CHAPTER 1: INTRODUCTORY CONCEPTS ON MOBILE COMMUNICATION

Communication is one of the integral parts of science that has always been a focus point for exchanging information among parties at locations physically apart. After its discovery, telephones have replaced the telegrams and letters. Similarly, the term "mobile" has completely revolutionized the communication by opening up innovative applications that are limited to one's imagination. Today, mobile communication has become the backbone of the society. All the mobile system technologies have improved the way of living. Its main success is that it has privileged a common mass of the society. In this chapter, mobile communications is introduced. Also, various terminologies common to this field, fundamental techniques and technologies, as well as the basic mobile network and call flow are introduced.

1.1 Introductory Concepts

1.1.1 Telecommunication

A basic communication model is shown in Figure 1.1.

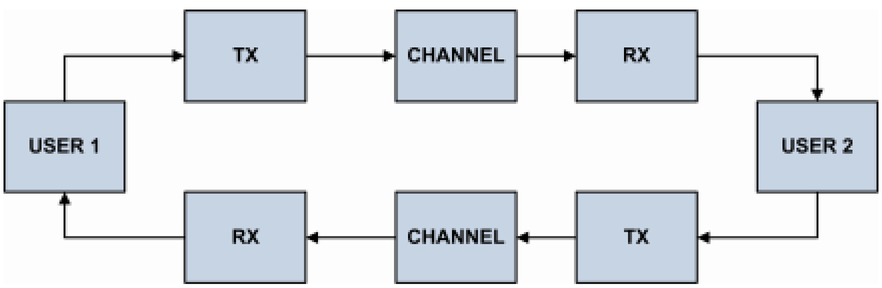

Figure 1.1: Basic communication model

Telecommunication is communication at a distance by technological means particularly through electrical signals or electromagnetic waves. Due to the many different technologies involved, the word is often used in a plural form, as telecommunications.

Early telecommunication technologies included visual signals, such as beacons, smoke signals, semaphore telegraphs, signal flags, and optical heliographs. Other examples of pre-modern telecommunications include audio messages such as coded drumbeats, lung-blown horns, and loud whistles. Electrical and electromagnetic telecommunication technologies include telegraph, telephone, teleprinter, radio, microwave transmission, fiber optics, communications satellites and the Internet.

The revolution in wireless telecommunications began in the 1900s with pioneering developments in radio communications by Guglielmo Marconi. Marconi won the Nobel Prize in Physics in 1909 for his efforts. Other highly notable pioneering inventors and developers in the field of electrical and electronic telecommunications include Charles Wheatstone and Samuel Morse (telegraph), Alexander Graham Bell (telephone), Edwin Armstrong, and Lee de Forest (radio), as well as John Logie Baird and Philo Farnsworth (television).

CHAPTER 1: INTRODUCTORY CONCEPTS ON MOBILE COMMUNICATION

1.1.2 Fixed-Line, Wireless, and Mobile Networks

The terminologies below are introduced to avoid any misinterpretations and to permit better distinction between them.

Fixed-Line network

A fixed-line network is a network where the terminals must be directly wired into a single exchange. This is known as the Public Switched Telephone Network or PSTN. An example is the CAMTEL's Fixed-Line network in Cameroon. This is one of the oldest form of a telecommunications system in this modern era. It should be noted that Fixed-Line here refers to the wired connection, not the mobility of the terminal. Indeed, there exist fixed terminals which do not connect to the network using wires, but rather without wires, wirelessly. In such a case, the network serving these terminals should be considered a wireless network.

Wireless network

A wireless network is a network in which terminals connect to the main exchanges through a wireless connection. Several examples include: Wi-Fi networks, WiMAX networks, GSM networks, and so on. The list is in exhaustive, as we are flooded with wireless networks all around. Again it should be noted here that a network is wireless based on its terminal's connection being wireless. But not all wireless networks are Mobile networks. Indeed, some terminals wirelessly connect to their networks, but do not necessarily permit the mobility of the user during a connection session.

Mobile network

A mobile network is a type of wireless network in which the mobility of the user's terminal is permitted. **By mobility we mean connection sessions are maintained all through the movement of the terminal**. Examples of mobile networks include: GSM networks, UMTS networks, Mobile WiMAX, LTE and so on. Now, this concept of mobility is quite tricky as it entails many technical challenges.

Question: How does a network permit mobility?

1.1.3 Analog Vs. Digital

These days we hear a lot of commercials on TV and Cables, and even much fuss about this Digital thing. Well let's state it simply that, a network is regarded as analog or digital depending on the type of **modulation** used within the network. ***Modulation***, basically, is the process of adapting a signal within its medium, so it can be carried from its origin to its destination. There are basically two ways of doing this: using analog signal carriers (Analog modulation); or using digital signal carriers (Digital modulation). The details of Modulation Techniques are not the purpose of this lecture, and as such are beyond the scope of this course, though, it is worthwhile to note that mobile networks have used both Analog and Digital modulation techniques along their evolution. Also, modern mobile networks are largely based on digital modulation techniques.

CHAPTER 1: INTRODUCTORY CONCEPTS ON MOBILE COMMUNICATION

1.2 Basic Mobile Network

1.2.1 Cellular Concept

Mobile networks need to accommodate a large number of users over a large geographic area with limited frequency spectrum, i.e., with limited number of channels. If a single transmitter/ receiver is used with only a single access station, then sufficient amount of power may not be present at huge distances from the station. For a large geographic coverage area, a high-power transmitter therefore has to be used. But a high-power radio transmitter causes harm to environment. Mobile communication thus calls for replacing the high-power transmitter by low-power transmitters through dividing the total coverage area into small segments, called cells. Each cell uses a certain number of the available channels and a group of adjacent cells, together use all the available channels. Such a group is called a cluster. This cluster can repeat itself and hence the same set of channels can be repeated or reused. Each cell has a low-power transmitter with a coverage area equal to the area of the cell. **This technique of substituting a single high powered transmitter by several low powered transmitters to support many users is the backbone of the cellular concept**.

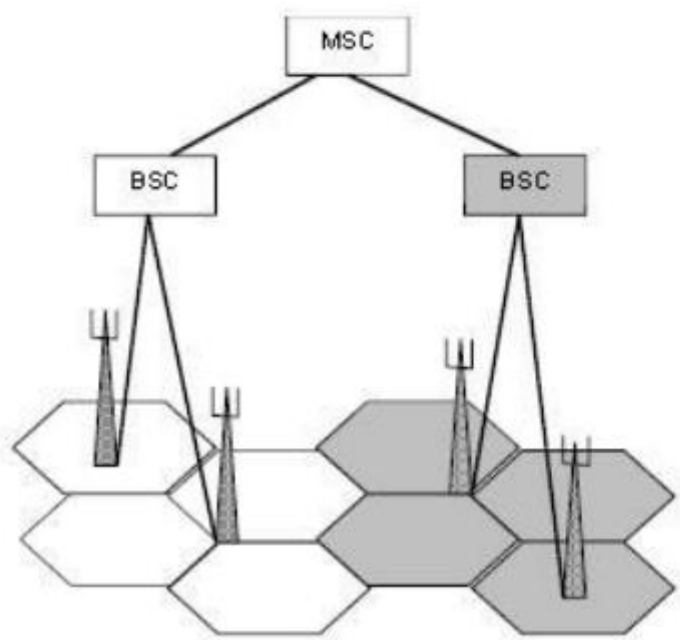

Figure 1.2: Cellular Concept

1.2.2 Basic Mobile Network

Figure 1.3 below depicts a basic mobile network structure.

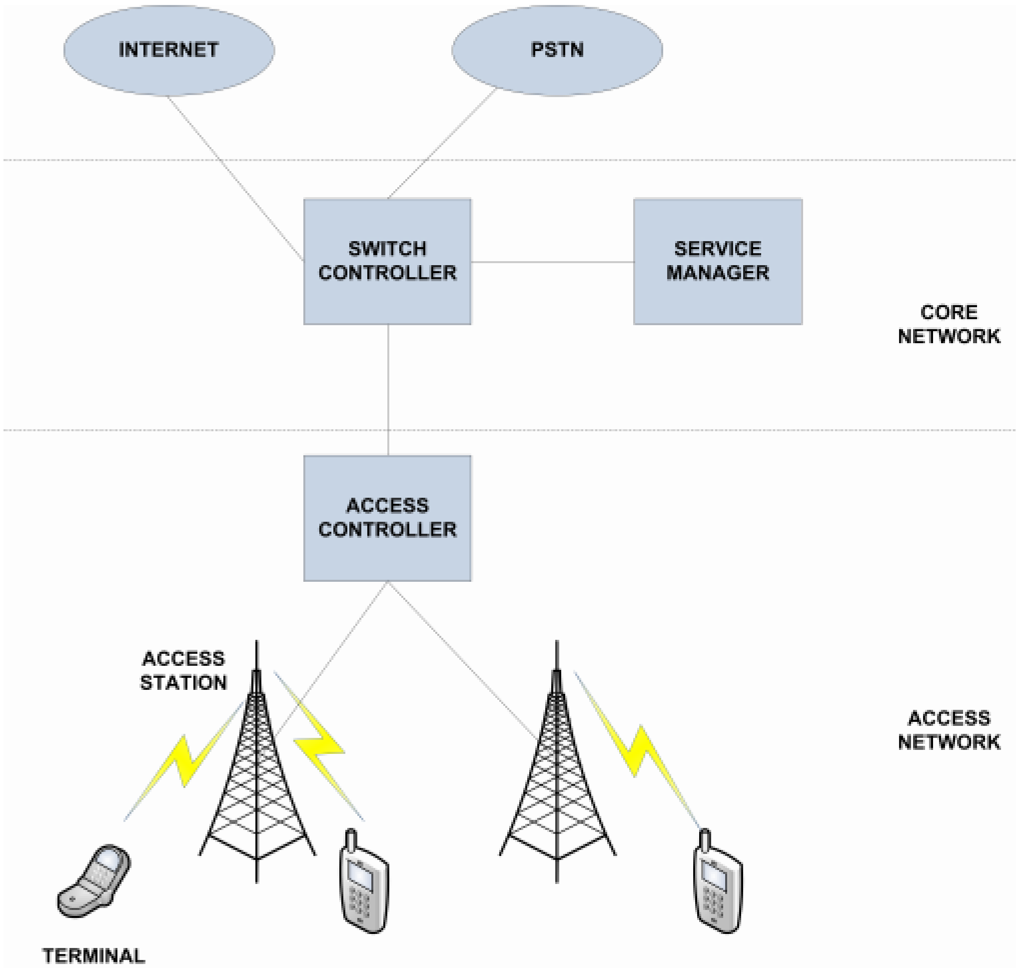

Figure 1.3: Basic Mobile Network

The elements are:

1. **Terminals**: These are the user devices which are used to gain access to the network. They can be mobile phones, internet keys, tablets etc.
2. **Access station**: These are the entry points to the network from the terminal's point of view. They provide air interface channels with which the terminals can wirelessly hook unto the network. Channels are assigned using specific algorithms.
3. **Access controller**: This entity manages the access stations providing what is known as ***terrestrial links*** to the user. It is this element that implements the channel allocation algorithms.
4. **Switch controller**: This is the heart of the mobile network. Indeed, it is this entity that manages the network's mobility features and at the same time switches through connection sessions. It also interconnects with other networks of different types like PSTNs, other mobile networks, internet, etc.

5. **Service manager**: This element authenticates users, identifies their service permissions, assess their access rights, and manages the billing of services. This is a very intelligent network element, and forms another part of the network's heart.

The terminals, access station and controller all belong to the ***Radio Access Network***, commonly referred to as **RAN**. The RAN is in charge of providing access to the user, by providing ***terrestrial links*.** These are the physical links with which call sessions are made to access the network. It uses digital modulation for air interface, and a varied type of ***multiple access technologies***. The RAN provides the coverage.

The switch controller and service manager all belong to the ***Core Network***. This network provides and manages the services and mobility of a mobile network. Switching, location update, billing, authentication, and signaling, are some of the words used to identify the functions of the Core Network. This network can serve many RANs, interconnecting them along the line, and also interconnecting with other Core Networks. This permits inter-Network communication. Also they connect with PSTNs and Internet gateways, ensuring a variety of services provided.

1.2.3 User plane and Control plane

Now, a telecommunication network permits communication between users. To achieve this, each network element (NE) within the network, must be able to communicate with each other. This is so as to coordinate the channeling of the communication session from one end to the other. The user data carrying the actual message content moves in the network on the ***User plane***. Whereas, the communication data between network elements is done within the network on the ***Control Plane***.

It is essential to understand this fundamental notions, as they each present different aspects of the network, yet together form the network in its entirety. Control plane communication enables network element's resources to be allocated for the communication of User plane data.

Control plane = communication between NEs .e.g SS7 communication in GSM network. User plane = communication between users .e.g voice channels in a GSM network.

1.3 Evolution of Mobile Networks

The term "***Generation***" used to name successive evolutions of radio networks in general is arbitrary. There are several interpretations, and no official definition has been made despite the consensus behind ITU-R's labels. According to operators, a generation of network refers to the deployment of a new non-backward-compatible technology. The end user expects the next generation of network to provide better performance and connectivity than the previous generation. Meanwhile, GSM, UMTS and LTE networks coexist, end-users will only receive the benefit of the new generation architecture when they simultaneously:

- Use an access device compatible with the new infrastructure.

- Are within range of the new infrastructure, and
- Pay the provider for access to that new infrastructure.

1.3.1 First Generation (1G) networks

The First Generation (1G) networks were the analog cellular mobile communication networks in the period from the middle of 1970s to the middle of 1980s. The most important breakthrough during this period was the concept of cellular networks put forward by the Bell Labs in the 1970s, as compared to the former mobile communication systems. The cellular network system is based on cells to implement frequency reuse and thus greatly enhances the system capacity. The typical examples of the first generation mobile communication systems are the AMPS system and the later enhanced TACS of USA, the NMT and the others. The AMPS (Advanced Mobile Phone System) used the 800 MHz band of the analog cellular transmission system and it was widely applied in North America, South America and some Circum-Pacific countries. The TACS (Total Access Communication System) used the 900 MHz band. It was widely applied in Britain, Japan and some Asian countries. The main feature of the first generation mobile communication systems was that they used the frequency reuse technology, adopted analog modulation for voice signals and provided an analog subscriber channel every other 30 kHz/25 kHz. However, their defects are also obvious:

- Low utilization of the frequency spectrum
- Limited services
- No high-speed data services
- Poor confidentiality and high vulnerability to interception
- High equipment cost

1.3.2 Second Generation (2G) networks

To solve the fundamental technical defects of the analog systems, **digital mobile communication technologies** emerged and the ***Second Generation*** (***2G***) mobile communication systems represented by **GSM** and **IS-95** came into being in the middle of 1980s. The typical examples of the second generation cellular mobile communication systems are the **DAMPS** of USA, the **IS-95** and the European **GSM** system.

GSM (***Global System for Mobile Communications***) originated from Europe. Designed as the **TDMA** standard for mobile digital cellular communications, it supports a data rate of ***64 kbps*** and can interconnect with the **ISDN**. It uses the ***900 MHz*** band while the ***DCS1800*** system uses the ***1800 MHz*** band. GSM system uses **FDD** and **TDMA** modes and each carrier supports ***eight channels*** with a signal bandwidth of ***200 kHz***.

The **DAMPS** (***Digital Advanced Mobile Phone System***) is also called the **IS-54** (***North America Digital Cellular System***). Using the ***800 MHz*** band, it is the first of the two North America digital cellular standards and specifies the use of the TDMA mode.

The **IS-95** standard is another digital cellular standard of North America. Using the ***800 MHz*** or ***1900 MHz*** band, it specifies the use of the **CDMA** and has already become the first choice among the technologies of American **PCS** (***Personal Communication System***) networks.

Since the 2G mobile communication systems focus on the transmission of ***voice*** and ***low-speed data*** services, the **2.5G** mobile communication systems emerged in 1996 to address the ***medium rate data*** transmission needs. These systems include **GPRS/EDGE** and **IS-95B**. The CDMA system had a very large capacity that is equivalent to ten or even twenty times that of the analog systems. But the narrowband CDMA technologies came into maturity at a time later than the GSM technologies, their application far lags behind the GSM ones and currently they have only found large-scale commercial applications in North America, Korea and China. The major services of mobile communications are currently still voice services and low-speed data services. With the development of networks, data and multimedia communications have also witnessed rapid development; therefore, the target of the 3G mobile communication is to implement broadband multimedia communication.

1.3.3 Third Generation (3G) networks

The 3G mobile communication systems are a kind of communication system that can provide multiple kinds of high quality multimedia services and implement global seamless coverage and global roaming. They are compatible with the fixed networks and can implement any kind of communication at any time and at any place with portable terminals.

Put forward in 1985 by the **ITU** (***International Telecommunication Union***), the 3G mobile communication system was called the **FPLMTS** (***Future Public Land Mobile Telecommunication System***) and was later renamed as **IMT-2000** (***International Mobile Telecommunication- 2000***). The major systems include **WCDMA** and **CDMA2000**. On November 5, 1999, the 18th conference of ITU-R TG8/1 passed the Recommended Specification of Radio Interfaces of IMT-2000 and the **TD-SCDMA** technologies put forward by China were incorporated into the **IMT-2000 CDMA TDD** part of the technical specification.

The **3GPP** is an organization that develops specifications for a 3G system based on the **UTRA** radio interface and on the enhanced GSM core network. The **3GPP2** initiative is the other major 3G standardization organization. It promotes the CDMA2000 system, which is also based on a form of WCDMA technology. In the world of IMT-2000, this proposal is known as IMT-MC. The major difference between the 3GPP and the 3GPP2 approaches into the air interface specification development is that 3GPP has specified a completely new air interface without any constraints from the past, whereas 3GPP2 has specified a system that is backward compatible with IS-95 systems.

1.3.4 Fourth Generation (4G) networks

Fourth generation (**4G**) is a successor to the third generation 3G standards. In March 2008, the **ITU-R** specified a set of requirements for 4G standards, named the ***International Mobile Telecommunications Advanced*** (**IMT-Advanced**) specification, setting peak speed requirements for 4G service at ***100 Mbps*** for high mobility communication and ***1 Gbps*** for low mobility communication.

Two 4G candidate systems are commercially deployed: the **Mobile WiMAX** standard, and the first-release ***Long Term Evolution*** (**LTE**) standard. It has however been debated if these first release versions should be considered to be 4G or not, as discussed in the technical definition section below.

Since the first-release versions of Mobile WiMAX and LTE support much less than 1 Gbit/s peak bit rate, they are not fully IMT-Advanced compliant, but are often branded 4G by service providers. On December 6, 2010, ITU-R recognized that these two technologies, as well as others beyond-3G technologies that do not fulfill the IMT-Advanced requirements, could nevertheless be considered ”4G”, provided they represent forerunners to IMT-Advanced compliant versions and ”a substantial level of improvement in performance and capabilities with respect to the initial third generation systems now deployed”.

Mobile WiMAX Release 2 (also known as **Wireless MAN-Advanced** or **IEEE 802.16m**) and ***LTE Advanced*** (**LTE-A**) are IMT-Advanced compliant and backwards compatible versions of the above two systems, standardized during the spring 2011, and promising speeds in the order of 1 Gbit/s.

As opposed to earlier generations, a 4G system does not support traditional ***circuit-switched telephony service***, but **All-Internet Protocol** (**IP**) based communication such as IP telephony. The CDMA radio technology used in 3G systems, is abandoned in all 4G candidate systems and replaced by **OFDMA** multi-carrier transmission and other ***frequency-domain equalization*** (FDE) schemes, making it possible to transfer very high bit rates despite extensive multi-path radio propagation (echoes). The peak bit rate is further improved by smart antenna arrays for ***multiple-input multiple-output*** (**MIMO**) communications.

Figure 1.4 shows a brief evolutionary picture of mobile networks.

CHAPTER 1: INTRODUCTORY CONCEPTS ON MOBILE COMMUNICATION

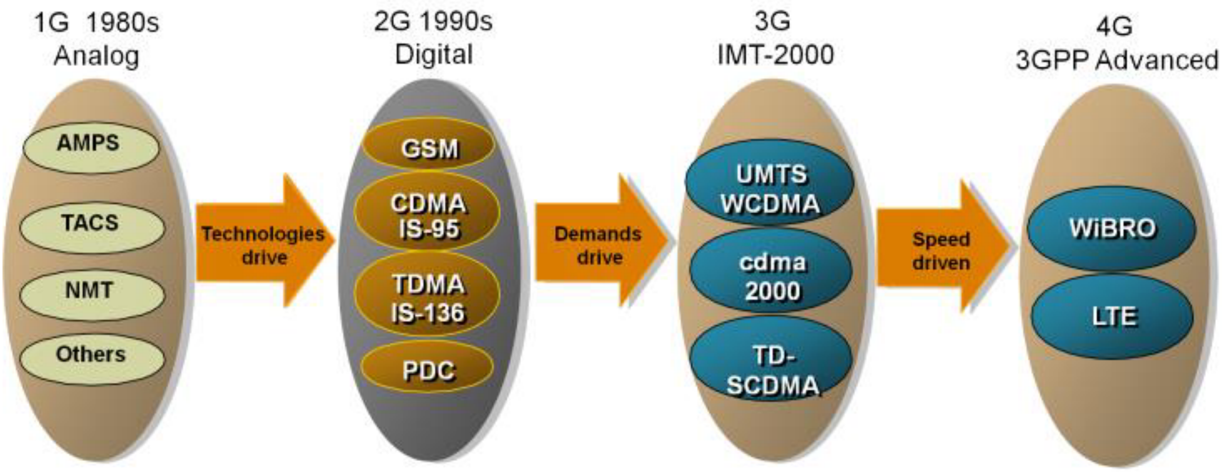

Figure 1.4: Mobile network evolution

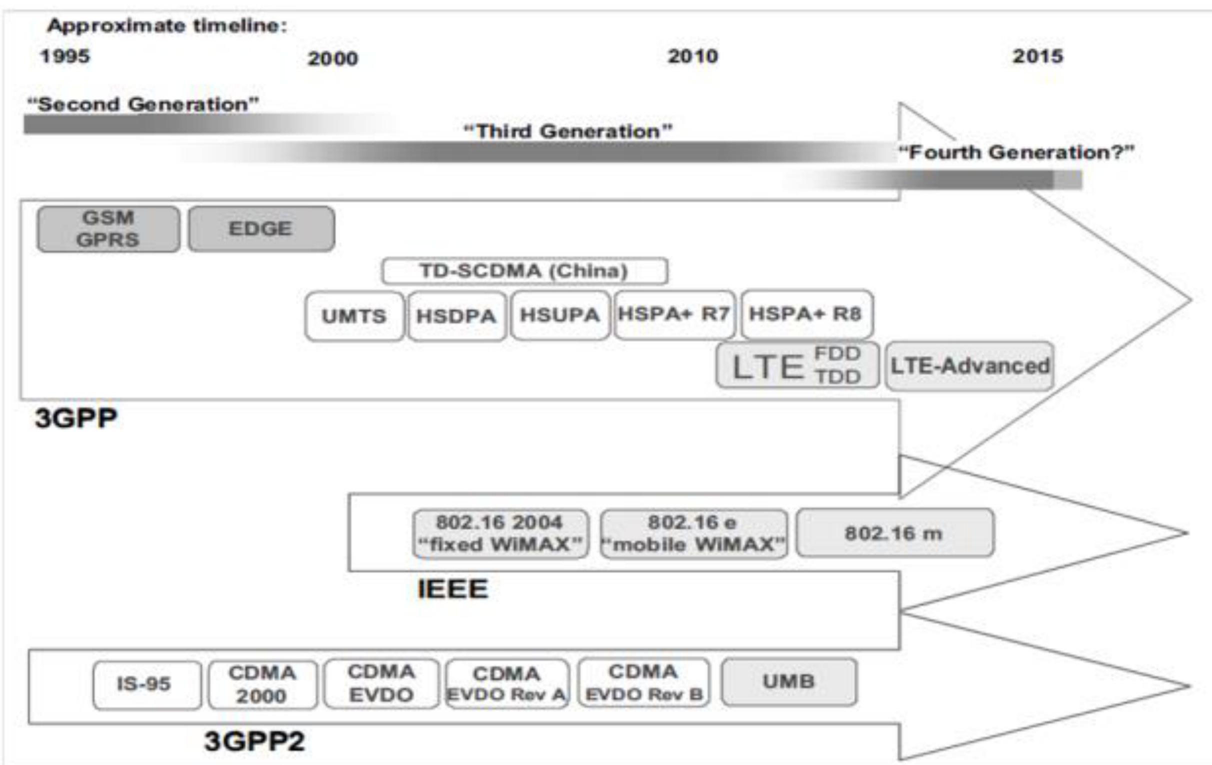

Figure 1.5: Evolutionary links

1.4 Fundamental techniques

1.4.1 Radio Transmission Techniques

Based on the type of channels being utilized, mobile radio transmission systems may be classified as the following three categories:

Simplex system

Simplex systems utilize simplex channels i.e., the communication is ***unidirectional***. The first user can communicate with the second user. However, the second user cannot communicate with the first user. One example of such a system is a pager.

Half Duplex system

Half duplex systems are radio systems that use half duplex radio channels which allow for ***non-simultaneous bidirectional communication***. The first user can communicate with the second user but the second user can communicate to the first user only after the first user has finished his conversation. At any given time, the user can only transmit or receive information. A walkie-talkie is an example of a half-duplex system which uses 'push to talk' and 'release to listen' type of switches.

Full Duplex system

Full duplex systems allow two way simultaneous communications. Both users can communicate to each other simultaneously. This can be done by providing two simultaneous but separate channels to both users. This can be achieved by one of the two methods: **Frequency Division Duplexing (FDD)** or **Time Division Duplexing (TDD)**.

Frequency Division Duplexing (FDD)

FDD supports two-way radio communication by using two distinct radio channels. One frequency channel is transmitted downstream/downlink from the Access station to the terminal (***forward channel***). A second frequency is used in the upstream/uplink direction and supports transmission from the terminal to the access station (***reverse channel***). Because of the pairing of frequencies, simultaneous transmission in both directions is possible. To mitigate self-interference between upstream and downstream transmissions, a minimum amount of frequency separation must be maintained between the frequency pair, known as the ***Duplex separation***. It is measured as a frequency gap as shown in 1.6.

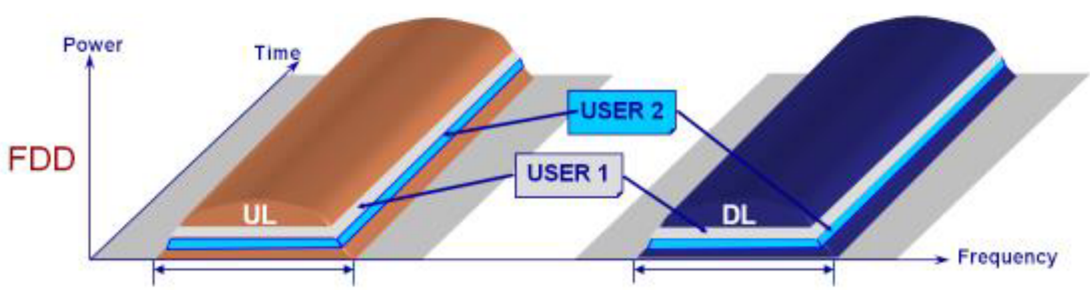

Figure 1.6: FDD

Time Division Duplexing (TDD)

TDD uses a single frequency band to transmit signals in both the downstream and upstream directions. TDD operates by toggling transmission directions over a time interval. This toggling takes place very rapidly and is imperceptible to the user.

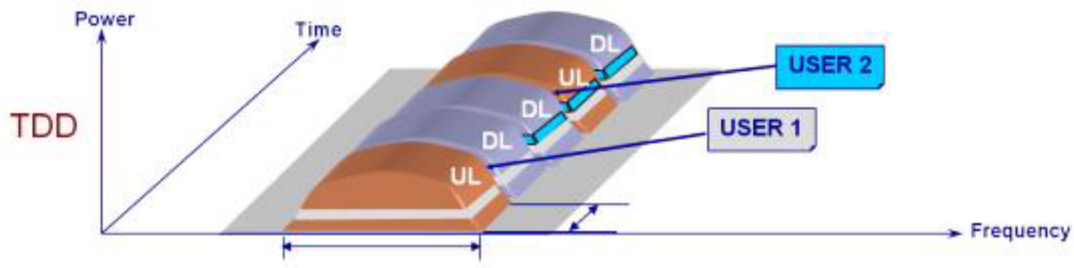

Figure 1.7: TDD

1.4.2 Multiple Access Technologies

1. Frequency Division Multiple Access

FDMA means dividing the whole available spectrum into many single radio channels (transmit/receive carrier pair). Each channel can transmit one-way voice or control information. Analog cellular systems are typical examples of FDMA structure.

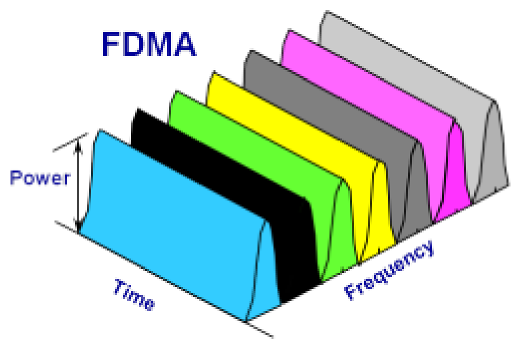

Figure 1.8: FDMA

2. Time Division Multiple Access (TDMA)

TDMA means that the wireless carrier of one channel bandwidth is divided into multiple time division channels in terms of time (called timeslot). Each user occupies a timeslot and receives/transmits signals within this specified timeslot. Therefore, it is called time division multiple access. This multiple access mode is adopted in both digital cellular system and GSM.

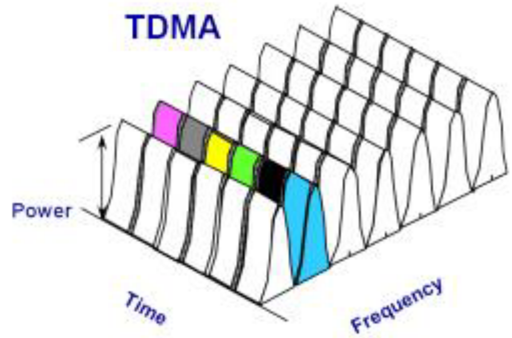

Figure 1.9: TDMA

3. Code Division Multiple Access

CDMA is a multiple access mode implemented by Spreading Modulation. Unlike FDMA and TDMA, both of which separate the user information in terms of time and frequency, CDMA can transmit the information of multiple users on a channel at the same time. The key is that every information before transmission should be modulated by different ***Spreading Code*** to broadband signal, then all the signals should be mixed and send. The mixed signal would be demodulated by another ***Spreading Code*** at the different receiver. Because all the Spreading Code are ***orthogonal***, only the information that was be demodulated by same Spreading Code can be reverted in mixed signal.

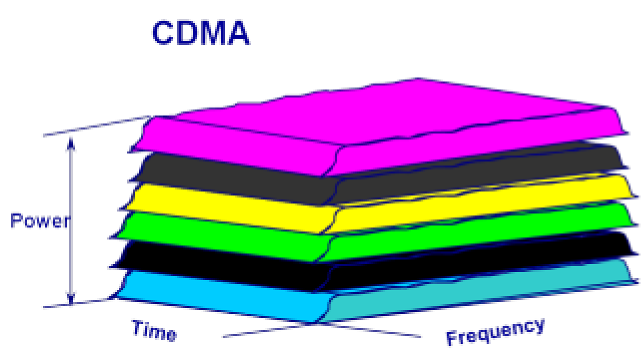

Figure 1.10: CDMA

4. OFDM/OFDMA

Orthogonal Frequency Division Multiplexing (**OFDM**) is a multicarrier transmission (multiplexing) technique, which divides the available spectrum into many carriers, each one being modulated by a low rate data stream. OFDM is similar to FDMA in that the multiple user access is achieved by subdividing the available bandwidth into multiple channels, which are then allocated to users. However, OFDM uses the spectrum much more efficiently by spacing the channels much closer together. This is achieved by making all the carriers orthogonal to one another, preventing interference between the closely spaced carriers. Conceptually, OFDM is a specialized FDM, the additional constraint being: all the carrier signals are orthogonal to each other.

In OFDM, the sub-carrier frequencies are chosen so that the sub-carriers are orthogonal to each other, meaning that cross-talk between the sub-channels is eliminated and inter-carrier guard bands are not required. This greatly simplifies the design of both the transmitter and the receiver; unlike conventional FDM, a separate filter for each sub-channel is not required.

Orthogonal Frequency-Division Multiple Access (**OFDMA**) is a multi-user version of the OFDM. Multiple access is achieved in OFDMA by assigning subsets of subcarriers to individual users. This allows simultaneous low data rate transmission from several users. OFDMA resembles code division multiple access (CDMA) spread spectrum, in that users can achieve different data rates by assigning a different code spreading factor or a different number of spreading codes to each user.

The difference between OFDM and OFDMA is that OFDMA has the ability to dynamically assign a subset of those subcarriers to individual users, using either TDD or FDD for multiple users. OFDMA simultaneously supports multiple users by assigning them specific sub channels for intervals of time. Point-to-point systems are OFDM and do not support OFDMA. Point-to-multipoint fixed and mobile systems use OFDMA. OFDM technologies typically occupy nomadic, fixed and one-way transmission standards, ranging from TV transmission to Wi-Fi as well as fixed WiMAX and newer multicast wireless systems like Qualcomm's Forward Link Only (FLO). OFDMA, however, adds true mobility to the mix, forming the backbone of many of the emerging technologies including LTE and mobile WiMAX.

1.5 Generic Call Flow

We will now finally delve into how a call is made in a mobile network. We will use our basic mobile network developed earlier on. All concepts we have learned earlier on will apply here to form a complete story. First let us define our actors.

1.5.1 The Actors

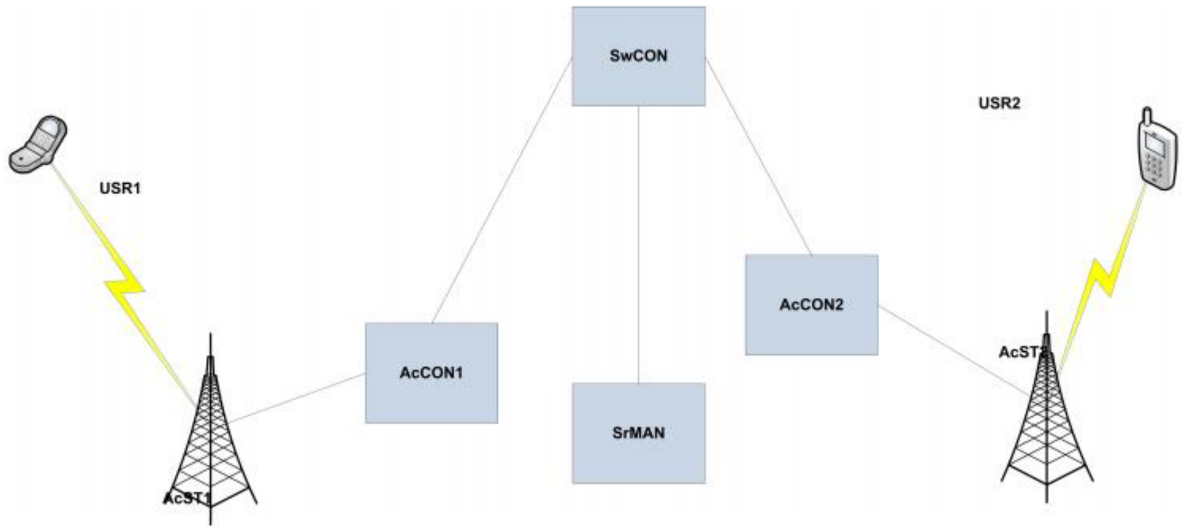

Figure 1.12: The Actors

Shown in 1.12 are the main actors involved in the process of making a call. Their functions were well defined in section 1.2.2.2. They are:

1. **USR1 and USR2:** These are the network terminals.
2. **AcST1 and AcST2**: Access Stations.
3. **AcCON1 and AcCON2**: Access Controllers.
4. **SwCON:** Switching Controller.
5. **SrMAN**: Service Manager.

1.5.2 The Plot

Let us define interfaces for all actors, and divide into user plane and control information. **As a reminder, user plane carries the user data, while control plane carries NE communications.**

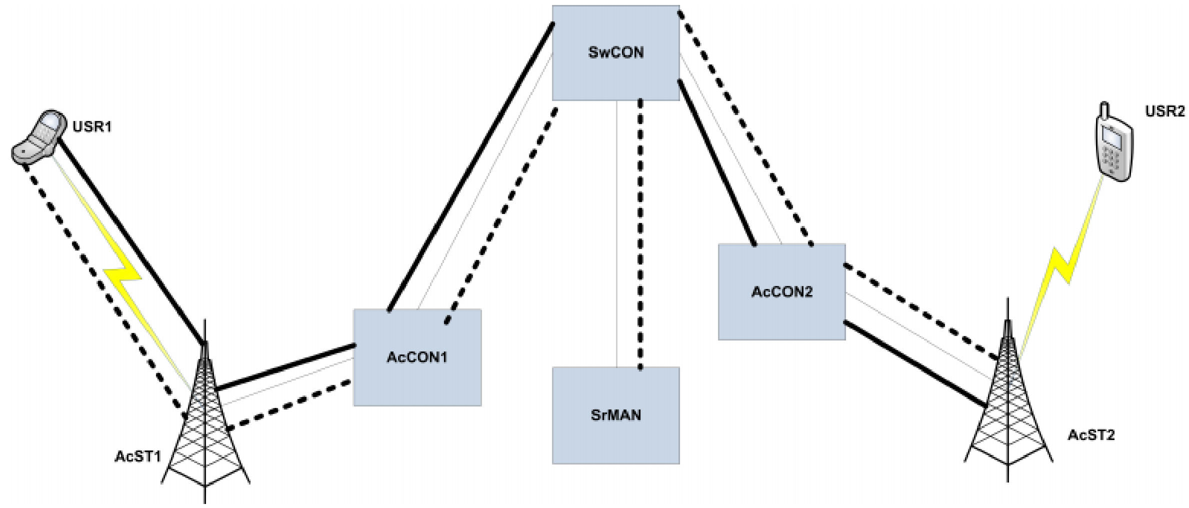

Figure 1.13: The Plot

The Full lines represent user plane path, while the dotted lines represent control plane path. The plot is for user 1 to successfully make and terminate a call with user 2.

1.5.3 The Act

Using Figure 1.13, let us explain the ACT of Calling or making a mobile call. In the industry, this is known as a **communication flow**.

1. **Radom Access**: USR1 requests from AcCON for a channel to communicate in control plane.
2. **Service Access**: After a control plane channel is established, USR1 can now communicate with the Core Network .i.e the SwCON. The SwCON will immediately request the SrMAN to check if USR1 is not illegal, and to what services he has been subscribed. Once a response is received from SrMAN as positive, SwCON will then ask USR1 to state its business.
3. **Service request**: USR1 will respond with the address of USR2 as user to be called. SwCON will request SrMAN to identify the legality of USR2 in its network, and also for the current location of USR2. Once USR2 is found, SwCON will page it, through AcCON2 and AcST2, informing it of a call. USR2 will also request from its serving AcCON2 for a communication channel. With this channel it will aknowledge the page message of SwCON.
4. **Service following**: Once SwCON receives a response from USR2, it then sends a ringtone to USR2 notifying it to pick up the call, and a feedback dial-tone to USR1 notifying a ringing. Once USR2 picks up, a voice channel is set up to carry the user traffic in the user plane, End-to-End.
5. **Call processing and termination**: Once call is started, USR1 can talk to USR2. When call is over, USR1 drops the line, sending a message to SwCON on control plane that it has terminated call. SwCON will then release all communication resources, as well as the

AcCON will release the links to the terminals. Call was started and finished successfully, now next session is awaited.

1.6 Future Trends

Assignment: Research on 5G networks and Internet of Things.