcasting capabilities compared with 3G cellular networks supporting in this way time-critical vehicle application. It is clear that 5G will need Gbits backhaul and, so far, only fibre optics and wireless can provide these services. In this case, Fifth Generation technology should adapt itself to a much optimized network in terms of coverage, latency and mobility. Finally, as reliable V2V services shall be provided in a variety of cases, including the out-of coverage scenario, where one or both devices in communication cannot get network connectivity, network flexibility and the system ability to integrate in multi-RAT environments is required. Thus Vehicle–to–Vehicle communication can be achieved with 5G technology.

- VEHICLE- TO-INFRASTRUCTURE COMMUNICATIONS

Vehicle-to-Infrastructure (also known as V2I) or Vehicle-to-Everything (V2X) Communication is a technology which allows vehicles to communicate with infrastructure elements. Such elements could be traffic lights, road signs or other connected to network appliances which enable exchange of critical safety and operational data between vehicles and roadway infrastructure. The basic concept was that sensors on the vehicle would communicate with sensors on the roadway or other elements in order to enable “hands-off” and “feet-off” but not “mind-off” driving.




*Graphic 3.3: This graphic illustrates the vehicle-to-infrastructure communication scenario.*

It's still up to the driver, obviously, to drive the car. However, V2I is an enabling technology that one day will make even self-driving cars much safer by helping them see and react to invisible danger. V2I communication holds great potential for intelligent transport system management as it is designed in order to increase safety, efficiency and convenience of the transportation system. To be more specific, V2I systems include safety implications as they give drivers warnings about potential hazards like a potential of a collision ahead and allow them to avoid accidents, or even automatically respond to changing driving conditions faster than typical human reaction times. Warnings about traffic blockages ahead also allow early re-routing to avoid traffic congestion. In order to ensure reliability and efficiency, M2M devices need to interface with sensors on the vehicles that measure velocity, external impacts but also can interface with in-vehicle components such as braking systems. Moreover, they should be able to provide position detection and tracking information services. Finally, in order to ensure safety and traffic optimization, vehicles should be able to upload and download traffic and safety information to a traffic information server. [26]

- CONNECTED NAVIGATION

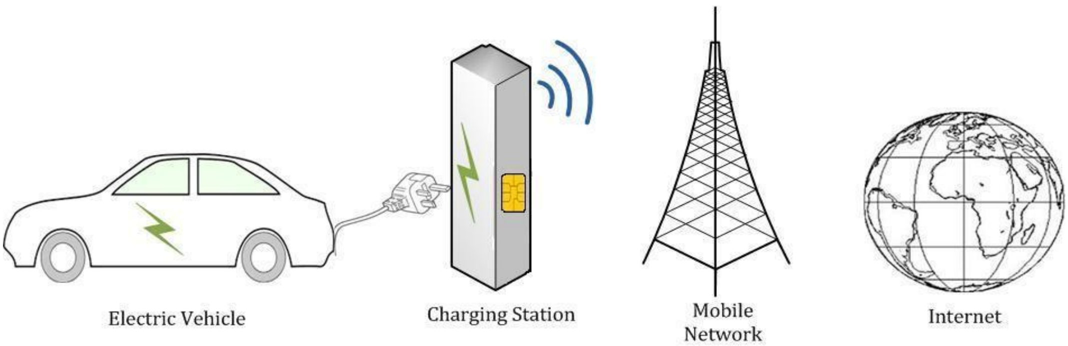
An automotive application which can provide useful information to drivers is connected navigation. The basic concept is to provide up-to-date traffic reports to users by radio broadcast standards or via cellular networks for mobile communications. The purpose of traffic reports is to inform the drivers about the traffic conditions that are relevant to the area where the users are driving, or about a location on their intended route so that they can easily alter their route to avoid traffic congestion if necessary. Traffic reports can be delivered to the driver verbally or visually. Where traffic information is given verbally, this could be done by using off-board text-to-speech conversion software. Where traffic reports are sent as data to the car, this could be done by using mobile phone networks via navigation providers. A navigation provider, offering a navigation service which is augmented by real-time traffic congestion data, could extend his product by including intelligent speed or lane advice to maximize traffic flow, or by adding a warning for local hazards such as road-works, or sudden traffic jam build up. The input data for their traffic application server would be obtained from either the regular channels (predictable, planned road works), or by further processing the received floating car data.

- REMOTE DIAGNOSTICS

Remote diagnostics is an automotive application which can be applied in several cases. Firstly, it could offer maintenance minders to users, for example warn them about when the vehicle reaches a certain mileage in order to inform them that the vehicle is due for service. Likewise, it could offer information about the vehicle's general condition, using inbuilt diagnostic reporting functions and transmit those reports to the owner. Finally, another case where remote diagnostics could be safety critical is in emergency cases. In particular, when a breakdown call is initiated manually by the driver, the system sends position data and vehicle status information to the roadside assistance service in order to ensure driver's safety. [26]

- Electric Vehicle Charging

One often-envisioned scenario for automotive M2M communications is electric vehicle charging. As plug-in hybrid electric vehicles and battery electric vehicle ownership is expanding, there is a growing need for widely distributed publicly accessible charging stations, some of which support faster charging at higher voltages and currents than are available from residential EVSEs. Many charging stations are on-street facilities provided by electric utility companies or located at retail shopping centres and operated by many private companies. These charging stations provide one or a range of heavy duty or special connectors that conform to the variety of electric charging connector standards. There are several applications of electric vehicle charging scenario, including the detection of nearest charging stations, the management of the charging process and parameters in the car and the generation of relevant records for billing purposes. The charging stations should be able to detect the presence of a vehicle and to establish the relevant communication links with the appropriate stakeholders (e.g. Consumer, Distribution Network Operator).

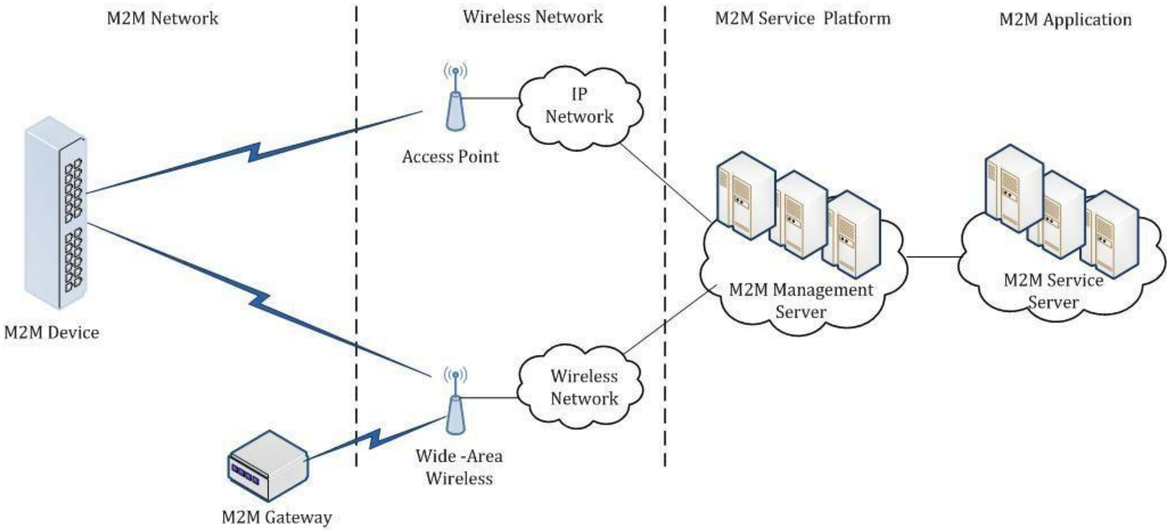



*Graphic 3.4: This graphic illustrates the electric vehicle charging scenario.*

According to graphic 3.4, when a vehicle reaches a charging station, the driver presents his credentials (e.g. user ID and password), probably by swiping his SIM card and then the charging station verifies his personal details through mobile network. Then the charging station determines the current state of charge of the vehicle and signals the local control point. The consumer becomes aware of the charge time and the payment details are signalled to the read data recipient and the consumer. Finally the charging station initiates the charge profile, switches to self-maintenance mode and signals standby. In order for this to be achieved, the EV systems need to be responsive, reliable, adaptive and designed in order to ensure secure communications and high Quality of Service.

### 3.3.3 Remote Maintenance and Control

M2M technology has real potential to provide more cost-effective autonomous techniques to help with remote monitoring and preventive maintenance. The basic concept of this use case is to enable monitor systems and controls remotely. Such systems could be computer-controlled machinery or home appliances with communication capabilities, such as controlling lighting and heating at a residence or business. Turning lighting on or off may or may not be time sensitive, depending on whether it is done in preparation for someone's arrival (e.g., wanting the lights on when one arrives home) or needing to turn them on remotely because someone has arrived and has no means to turn on lighting. Adjusting heating is unlikely to be time sensitive since heating or cooling has a much longer time constant than turning lighting on or off. Remote control of remote equipment, or equipment located in a hostile environment, is needed in many cases. Control (as well as monitoring) of these from a central location is desirable. In some environments, the presence of high temperatures, toxic fumes or radioactivity may make the environment hostile to humans. Remote control is clearly desirable in these situations. The requirements for these situations will generally fall into the real time and highly reliable categories, but "small data" will be sufficient for most of the interactions.




*Graphic 3.5: This graphic illustrates the network architecture for Remote Control of Home Appliances*

As for maintenance, possible use case is the installation and implementation of software updates which deal with flaws, or add features. These may be infrequent, but could be significant in size and scope. The requirements for remote maintenance are for moderate amounts of data that are not particularly time sensitive, hence does not present a big problem for the network operator. Software updates can present a problem, especially if they are large and frequent, or if they are large and need to be done to many devices at the same or nearly the same time. According to graphic 3.5, in the case of remote control of home appliances, there are several procedures that have to take place in order to ensure that M2M communications will be secure and reliable. Such procedures are system registration, requests and controls of remote operations. In particular, all the home appliances have to perform registration in the M2M system and then connect to the wireless network or setup a connection with the M2M gateway. Registration process includes the capability of the system to maintain information about the M2M devices such as types of home appliances, networking technologies, etc. Therefore, the remote control user requests a remote operation, probably by using the handset or his computer in order to manage his home appliance remotely. The result of the requested operation is returned to the remote control user from the home appliance through wireless network. [27]

### 3.3.4 Healthcare

There are a number of situations where untethered health monitoring is highly desirable. The healthcare industry is also looking into improvement of patient care through instant device communications, remote monitoring, homecare and disease management. These systems use sensors and devices, which in most cases are applied on patients' bodies, in order to monitor vital signs such as blood pressure, heart rate, body temperature and other body functional parameters through a wide area network. The obtained data are then sent periodically to the healthcare provider. In some instances, the monitoring of vital signs may observe a crisis requiring rapid intervention, such as when heart rhythm changes indicate a heart attack. In such cases, the requirement is that communication from the sensor to the appropriate responders must be rapid and highly reliable as a life may be at stake. In other instances, a trend line may be sought and the data may be accumulated by the sensors and periodically sent to a central point for analysis. The situation is not immediately life threatening but the correct diagnosis depends on having adequate data on which to base it. Especially for elderly but also for handicapped persons, another monitoring function may be related to falls. An accelerometer in a sensing device can detect when the person falls and could either initiate communication with a response centre immediately, or alert the person and allow for a short period of time in which the person can indicate whether help is needed, or if no response provided, then communicate with a response centre. As these applications can be life critical, the deployment of these scenarios can be very challenging. The requirements in this category include real time, reliable communications for emergency situations or slightly less urgent situations. Healthcare systems should also be secure enough in order to ensure that private information is not stolen. One of the issues that arise in these cases is that mobile service may not be available everywhere. In some buildings, there is enough steel in the structure to reduce signal strength to unusable levels when near the core of the building. Therefore, reliability, security, availability and coverage are required. [27]

### 3.3.5 Tracing and Tracking

Tracing and tracking of assets has long been the basis for M2M types of applications. Especially when assets are moved from place to place, it is often desirable to have a view of their status and condition. Logistic applications are a good example of the use of M2M in a way that is both dispersed and highly mobile. Logistics business and generally every business that involves transport could benefit from the tracking of ships, trucks and vehicles. For example, the monitoring of parameters such as temperature of the goods and location of the trucks could automate the processes and become the basis for new business models and new forms of fees and taxes. In some cases, the tracking needs to be continuous and in real time or near real time, e.g., for local delivery. In other cases, less frequent monitoring is sufficient, e.g., long haul delivery where the fact that an item is loaded and the estimated time of arrival are known. In the former case, frequent monitoring of location and status may be important while, in the latter case, infrequent monitoring is sufficient. When a vehicle is transporting many items of cargo, it is should not be necessary to communicate with each of them frequently, but rather it is important to communicate with items that are being loaded or off-loaded at stations. The requirements from the network operator's point of view can vary widely. If the collected data that have been collected at selected points are time tolerant, and can be sent at a later time to a central point, the resulting data traffic will normally be quite manageable. Tracking of items being stored in a warehouse will not be time sensitive while the items are being stored, however much of the data for tracking items being transported will be relatively time sensitive, and in some cases very much so. Hence, some of the data will be non-time sensitive "bulk" data, and other will be time sensitive "small data".

### 3.3.6 Digital Payments

Digital payments are becoming a high priority for many mobile operators as they are quickly gaining acceptance across the globe. M2M has already gained great importance in relation to cash-free payment, whereby a smartphone or another mobile device is held in front of a payment terminal. These terminals are used to handle debit or credit card payments. Early forms which used a dial up circuit-switched connection from a fixed terminal faced several limitations such as low speed and cumbersomeness. To be more specific, as the terminal was in a fixed location there was more time required to establish the circuit-switched connection than to execute the query response. On the contrary, with packet switching a session could be maintained as long as needed and would be ready for use essentially instantaneously. This creates both time and cost efficiencies for the customers, increasing in this way the quality of service. However, these services need to be trustworthy and ensure that they will provide secure authentication and payment process.

### 3.3.7 Smart Home and Smart Buildings

The rise of WiFi's role in home automation has primarily come out due to the network nature of deployed electronics where home electronic devices have started becoming part of the home IP network and due the increasing rate of adoption of mobile computing devices. The basic concept of smart homes is the development of a technology, which enables the occupants to use a single device in order to manage and control all electronic devices. Effective home automation can be enhanced by bundling functionality and services onto a single M2M-enabled digital home gateway which can support IPTV, broadband wireless, media storage and distribution, medical and home automation and more. A virtualized software platform can allow different service providers or utilities to run concurrently on the same box without interference. Visualization and control can be achieved by connecting via smartphone, TV, tablet or netbook. Buildings represent another area where energy efficiencies can be made. In offices, hotels or campuses, it is reasonable to suggest that people do not have the same motivations as they do at home to conserve energy. The potential for M2M to automate is magnified for buildings because the goal is not only to save energy but also to implement security. [30]

## 3.4 Networking Technology in M2M Notifications

Mobile traffic today is driven by activities such as phone calls and internet services. However, this decade is widely predicted to see the rise of Machine-to-Machine communications with billions of devices - with less predictable traffic patterns - joining the network. These communications will involve automotive, healthcare and other applications that require more bandwidth, higher data rates and greater capacity.

### 3.4.1 New Traffic Management Methods

As mentioned before, wireless data traffic is going to grow up to a thousand fold until 2020 due to the emergence of internet of things. Therefore, network operators need to exercise new, more effective traffic control methods in order to avoid network congestion and maintain customer satisfaction. However, current methods for addressing unexpected application behaviour on wireless networks are limited to overload prevention. A more efficient approach would operate at three complementary levels; application level management, RAN signalling overload control and core network overload control. Overload protection mechanisms at the RAN and core network would prevent flawed applications from abusing the network, while application-level management would enable more efficient use of network resources. More specifically:

- Application-level management – offers the ideal vantage point for M2M traffic management, by allowing network operators to take diverse application requirements into consideration.

- RAN signalling overload control – focuses on communication between a device and the access network. If these transactions overload the network, the RAN can broadcast a message to block further access until the overload condition is resolved.

- Core network overload control – provides another level of overload control. If the first access network node is not a bottleneck but the core network is, then the access network can be instructed to block further accesses for M2M service requests.

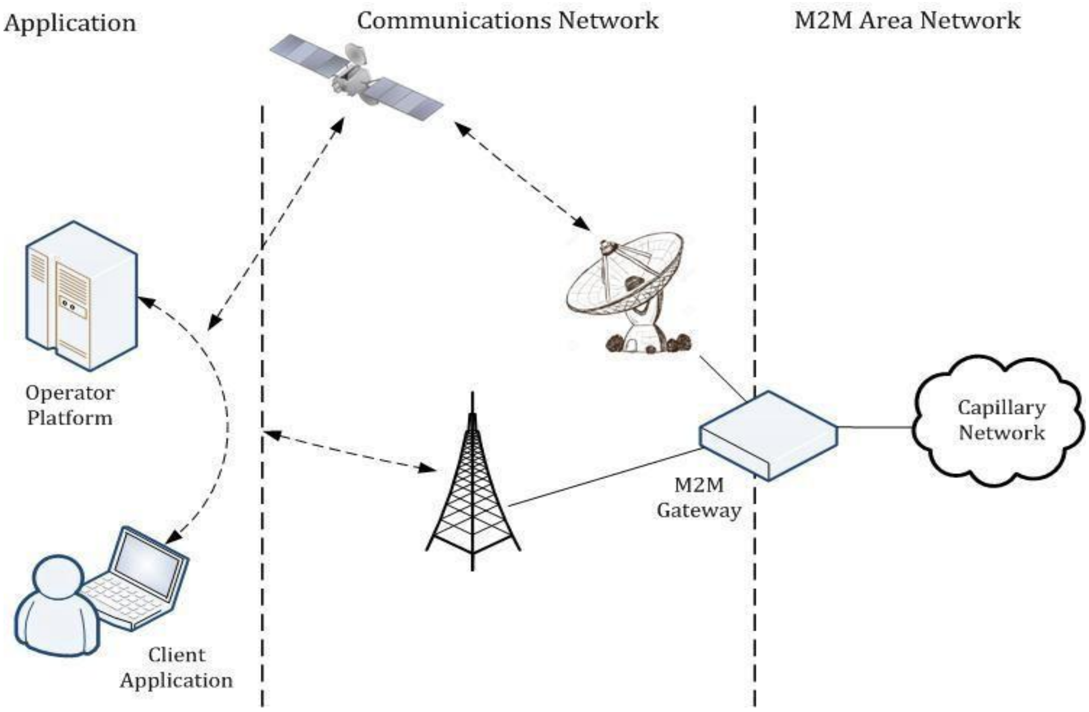
### 3.5 Network Requirements for M2M Communications

An ideal M2M communication technology would allow instantaneous secure access to the Internet anywhere in the world at any speed. It would work equally well indoors as outdoors, it would have unlimited range, zero latency and unlimited throughput, while costing virtually nothing and consuming no energy. It would provide access and management to data necessary to use M2M efficiently while ensuring the protection of privacy. Network requirements for M2M communications also include:

- Support for a numbering and addressing system which can accommodate a huge number of machines and a greater variety of devices.
- Support configuration and management of various types of devices and appliances and upgrading of software on the devices in a secure way.
- Support of different traffic characteristics of M2M communications, such as small message size and regular transmission intervals.
- Low latency and high reliability.
- Low and ultra-low power consumption especially for battery- operated devices.
- Support of different types of networks and technologies.
- Support of different types of applications and services.
- Support of data storage, notification, formatting, translation, collection and reporting.
- Security and privacy of the exchanged data considering that machines would carry large amounts of private and sensitive information.
- Seamless mobility functions for machines.

### 3.6 M2M Network Architecture

Considering the potential variety of Machine-to-Machine services with different requirements, it is almost impossible to provide connectivity and services to M2M nodes under a single unified architecture. Therefore, it is important to design a standard end-to-end M2M communication network architecture which will be able to support the flexible architecture and provide global integration among diverse solutions in M2M applications. Although every particular deployment of M2M is unique, there are four basic stages that are common to most M2M based applications including collection, transmission, assessment of data and response to the available information.




*Graphic 3.6: This graphic illustrates the basic M2M network architecture.*

M2M devices reply to requests for data contained within them or transmit the data automatically. They can be of various kinds – temperature sensors, motion detectors, level indicators, etc. If the monitored machine is sufficiently complex, it can use the M2M module as its modem enabling the transmission of the data. However, if the monitored machine is made of switches and simple circuits and is not able to exhibit a sufficiently intelligent behaviour, then it is appointed the slave role and is controlled by the M2M module. M2M devices may constitute an M2M area network, which can be realised as, e.g. a Bluetooth based personal area network of body sensors. M2M gateway provides interconnection of M2M devices and forwards data collected from them to communications network. The communications network serves as infrastructure for realising communication between M2M gateway and M2M end-user application or server. For this purpose cellular network, telephone lines and communication satellites can be used. The widespread coverage of cellular packet based networks and their continuously decreasing costs are the one of the main reasons that M2M is getting increasingly spread world-wide. There are several means of sending data over the cellular network, such as CDMA and GPRS. The advantage of cellular data services is the ability to send large amounts of data frequently. This means of data transfer is usually most convenient as telephone lines require implementation that can be rather complicated, and satellite transmissions, which are of particular use in remote monitoring over large distances, are commonly very cost and energy-inefficient. Finally, when data reach an M2M application, they can be analysed, reported and acted upon by a software agent or a process, depending on the specific system design. [28]

### 3.7 M2M Architecture Over Existing Telecommunication Technologies

To support wireless transmissions for a large number of devices, the M2M communications can work based on existing telecommunication systems such as 2G, 3G and 4G. The technologies that are being used are GSM, GPRS, CDMA, UMTS, WiMAX and LTE and related standards. For M2M applications mobile wireless offers both the possibility to be used in a dispersed as well as highly mobile set of configurations. It is, in many ways, the technology best suited to many M2M applications. Its appeal comes from some of the following:

- Near ubiquitous global availability anywhere. For this purpose LTE-A introduced a heterogeneous network (HetNet) as special network architecture.
- Centralized control through the use of SIM-cards. This allows instant activation without user interaction.
- Support for roaming between networks.
- Reasonable coverage indoors.

However, there are some drawbacks to the use of previous mobile wireless technologies which should be taken into account when designing an M2M solution based on them. One significant drawback is the lack of coverage. Although 2G technologies are universally deployed, their network coverage is significantly low. Moreover, Second Generation technologies are insufficient in most cases for a plethora of reasons as they lack in efficiency, capacity and reliability. Third Generation systems are also deployed in the most countries, but they offer limited coverage comparing to 4G which is not yet widely available though. Dark spots can be a considerable problem for static deployments. At these locations the network will not be able to deliver service for a longer period, even though the network is available. The dark spots will exist more indoors than outdoors, but can be everywhere. During the lifetime of an M2M deployment a small percentage will experience a lack of coverage at a location for longer or shorter periods of time. It is not known where and when the dark spot will occur and how long it will last. Being able to roam on multiple networks significantly decreases the chance of dark spots occurring. Some operators offer this solution for their customers, by using a foreign or international SIM card. Finally, 2G, 3G and 4G networks are scheduled to be decommissioned and replaced by 5G networks in the coming years. Building an M2M solution that only functions on these technologies may not be future proof.

### 3.8 LTE Enhancements for M2M

Machine-to-Machine communication, with its capability of providing diverse set of applications and services, is considered to be a key technology enhancement for 4G LTE-Advanced systems, and is anticipated to maintain its dominance in 5G systems as well. These enhancements address the issues of overload control, network support for M2M devices, device cost reduction, power saving for ultra-long battery life, signalling overhead, and coverage enhancement. To support coexistence of human and machine traffic, service differentiation of the different traffic types can be handled by various techniques. They include, for example, time-controlled access of M2M devices including access grant time and forbidden time interval, and limiting services to M2M devices if their behavior is not aligned with M2M features. Scheduling prioritization (e.g., through modifying the scheduling metric based on UE category), and semi-persistent scheduling to lower overhead can also be used. Using these techniques, the network is able to minimize the impact from machine traffic to human traffic. [29]

### 3.9 M2M Communications in 5G

It is forecasted that in 2020 the total number of connected devices will reach about 50 billion, almost double comparing to today’s number. A significant portion of the increase is perceived to be due to the emergence of Internet of Things (IoT) and the Machine Type of Communications (MTC) as M2M communications are considered to be a key element in future network systems. Naturally, the development of 5G technologies would need to take this key factor into account, apart from the enhancements currently being proposed for LTE-A systems. Conventional Mobile Broadband (MBB) is expected to be replaced with extreme MBB (xMBB), which provides new services such as virtual and augmented reality, higher resolutions, improved quality of experience and smart content delivery. The new use cases to be considered in such systems include massive and ultra-reliable MTC. Due to the diverse set of MTC use cases and scenarios, two different flavours should be investigated in the future 5G system design; low cost and low power consumption massive MTC and mission critical MTC (i.e. high category/ultra-reliable MTC), where latency and reliability are key elements to be considered. For low category or massive MTC, utility metering is one of the typical use cases. Generally, these type of devices are characterized by low bit rate requirements, low cost and low power consumption (e.g. 10 years battery life with “AA” battery), but with a massive deployment. This can be seen as the next step of development, based on the current LTE MTC work. For high category and mission critical MTC, automotive, industry automation and robot control are among the most important new areas which bring more stringent Quality of Service requirements in terms of latency, scalability and reliability as compared to traditional cellular services. Similarly, mission critical communications, which can help first responders work safer, smarter and faster in disasters and day-to-day incidents, have similar requirements as well. Current wireless communication systems such as 2G, 3G, 4G cannot satisfy the requirements of the most demanding automotive safety services. The QoS level to be provided with 5G system need to meet the requirements resulting from future highly automated driving and future industry Internet and go well beyond what can be achieved with any wireless communication technology today. The most important requirements currently for M2M communication in 5G systems currently being studied are:

- Maximum allowable end-to-end latency, including retransmits less than 5ms.
- Reliability, for example packet loss rate 99.999%.

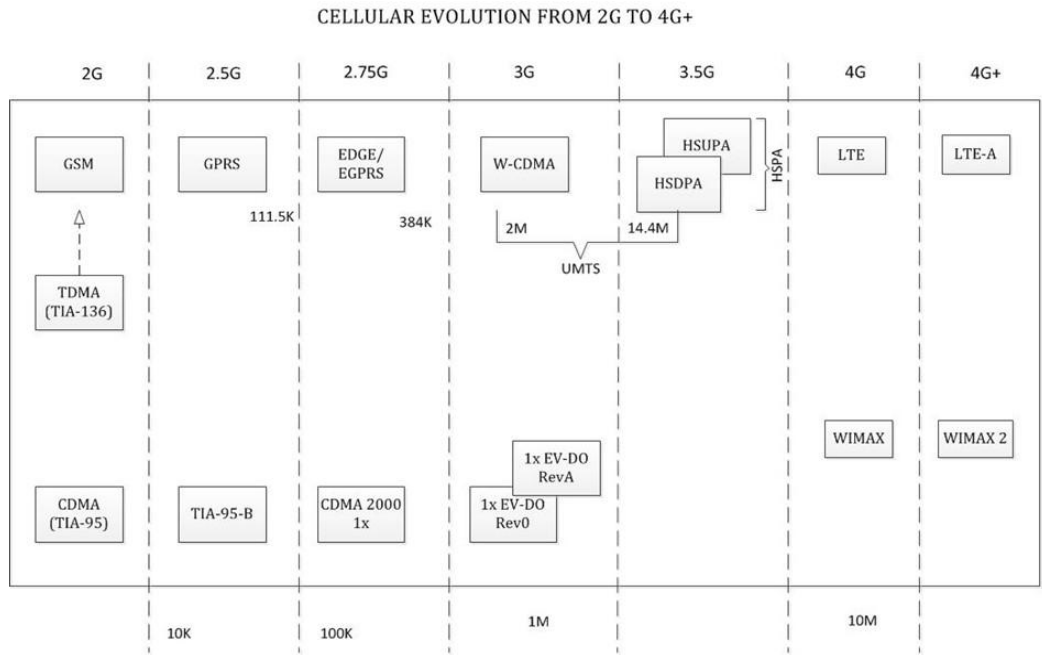
While the performance measurements and defining key performance indices of such requirements are challenging, one of the key consideration is the probability of avoidance of undesired events. For Massive Machine Communications (MMC), three different radio access types are also envisioned in–direct access (MMC-D) to the access network, with accumulation/aggregation point (MMC-A) which accumulates the traffic locally and sends it to the access point, and direct M2M communication between MTC devices using for e.g. D2D communication. The performance requirement for such communication is assumed to be more relaxed with data delivery having higher delay constraints. The key consideration would be on providing efficient access and optimized scheduling for such devices. [29]

### 3.10 Security

Currently, as M2M communications aren't considered as rewarding, as traditional personal computer communications in terms of money and glory for hackers, the attacks reported on machines are yet a fraction of the ones in the personal computer world. However, the prospective growth of M2M technologies associated with 5G networks raises concerns on the security adequacy of such systems. And it seems that the structure of the M2M communications makes them more vulnerable to attacks, compared to computers today. In particular, the demand for continuous 24/7 availability would inevitably accompany sudden outages of the software, with possible sequent security leaks. Also, most machines using M2M communications will be designed to run autonomously, causing attack detection and device repair a much more difficult process. Beside the dominant vulnerabilities forth-mentioned, one should consider that M2M communications will use standard operating systems, with similar well known weaknesses, and communications standards and protocols that are already in use, familiar to the potential hacker. The core of the communications security design would be based upon the principles of Authentication, Availability, Confidentiality and Integrity. Also, the concept of totally secured systems should be omitted as it is a practically impossible state. Instead, an alterable approach will be adopted aiming for secure enough communications, by finding the right balance between the effort needed to breach the protection of the system and the motivation of the potential attacker, id est the time and resources willing to be spent on such effort. For that effect, it is important to identify the categories of the possible attackers, in order to determine the amount of effort/cost the attacker would be willing to spend. The four types of hacking in M2M communications and the corresponding targets are: Buzz and glory attackers targeting consumer related services, cyber terrorists targeting governmental IT, cyber criminals targeting financial transactions and fraud concerning utilities. Moreover, for the determination of the appropriate level of security, risk analysis and defence analysis should be performed. Risk analysis would include the attractiveness of the system to threats, probable technical weaknesses in authentication or confidentiality, the expected cost of the attack for each possible vector and finally, the anticipated damage sustained in the event of a violation. On the other hand, the defence analysis would concentrate on identifying methods to detect intrusion or break of authentication, methods for quick encounter of hacking incidents and measures to sufficiently prevent such incidents from reoccurring, Furthermore, together with the integrator and the component suppliers, security experts should translate the security demands of the service provider into technical requirements that increase the cost of potential attacks.

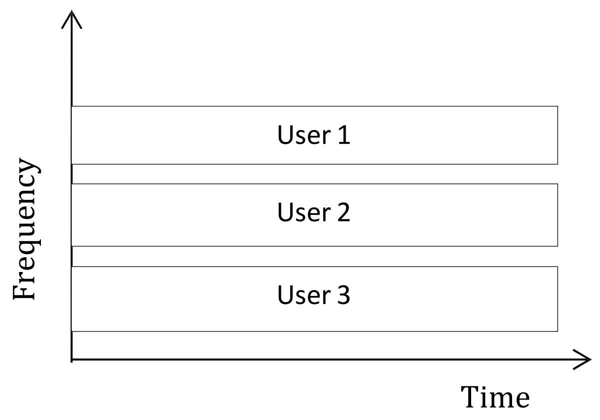
# 4. LIST OF FIGURES

**GRAPHIC 1.1**



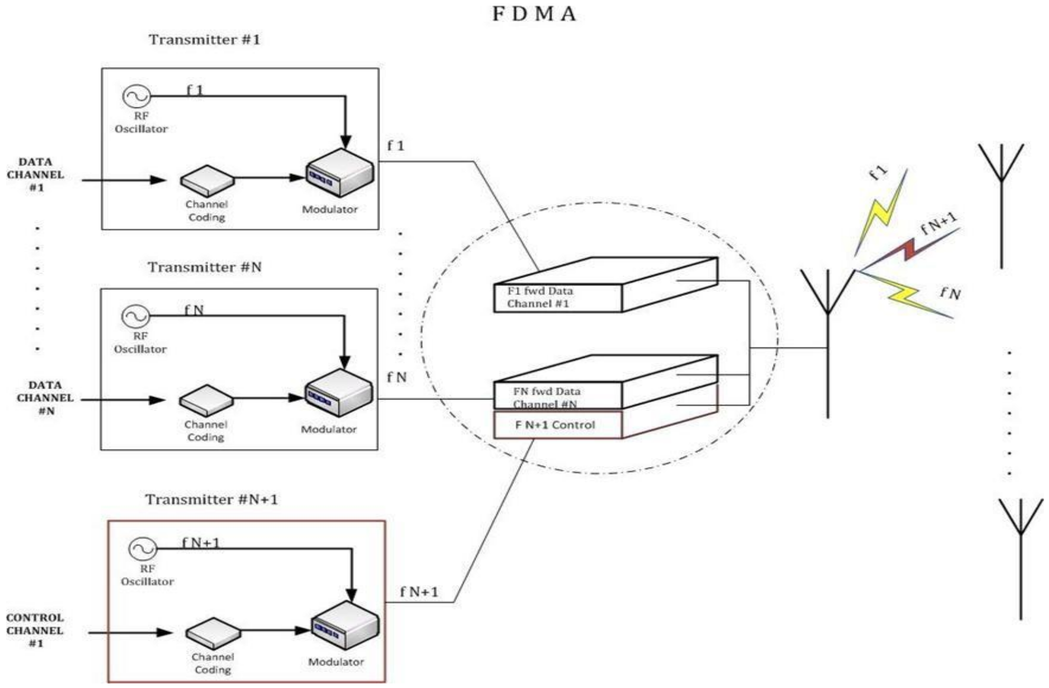

*Graphic 1.1: This graphic illustrates the evolution in network standards from second to fourth generation of mobile networks.*

**GRAPHIC 1.2**



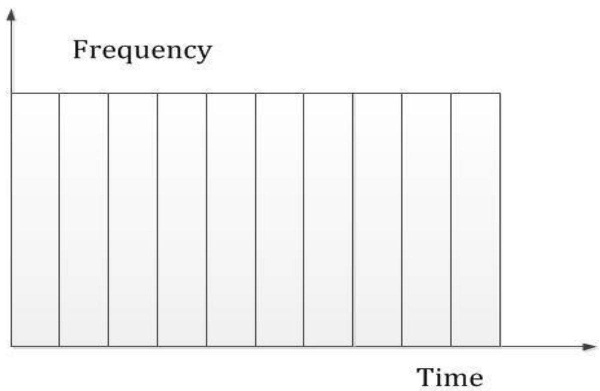

*Graphic 1.2: This graphic illustrates how FDMA would allocate a subcarrier to a particular user in a 1G wireless system.*

## GRAPHIC 1.3



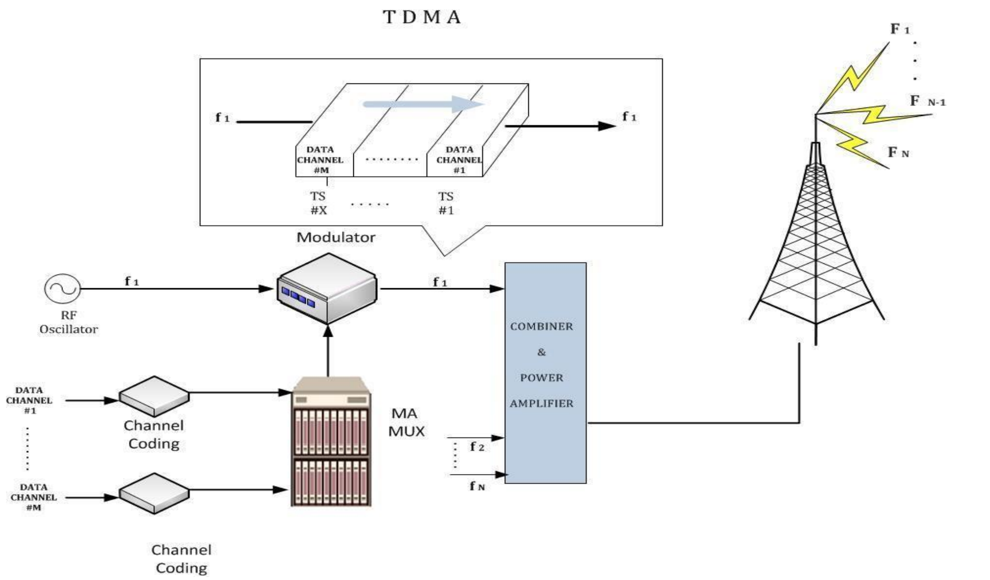

*Graphic 1.3: This graphic illustrates the FDMA technique.*

## GRAPHIC 1.4



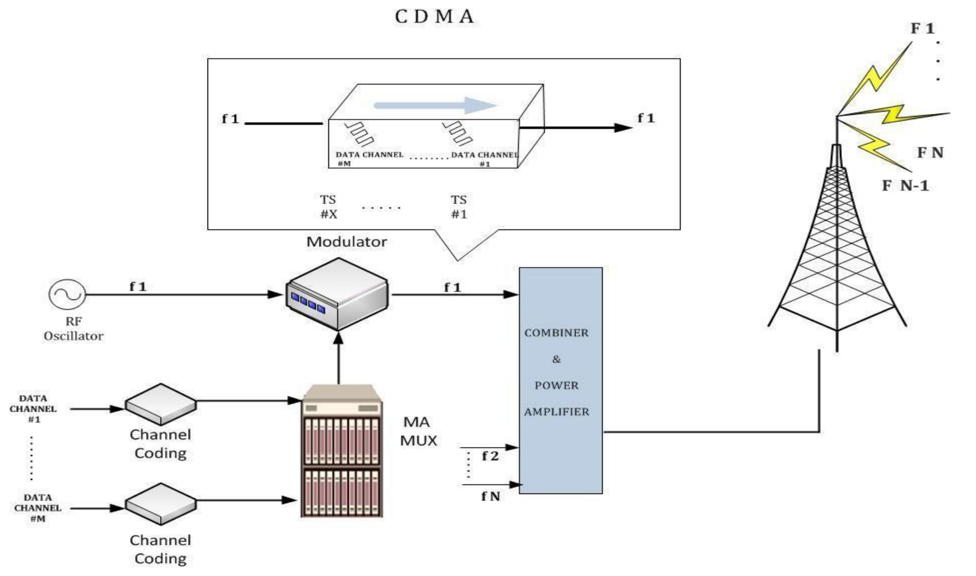

*Graphic 1.4: This figure illustrates how TDMA would allocate a timeslot to a particular subscriber in a 2G wireless system.*

**GRAPHIC 1.5**



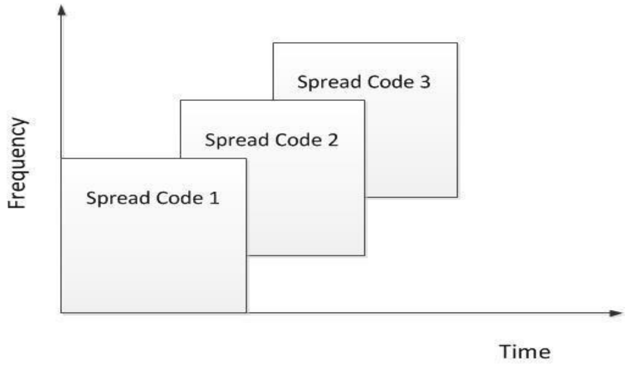

*Graphic 1.5: This graphic illustrates how a channel is divided in the frequency domain among multiple users in TDMA.*

**GRAPHIC 1.6**



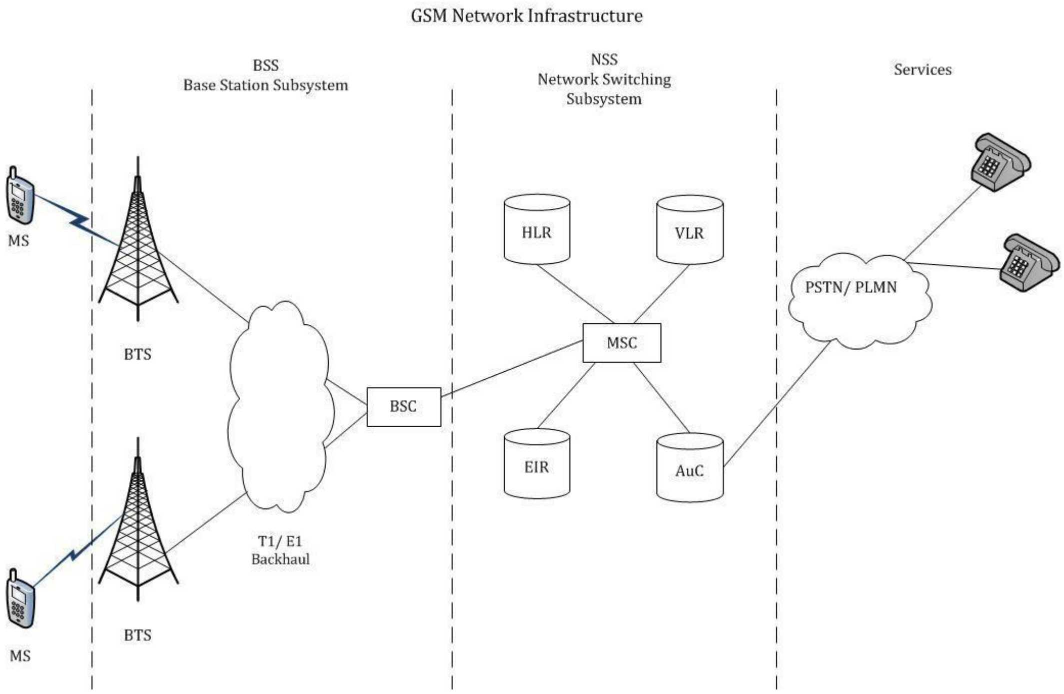

*Graphic 1.6: This graphic illustrates how several transmitters can send information simultaneously over a single communication channel.*

**GRAPHIC 1.7**



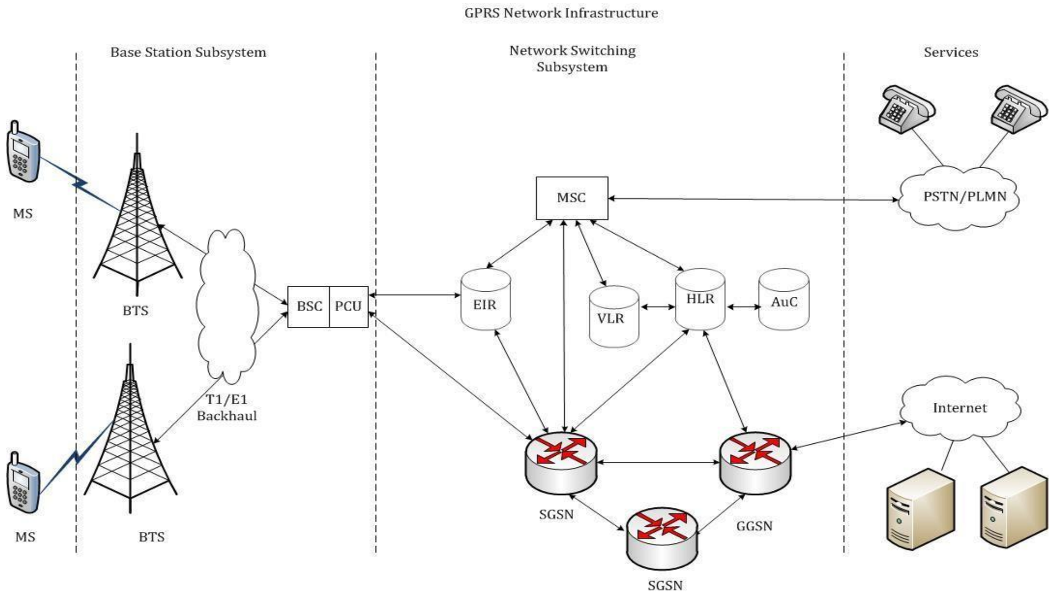

*Graphic 1.7: This graphic illustrates the CDMA technique*

**GRAPHIC 1.8**



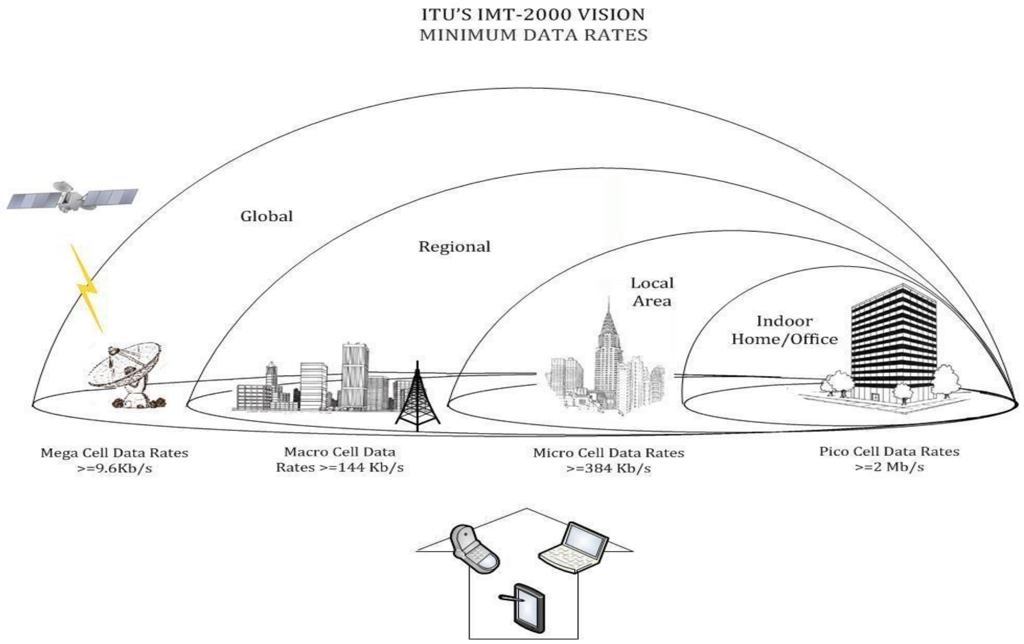

*Graphic 1.8: This graphic illustrates the GSM system*

**GRAPHIC 1.9**



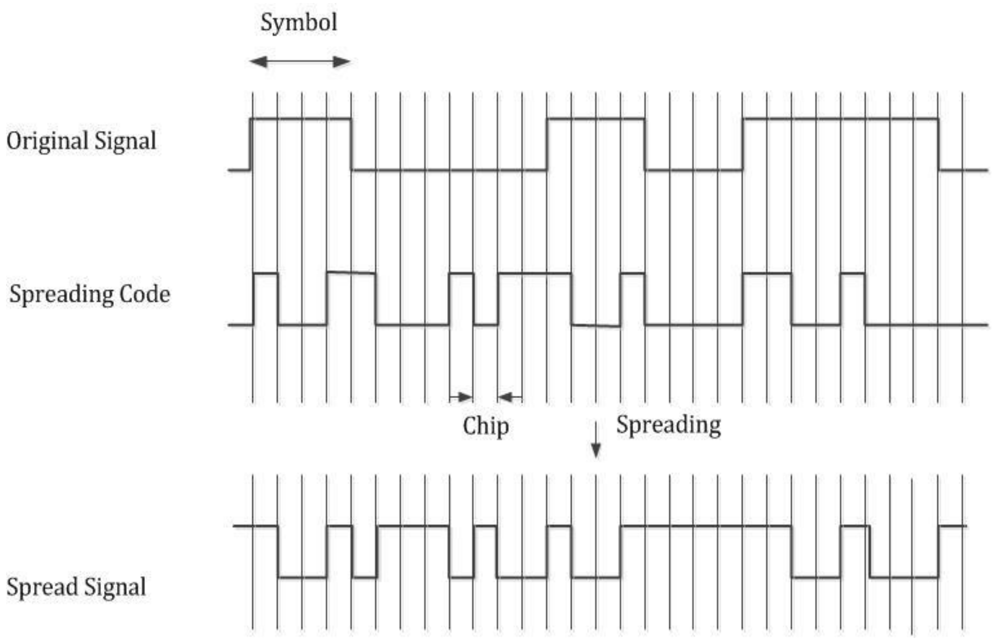

*Graphic 1.9: This graphic illustrates the GPRS network architecture*

**GRAPHIC 1.10**



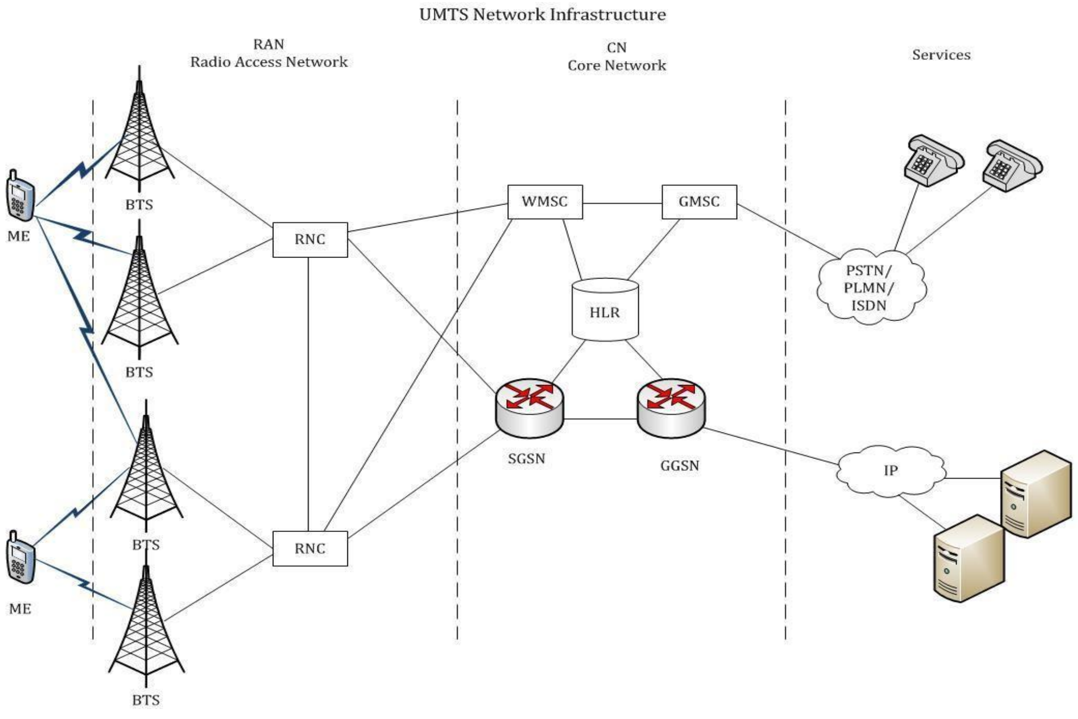

*Graphic 1.10: This graphic illustrates the ITU'S vision for the minimum data rates that third generation systems should support.*

**GRAPHIC 1.11**



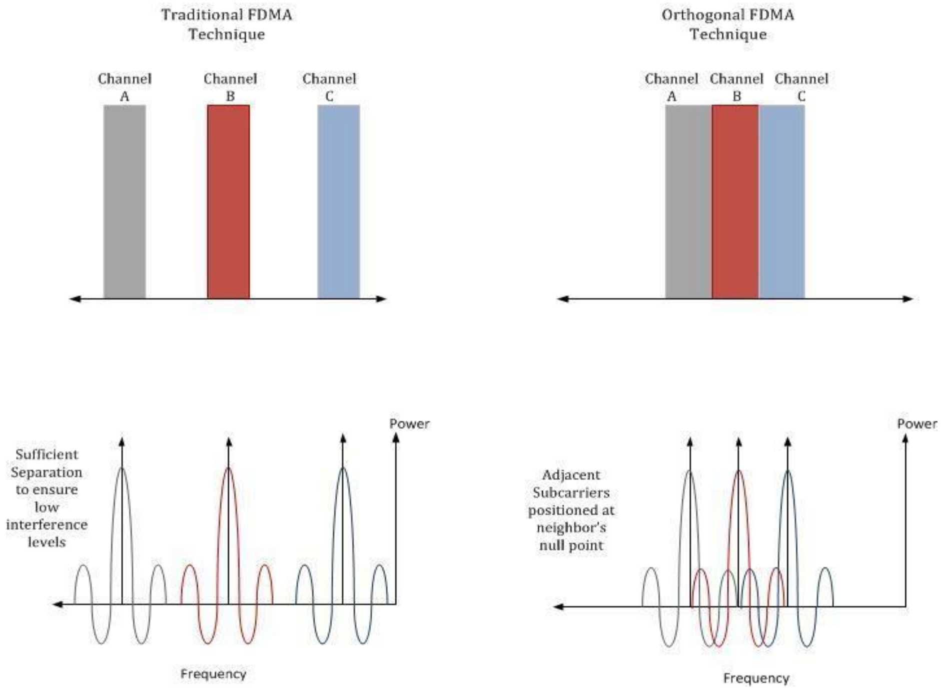

*Graphic 1.11: This graphic illustrates how the incoming signal is transformed and spread through W-CDMA technique.*

**GRAPHIC 1.12**



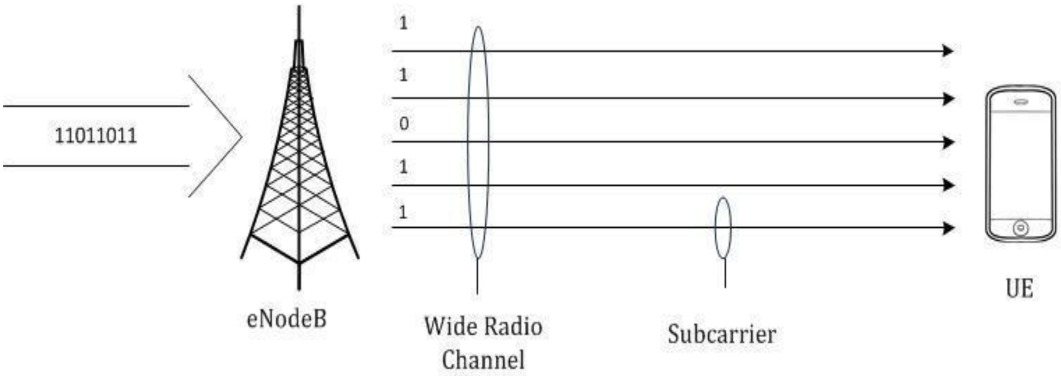

*Graphic 1.12: This graphic illustrates the UMTS network architecture.*

**GRAPHIC 1.13**



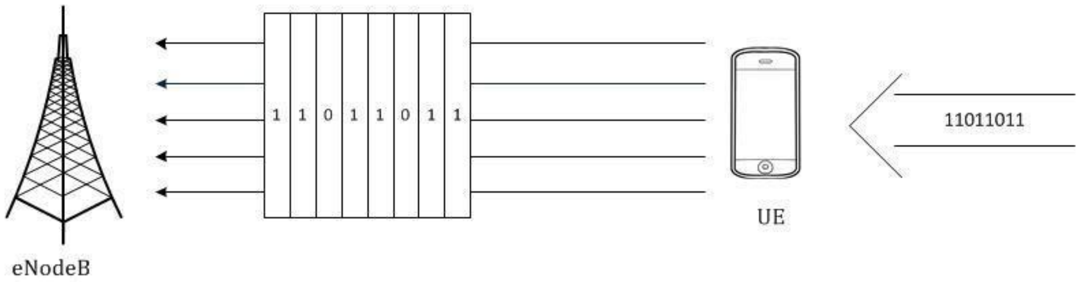

*Graphic 1.13: This graphic illustrates the difference between the traditional and the orthogonal FDMA technique*

**GRAPHIC 1.14**



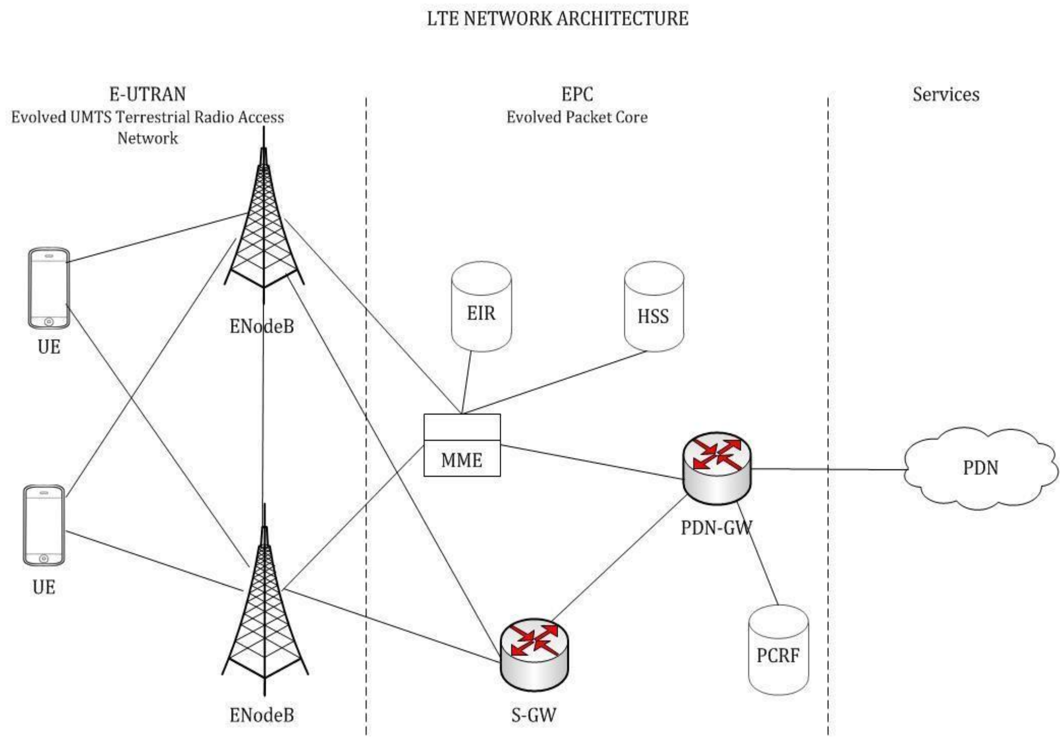

*Graphic 1.14: This graphic illustrates how the incoming data is separated and transferred across different subcarriers through the OFDMA technique.*

**GRAPHIC 1.15**



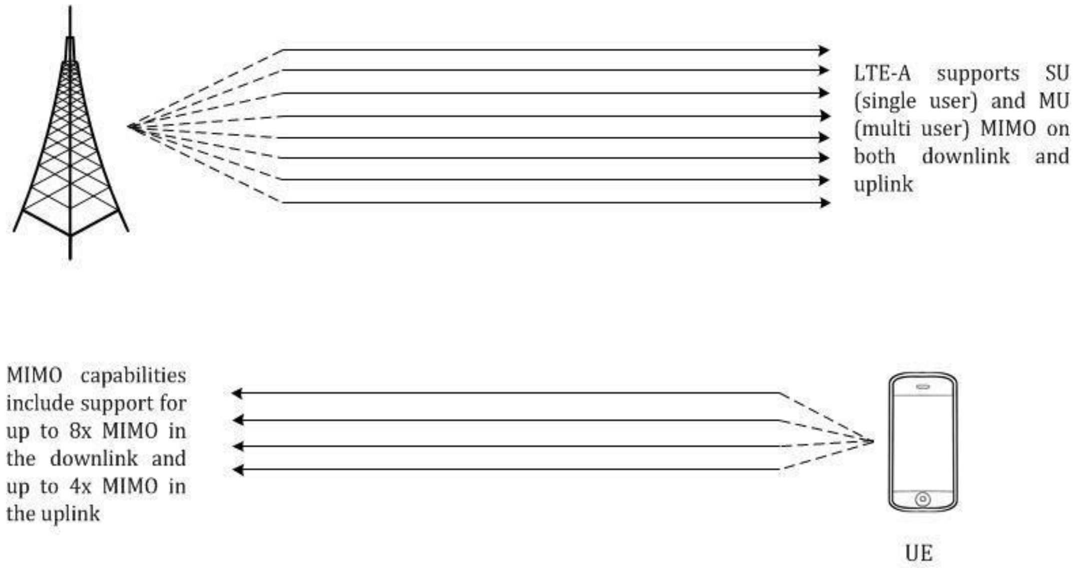

*Graphic 1.15: This graphic illustrates how the incoming data is separated and transferred across different subcarrier through the SC-FDMA technique.*

**GRAPHIC 1.16**



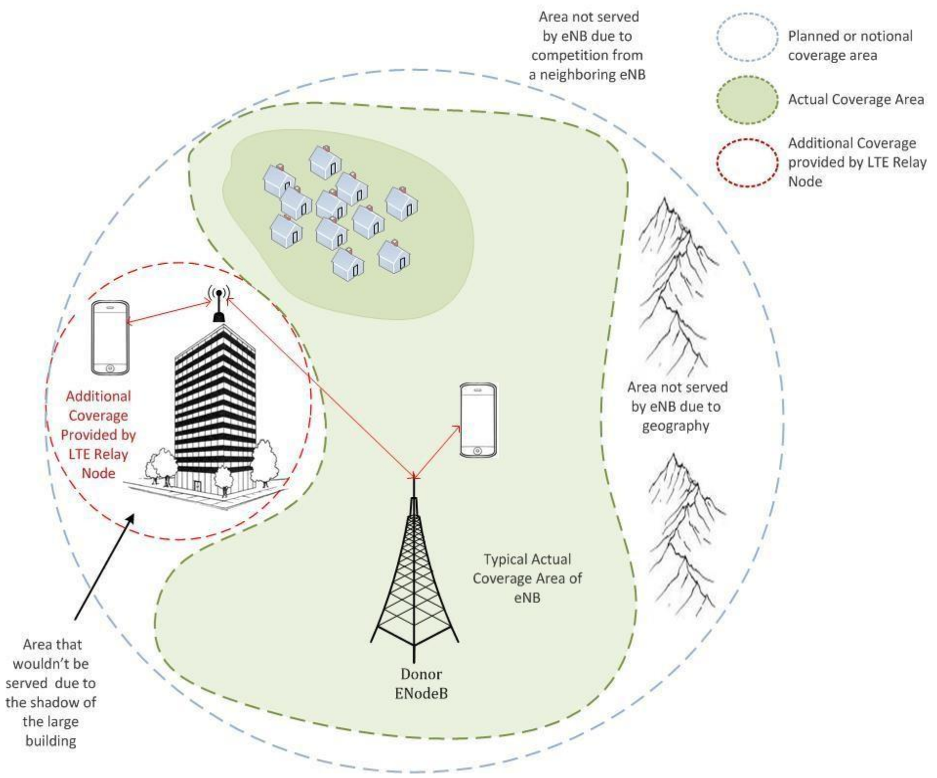

*Graphic 1.16: This graphic illustrates the 4th Generation Network Architecture*

**GRAPHIC 1.17**



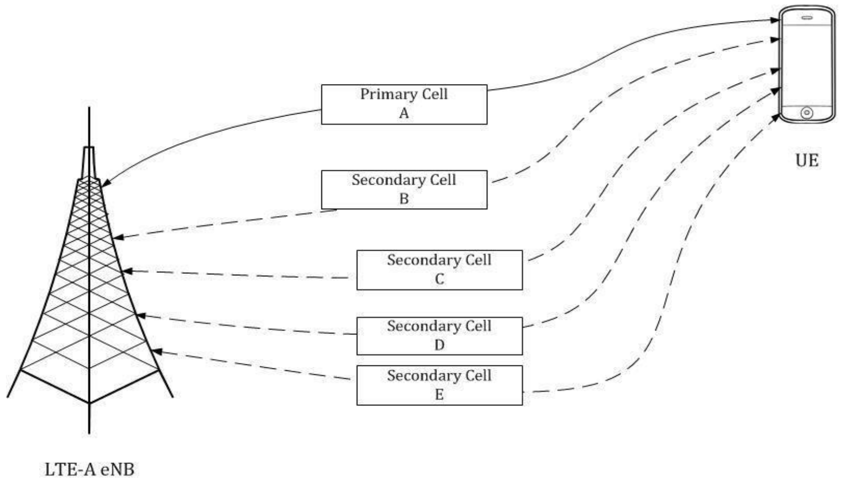

*Graphic 1.17: This graphic illustrates how data are transmitted in both uplink and downlink, through MIMO technique.*

**GRAPHIC 1.18**



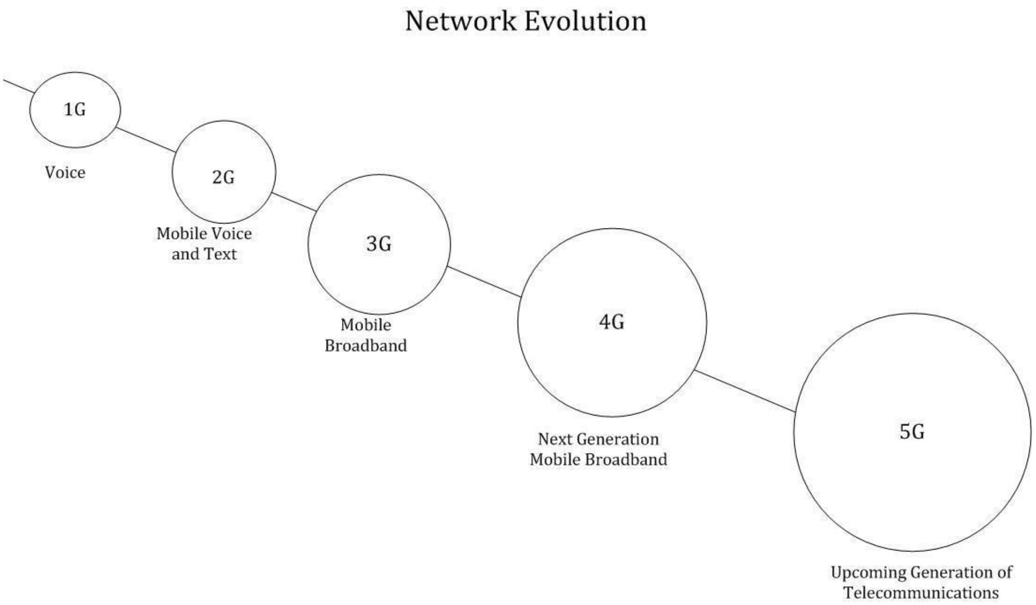

*Graphic 1.18: This graphic illustrates how actual coverage is increased by the use of an LTE Relay Node.*

**GRAPHIC 1.19**



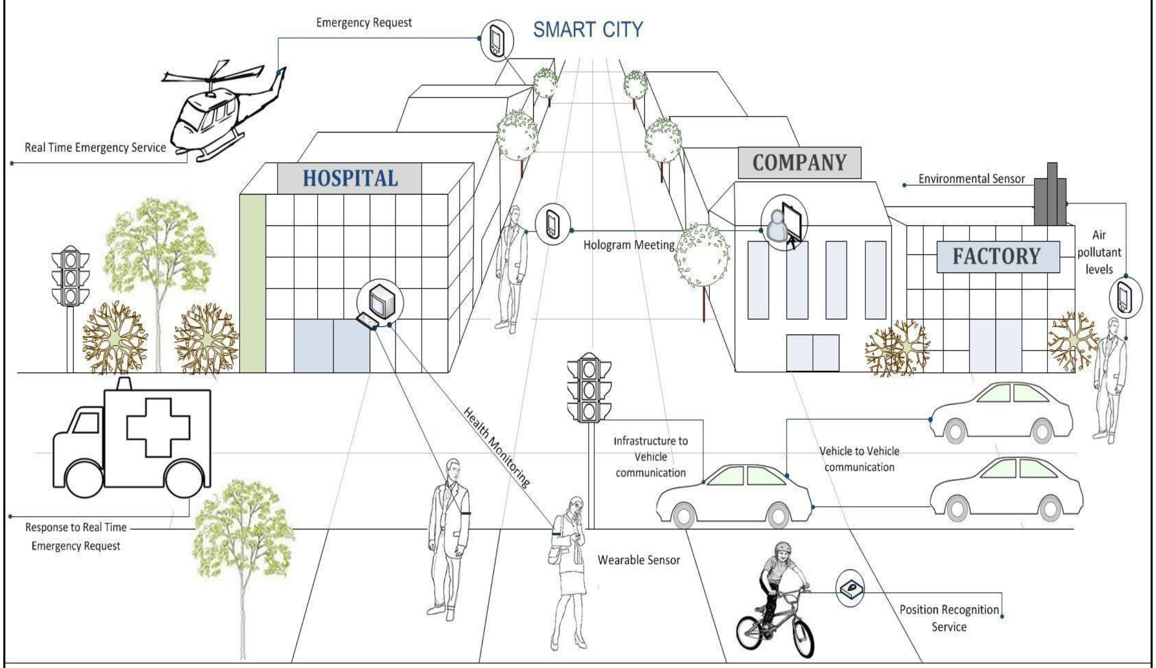

*Graphic 1.19: This graphic illustrates how an eNodeB can assign capacity to a UE on multiple cells simultaneously.*

**GRAPHIC 2.1**



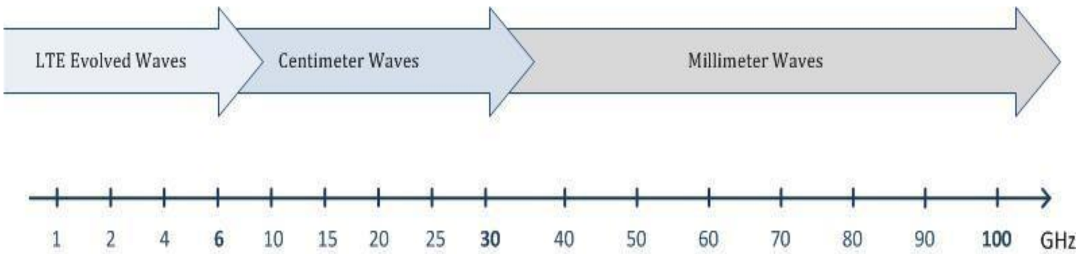

*Graphic 2.1: This graphic illustrates the network evolution from First to Fifth Generation of Networks.*

**GRAPHIC 2.2**



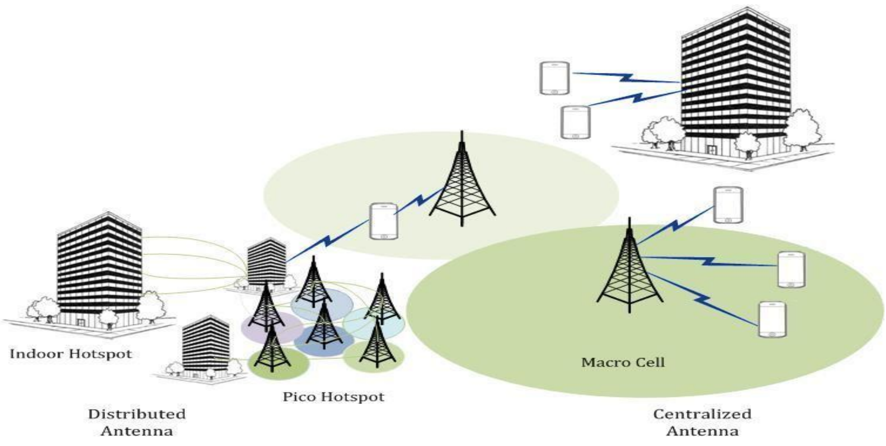

*Graphic 2.2: This graphic illustrates the use cases that 5th Generation Systems could provide among users in a "smart city".*

**GRAPHIC 2.3**



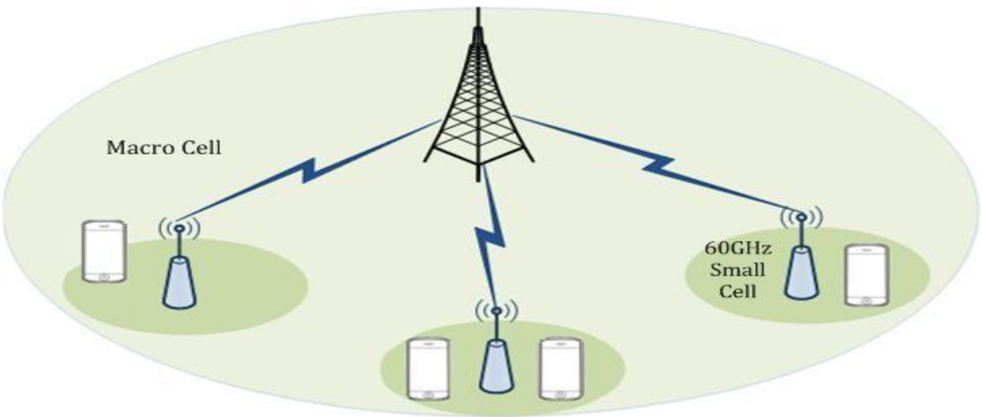

*Graphic 2.3: This graphic illustrates the frequency bands that are expected to operate in Fifth Generation Systems.*

**GRAPHIC 2.4**



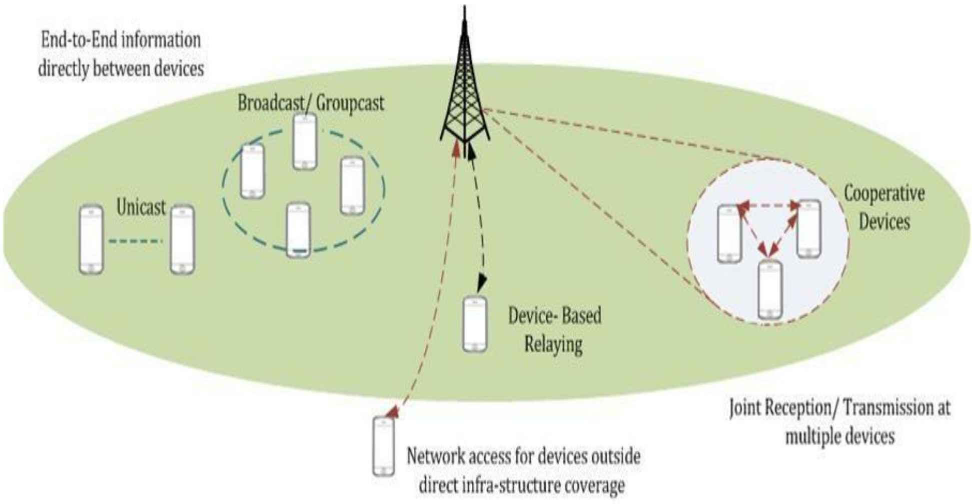

*Graphic 2.4: This graphic illustrates the Massive MIMO scenarios.*

**GRAPHIC 2.5**



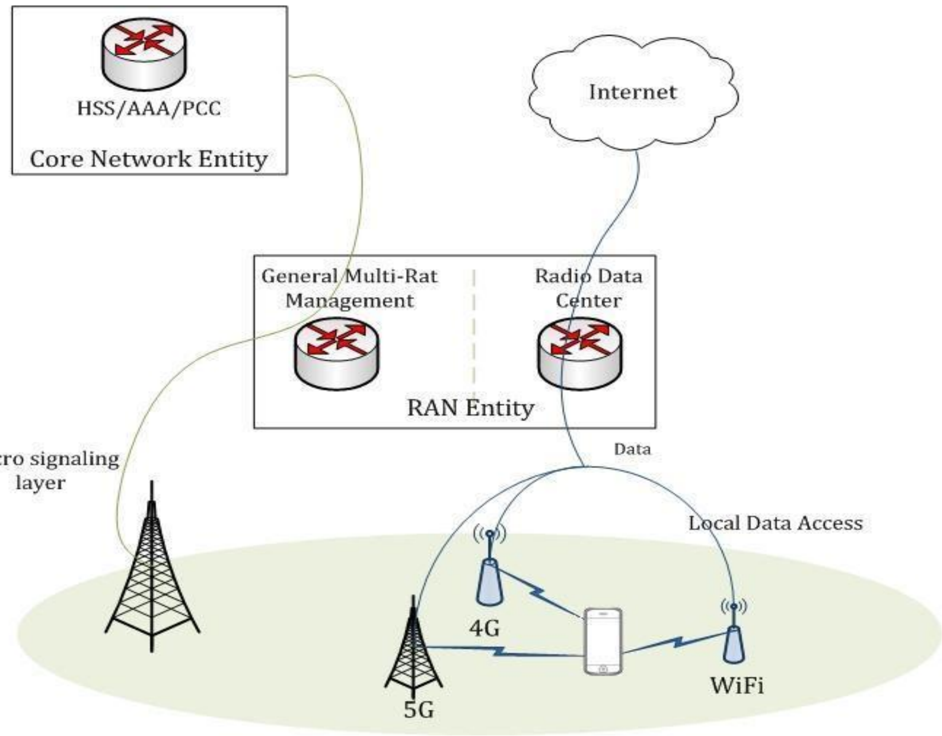

*Graphic 2.5: This graphic illustrates the small cell solution*

**GRAPHIC 2.6**



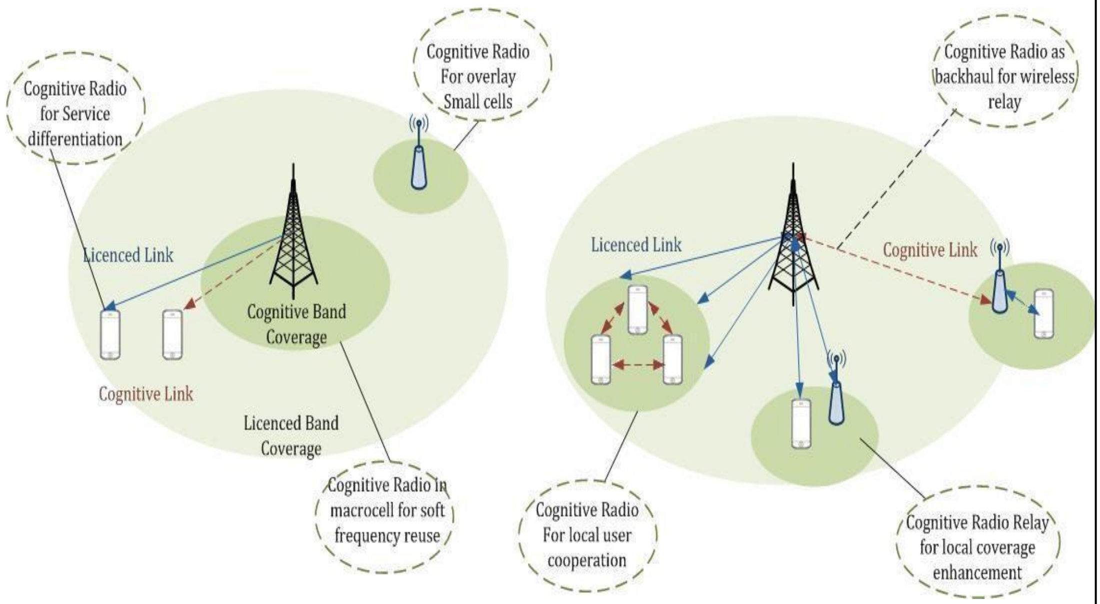

*Graphic 2.6: This graphic illustrates the wireless access solution*

**GRAPHIC 2.7**



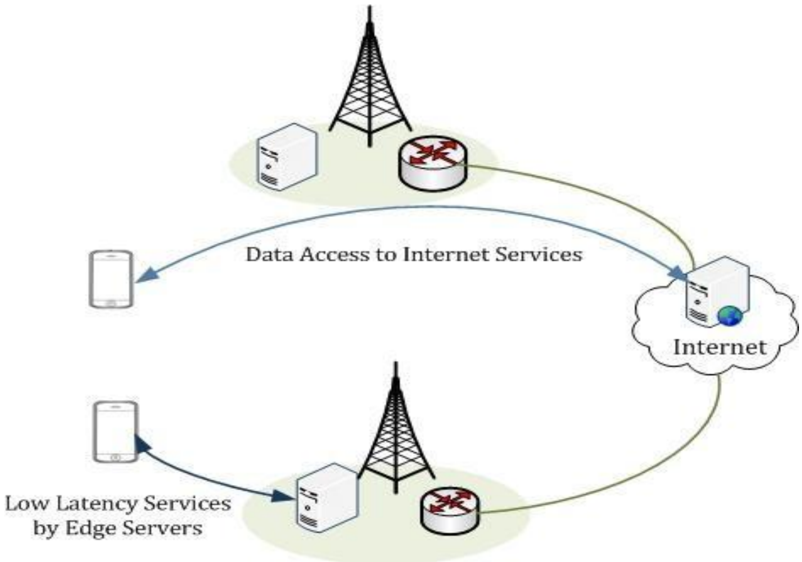

*Graphic 2.7: This graphic illustrates the Multi-RAT solution*

**GRAPHIC 2.8**



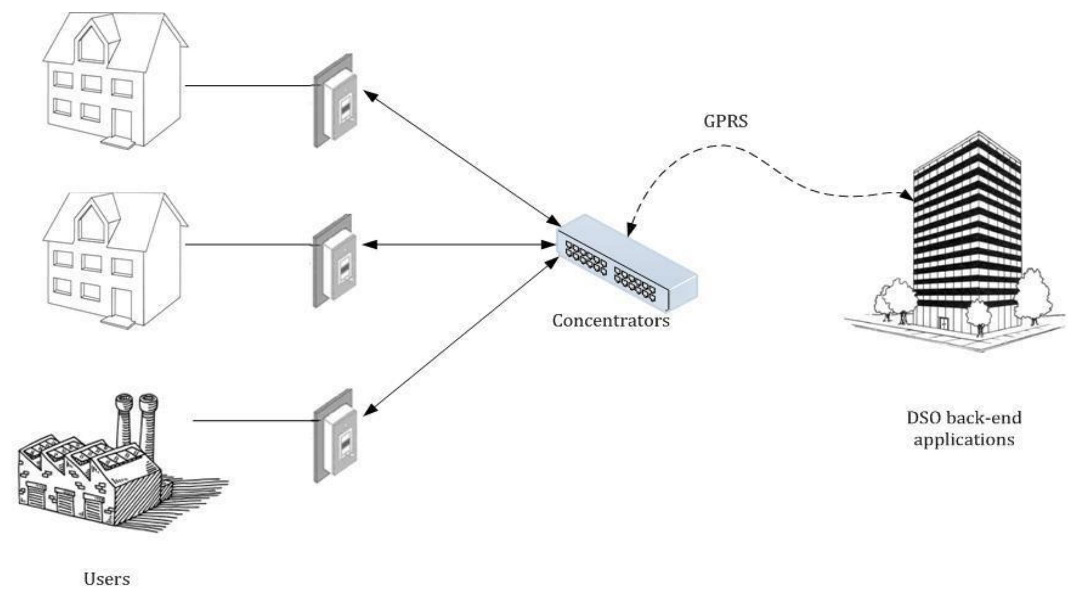

*Graphic 2.8: This graphic illustrates the architecture and usage scenarios of cognitive cellular networks.*

**GRAPHIC 2.9**



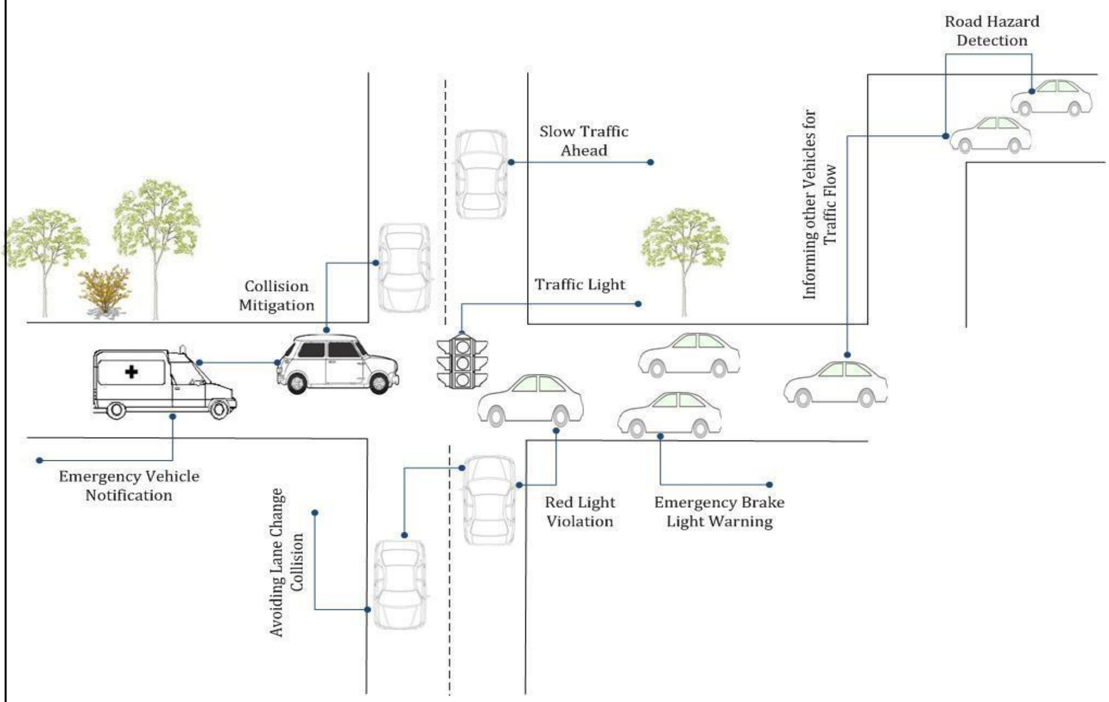

*Graphic 2.9: This graphic illustrates the flat network architecture.*

**GRAPHIC 3.1**



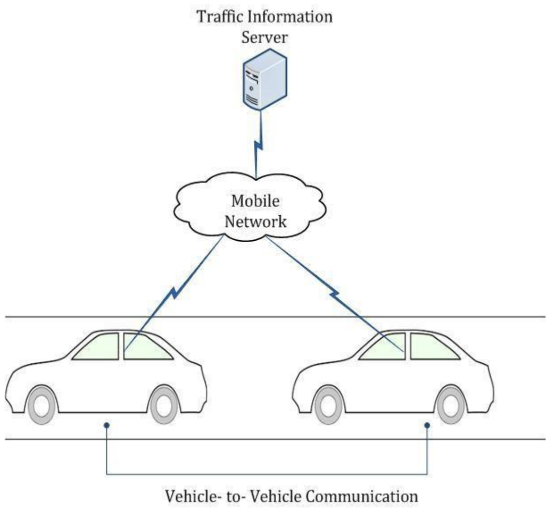

*Graphic 3.1: This graphic illustrates a smart metering deployment scenario*

**GRAPHIC 3.2**



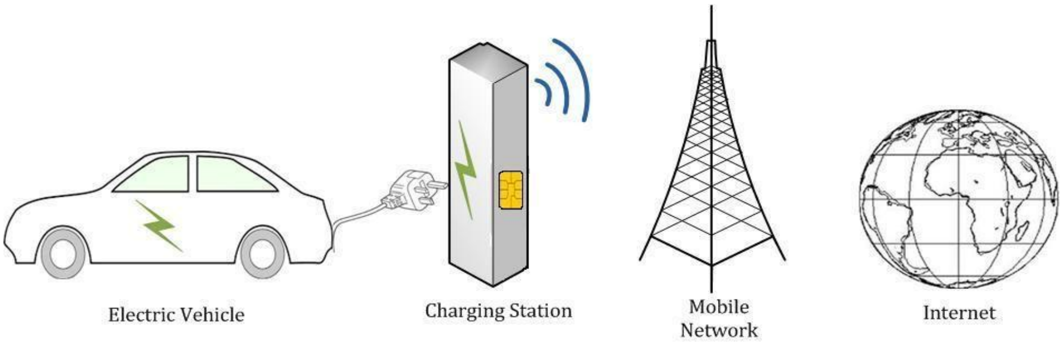

*Graphic 3.2: This graphic illustrates the vehicle-to-vehicle communication scenario.*

**GRAPHIC 3.3**



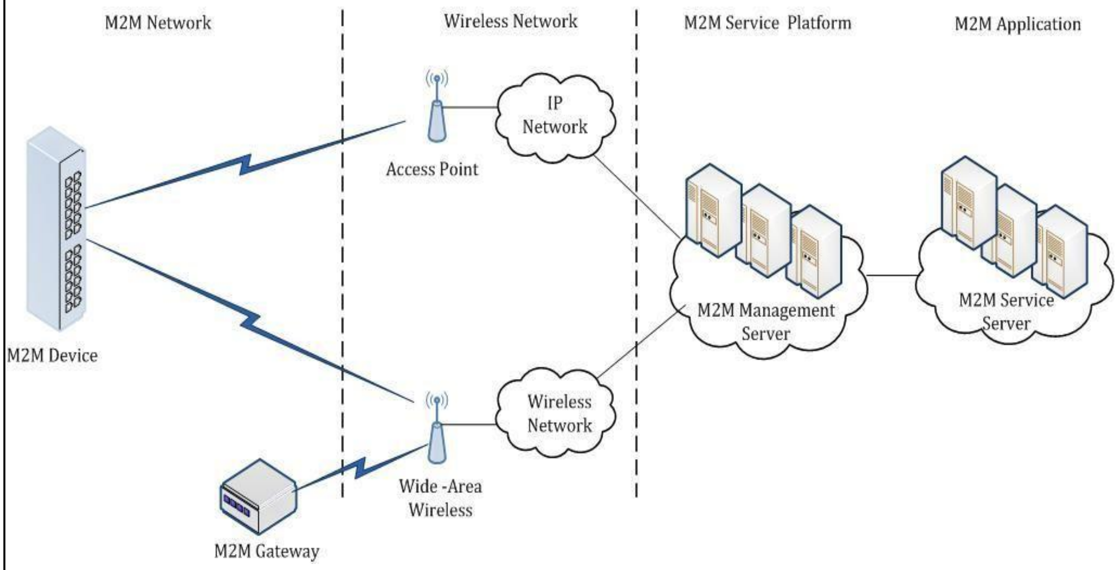

*Graphic 3.3: This graphic illustrates the vehicle-to-infrastructure communication scenario.*

**GRAPHIC 3.4**



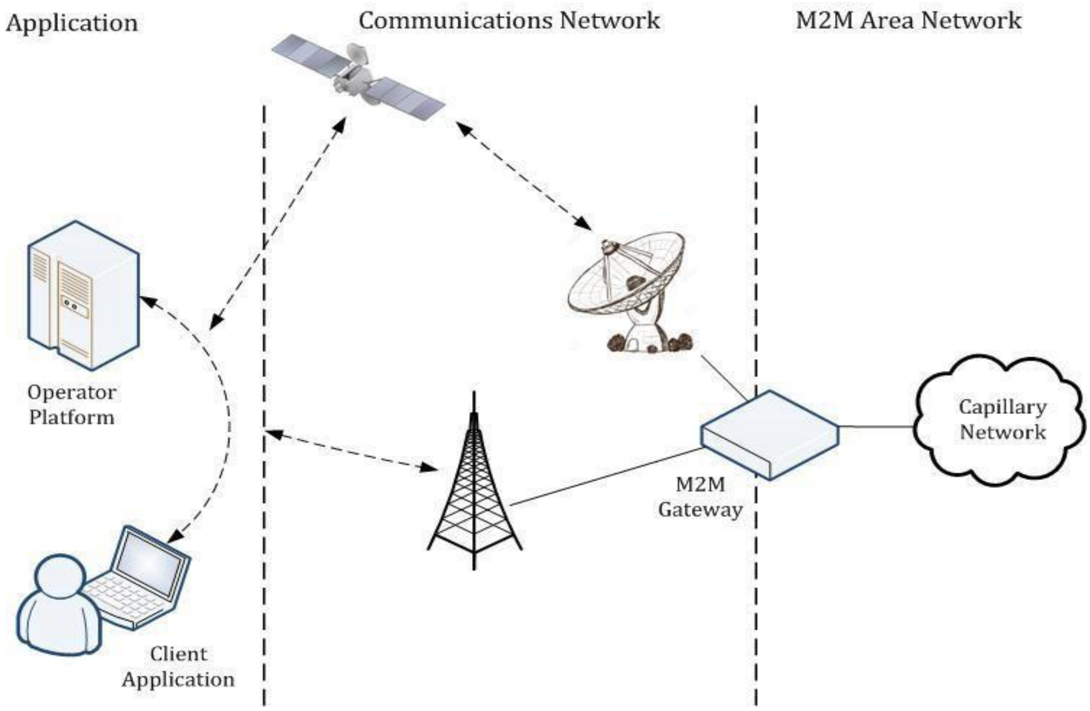

*Graphic 3.4: This graphic illustrates the electric vehicle charging scenario.*

**GRAPHIC 3.5**




*Graphic 3.5: This graphic illustrates the network architecture for Remote Control of Home Appliances*

**GRAPHIC 3.6**




*Graphic 3.6: This graphic illustrates the basic M2M network architecture.*

# 5. CONCLUSIONS

The last few years have witnessed a phenomenal growth in the wireless industry. The ever growing demands for higher data rates, greater capacity and better quality of services triggered operators to come up with new network technologies. There are lots of improvements from 1G, 2G, 3G, and 4G to 5G in the world of telecommunications. The First Generation (1G) analogue systems, introduced the basic mobile voice services, while the Second Generation (2G) has fulfilled capacity and coverage enhancements. This is followed by the Third Generation (3G) and Fourth Generation (4G) which introduced mobile broadband and offered higher data transfer speeds. Unlike predecessor systems, which focused on providing voice and data services, operators' research for 5G needs to focus on users and their needs. So Fifth Generation technology is expected to bring tremendous changes in the way that network is used till today. Due to the emergence of technological innovations such as Internet of Things Technologies (IoT) it is forecasted that by 2020 the number of devices connected to the network will be a thousand times bigger. User equipment will no longer be limited to smartphones or tablets but there will be smart devices such as wearables, home appliances, vehicles etc. These devices will extend their capabilities to various applications such as Machine-to-Machine Communications. Therefore, 5G network needs a flexible and superior architecture in order to support all these new use cases and scenarios that are analyzed in this project. As a conclusion, we can point out that there is still research and experimentation to be done in order for 5G systems to provide fully integrated M2M services.

# ACRONYM LIST

| | |
|---|---|
| 1G | First Generation |
| 1xEV-D0 | 1x Evolution data only |
| 2G | Second Generation |
| 4G | Fourth Generation |
| 5G | Fifth Generation |
| AMPS | Advance Mobile Phone Service |
| APN | Access Point Name |
| AUC | Authentication Centre |
| BSC | Base Station Controller |
| BSS | Base station Subsystems |
| BTS | Base Transceiver Station |
| CDMA | Code Division Multiple Access |
| cdmaOne | Code Division Multiple Access one |
| CN | Core Network |
| CS | Circuit switched |
| D2D | Device – to -Device |
| D-AMPS | Digital Advanced Mobile Phone System |
| DSO | Distribution Service Operator |
| E-DCH | Enhanced Dedicated Channel |
| EDGE | Enhanced Data Rates for Global Evolution |
| EGPRS | Enhanced GPRS |
| EIR | Equipment Identity Register |
| eNB | Evolved Node B |
| EPC | Evolved Packet Core |
| ETSI | European Telecommunications Standards Institute |
| E-UTRAN | Evolved UMTS Terrestrial Radio Access Network |
| EV | Electric Vehicle |
| FBMC | Filter-Bank Multi-Carrier |
| FDD | Frequency-division duplex |
| FDMA | Frequency-division Multiple Access |
| FFSK | Fast Frequency Shift Keying |
| FQAM | Frequency and Quadrature Amplitude Modulation |
| GFDM | Generalized Frequency-Division Multiplexing |
| GGSN | Gateway GPRS Support Node |
| GMSC | Gateway Mobile Services Switching Centre |
| GMSK | Gaussian Minimum Shift Keying |
| GPRS | General Packet Radio Service |
| GSM | Global System For Mobile Communications |
| HARQ | Hybrid Automatic Repeat request |
| HLRv | Home Location Register |
| HSDC | High-Speed Circuit-Switched Data |
| HSDPA | High Speed Downlink Packet Access |
| HS-DSCH | High-Speed Downlink Shared Channel |
| HSPA | High Speed Packet Access |
| HSS | Home Subscriber Server |
| HSUPA | High Speed Uplink Packet Access |
| ICN | Information Centric Networking |
| IMEI | International Mobile Equipment Identity |

| | |
|---|---|
| IMT-MC | IMT Multi-Carrier |
| IoT | Internet of Things |
| ITU | International Telecommunication Union |
| LTE | Long Term Evolution |
| M2M | Machine to Machine |
| ME | Mobile Equipment |
| MIMO | Multiple Input Multiple Output |
| MBB | Mobile Broadband |
| MMC | Massive Machine Communication |
| MMC-A | Massive Machine Communication Aggregation |
| MMC-D | Massive Machine Communication Direct |
| MME | Mobility Management Entity |
| MMS | Multimedia Message Service |
| MS | Mobile Station |
| MSC | Mobile Switching Centre |
| NFV | Network Function Virtualization |
| NMT | Nordic Mobile Telephone |
| NSS | network switching subsystem |
| OFDMA | Orthogonal FDMA |
| OMSS | Operation and Management Subsystems |
| PCRF | Policy and Charging Rules Function |
| PDC | personal digital communication |
| PDN-GW | PDN Gateway |
| PDP | Packet Data Protocol |
| PLMN | public land mobile network |
| PSTN | public switched telephone network |
| QAM | Quadrature Amplitude Modulation |
| QoS | Quality of Service |
| RAN | Radio Access Network |
| RF | Radio Frequency |
| RNC | Radio Network Controller |
| RRC | Radio Resource Control |
| SC-FDMA | Single Carrier Frequency Domain Multiple Access |
| SDN | Software Defined Networking |
| SGSN | Serving GPRS Support Node |
| SMS | Short Message Services |
| SMSS | Switching and Management Subsystem |
| TACS | Total Access Communications System |
| TCP | Transmission Control Protocol |
| TDD | Time Division Duplex |
| TDMA | Time Division Multiple Access |
| TTI | Transmission Time Interval |
| UDP | User Datagram Protocol |
| UE | User Equipment |
| UFMC | Universal Filtered Multi-Carrier |
| UMB | Ultra Mobile Broadband |
| UMTS | Universal Mobile Telecommunication System |
| UTRAN | UMTS Terrestrial Radio Access Network |
| V2I | Vehicle-to-Infrastructure |
| V2V | Vehicle-to-Vehicle |
| VLR | Visitor Location Register |
| VOIP | Voice Over IP |
| VPN | Virtual Private Network |

| | |
|---|---|
| W-CDMA | Wideband-CDMA |
| WiFi | Wireless Fidelity |
| WiMAX | Worldwide Interoperability for Microwave Access |

# REFERENCES

[1] Fourth Generation Mobile Networks / Advanced Cellular Network Planning and Optimisation: 2G/2.5G/3G...Evolution to 4G by Ajay R Mishra (ed) / John Wiley & Sons © 2007

[2] Kasera (2008) '2.5G Mobile Networks' /Tata McGraw-Hill Education

[3] Wikipedia /https://en.wikipedia.org/wiki/Base_station_subsystem

[4]Wikipedia/https://en.wikipedia.org/wiki/International_mobile_subscriber_identity

[5] Wikipedia/https://en.wikipedia.org/wiki/CDMA2000

[6] Network details & coverage maps at vzw.com. © 2010 Verizon Wireless

[7] Jenq-Neng Hwang (2009) Multimedia Networking: From Theory to Practice/ Cambridge University Press

[8] The evolution to 4G cellular systems: LTE-Advanced/Ian F. Akyildiz ∗, David M. Gutierrez-Estevez, Elias Chavarria Reyes/Broadband Wireless Networking Laboratory, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332, United States

[9] 5G Vision and Requirements Of 5G Forum, Korea Prof. Yongwan Park [ywpark@yu.ac.kr] Feb. 2014

[10] 4G Americas, October 2014, 4G Americas' Recommendations on 5G Requirements and Solutions, available at: *http://www.4gamericas.org/files/2714/1471/2645/4G_Americas_Recommendations_on_5G_Requirements_and_Solutions_10_14_2014-FINALx.pdf*

[11] The IEEE ICC 2015 4th International Workshop on Small Cell and 5G Networks (SmallNets)

[12] F. Rusek, D. Persson, B. Lau, E. Larsson, T. Marzetta, O. Edfors, and F. Tufvesson, ``Scaling up MIMO: Opportunities and challenges with very large arrays,'' IEEE Signal Process. Mag., vol. 30, no. 1, pp. 40-60, Jan. 2013.

[13] 5G SIG white paper - CHOICE project available at:

http://euchina-ict.eu/wp-content/uploads/2015/01/5G-SIG-white-paper-first-version.pdf

[14] Xuemin Hong, Jing Wang, Cheng-Xiang Wang, and Jianghong Shi, "Cognitive Radio in 5G: A Perspective on Energy-Spectral Efficiency Trade-off"

[15] IMT-2020 (5G) Promotion Group 5G Network Technology Architecture White Paper, availableat: file:///E:/Documents/Downloads/WHITE%20PAPER%20ON%205G%20NETWORK%20TECHNOLOGY%20ARCHITECTURE.pdf

[16]© Nokia Solutions and Networks 2015/ 5G Radio Access System Design Aspects/ FutureWorks

[17] Calum Dewar, Dan Warren, (December 2014) ANALYSIS Understanding 5G: Perspectives on future technological advancements in mobile © GSMA Intelligence

[18] Candès, Emmanuel J.; Romberg, Justin K.; Tao, Terence (2006). "Stable signal recovery from incomplete and inaccurate measurements" (PDF). Communications on Pure and Applied Mathematics 59 (8): 1207–1223. doi:10.1002/cpa.20124

[19] Donoho, D.L. (2006). "Compressed sensing". IEEE Transactions on Information Theory 52 (4): 1289–1306. doi:10.1109/TIT.2006.871582

[20] Xiao Wang; Zhifeng Zhao; Ning Zhao; Honggang Zhang (2010). “On the application of compressed sensing in communication networks”. Communications and Networking in China (CHINACOM), 2010 5th International ICST Conference.

[21] IMT-2020 (5G) Promotion Group 5G Network Technology Architecture White Paper (2015)

[22] Watson, D. S., Machine to Machine (M2M) Technology in Demand Responsive Commercial Buildings, presented on 2004 ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA, USA, August 2004

[23] Ericsson White paper Machine-to- Machine exploring potential operator roles Uen 284 23-3240 | September 2014

[24] “Lightweight M2M”: Enabling Device Management and Applications for the Internet of Things, Guenter Klas, Vodafone/Friedhelm Rodermund, Vodafone/Zach Shelby, ARM/Sandeep Akhouri, Ericsson/an Höller, Ericsson (Feb 26th, 2014)

[25] M2M Communications: A Systems /David Boswarthick, Omar Elloumi, Olivier Hersent @2012 John Wiley and Sons

[26] Machine to Machine communications (M2M); Use cases of Automotive Applications in M2M capable networks/ ETSI TR 102 898 V1.1.1 (2013-04)/ © European Telecommunications Standards Institute 2013.

[27] Impact of M2M communications and non-M2M mobile data applications on mobile networks/ ITU-T Technical Paper TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU(15 June 2012)

[28] Basic principles of Machine-to-Machine communication and its impact on telecommunications industry/ V. Galetić*, I. Bojić**, M. Kušek**, G. Ježić**, S. Dešić*, D. Huljenić** Ericsson Nikola Tesla Krapinska 45, Zagreb, Croatia

[29]Recent Advancements in M2M Communications in 4G Networks and Evolution Towards 5G Rapeepat Ratasuk‡, Athul Prasad†, Zexian Li†, Amitava Ghosh‡, and Mikko A. Uusitalo† ‡Nokia Networks, Arlington Heights, IL, USA.

[30] Machine-to-Machine (M2M) Gateway: Trusted and Connected Intelligence Iain Davidson Networking Marketing Manager, EMEA/Freescale Semiconductor, IncDocument Number: M2MGATEWAYWP REV 0/October 2013

# BIBLIOGRAPHY

## BOOKS


- Ajay R. Mishra (2007) '**Advanced Cellular Network Planning and Optimisation: 2G/2.5G/3G...Evolution to 4G**'/ John Wiley & Sons

- Jenq-Neng Hwang (2009) **Multimedia Networking: From Theory to Practice**/ Cambridge University Press

- **The evolution to 4G cellular systems: LTE-Advanced**/Ian F. Akyildiz ∗, David M. Gutierrez-Estevez, Elias Chavarria Reyes/Broadband Wireless Networking Laboratory, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332, United States

- Kasera (2008) '**2.5G Mobile Networks**' /Tata McGraw-Hill Education


## PAPERS


- 4G AMERICAS, OCTOBER 2014, **4G AMERICAS' RECOMMENDATIONS ON 5G REQUIREMENTS AND SOLUTIONS**, AVAILABLE AT: http://www.4gamericas.org/files/2714/1471/2645/4G_Americas_Recommendations_on_5G_Requirements_and_Solutions_10_14_2014-FINALx.pdf

- **5G Vision and Requirements Of 5G Forum**, Korea Prof. Yongwan Park [ywpark@yu.ac.kr] Feb. 2014

- **5G: A Technology Vision** Copyright © Huawei Technologies Co., Ltd. (2013)

- White paper - **5G Use Cases and Requirements** /© Nokia Solutions and Networks 2014

- **5G SIG white paper - CHOICE project** available at: http://euchina-ict.eu/wp-content/uploads/2015/01/5G-SIG-white-paper-first-version.pdf

- **5G radio Access ericsson- TECHNOLOGY AND CAPABILITIES** /White paper /Uen 284 23-3204 Rev B | February 2015

- **TOWARDS THE 5G ENVIRONMENT Making Research Steps with Meaningful Results**/ Fraunhofer FOKUS/ A whitepaper of the Fraunhofer FOKUS Open5Gcore Project (www.Open5GCore.net)

- Calum Dewar, Dan Warren, (December 2014) ANALYSIS **Understanding 5G: Perspectives on future technological advancements in mobile** © GSMA Intelligence
- **Millimetre Wave Mobile Communications for 5G Cellular: It Will Work!** / 2013 IEEE/ Digital Object Identifier 10.1109/ACCESS.2013.2260813

- **5G: Challenges, Research Priorities, and Recommendations** Joint White Paper/ Final version, after public consultation September 2014/ European Technology Platform for Communications Networks and Services NetWorld 2020 ETP Expert Working Group

- **NGMN 5G Initiative** Rachid El Hattachi/ Javan ErfanianNGMN Board/ 17th of February 2015

- © Nokia Solutions and Networks 2015**/ 5G Radio Access System Design Aspects**/ FutureWorks

- **5G Vision**, DMC R&D Center, Samsung Electronics Co., Ltd./February 2015

- **IMT-2020 (5G)** Promotion Group 5G Network Technology Architecture White Paper, availableat: file:///E:/Documents/Downloads/WHITE%20PAPER%20ON%205G%20NETWORK%20TECHNOLOGY%20ARCHITECTURE.pdf

- **ADVANCED WIRELESS COMMUNICATIONS INFRASTRUCTURE Technical, economic, and regulatory conditions of UMTS network deployment**
  Johannes M. Bauer, Rudi Westerveld, Carleen F. Maitland
  September 2-3, 2001 in Dublin, Ireland

- Watson, D. S., **Machine to Machine (M2M) Technology in Demand Responsive Commercial Buildings**, presented on 2004 ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA, USA, August 2004

- Ericsson White paper **Machine-to- Machine exploring potential operator roles** Uen 284 23-3240 | September 2014