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WIRELESS SYSTEMS IN DEVELOPING COUNTRIES

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DEDICATION

To all members of my family lost in the Genocide perpetrated against the Tutsis in 1994,
you are and will always be in my heart

Abstract

The technology is among the important tools for sustainable development in the world. The way is spread in various countries is somehow dissimilar according the economic resources of each country.

It is for that reason our work focuses on the use of technology in different countries with a particular attention to developing countries. The technology on which we underscored is wireless system, as emphasized by many examples is nowadays more used than wired system thanks to its advantages in deployment and utilization.

In order to analyze how wireless systems are used in developing countries certain methodologies are adopted. At first sight, the current use of wireless systems in developing world is shown with the aid of a table. Above all, we have also considered the architecture of wireless systems where through a project aimed to make intelligibility tests an architecture is designed and implemented with wireless equipments.

Among the principal methods for the transmission of data in wireless systems, the multicast transmission is analyzed with greater interest through the protocols and algorithms most important. This study suggests that the multicast transmission makes better use of wireless systems.

Taking into account the best utilization of wireless system, it is obviously clear that this technology would not be well utilized and exploited when the frequency is not well managed. Therefore, a study concerning the spectrum management, spectrum cost and methodologies applicable in both developed and developing countries is carried out which further

availed to suggest a better frequency utilization in developing countries.

At the end of this work it is observed that the use of wireless technologies is moving forward rapidly in developing countries as indicated by the rapid growth of mobile phone users and other wireless technologies. The implementation of new technologies is easier in these countries as it does not require an upgrade from old to new technologies which sometimes seems impossible or demands expensive and a lot of work. Several conclusions are then drawn for particular cases.

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Chapter 1

Introduction

To achieve sustainable development, any country should take in consideration its technology sector updating it to the new technologies. Developed and developing countries are responding to the growth of technologies either wired or wireless technologies and it has been seen that wireless technologies tend to dominate the wired technologies in applications thanks to the benefits offered by wireless technology. Among those benefits there are *the cost* where wireless system is less expensive due its ability of being installed without wires which yields *to rapid implementation*, *mobility* and *portability* that facilitate users to move from one location to another, *feasibility with new wireless applications*, *easy failure location* that permits the easy detection of technical problems, and many other benefits that are not cited here.

Wireless technology is an enormous potential alternative to wired networks that is changing the way people and things communicate. With its technologies like GSM, GPRS, EDGE, UMTS, mobile wireless, fixed wireless, portable wireless and other technologies, wireless technology is speedily evolving at the same time playing an important role in daily life of the worldwide population. This work discusses concepts common to different types of wireless systems with emphasis on wireless system applications, the spread of different types of wireless systems in developing countries as well as their spectrum management

comparing them with the current wireless system situation in developed countries.

This work is organized as follows: Chapter 2 describes the spread of wireless systems with the aid of an overall mapping that figure out the utilization of wireless systems in the world and a special focus on developing world. In chapter 3, a case study that shows an example of wireless system applications is presented through a project realized with acoustic department of Ferrara for intelligibility tests. The project done offered the benefits such as allowing the tests to be performed in a wireless and non acoustical environment permitting multi users tests which have not yet been done. Chapter 4 discusses the multi users of the same wireless services which reflects to multicast wireless, different protocols and algorithms are studied and suggestions have been made regarding the utilization of this technology in developing countries. In the last chapter of this thesis, chapter 5, the management and the cost of the spectrum in some developing countries are studied comparing the methodology used in developing and developed countries for a better utilization of the frequency. In the conclusion made for this part, some suggestions have been presented in order to ameliorate the best use of the spectrum in developing world.

Chapter 2

Spread of Wireless Systems

In this speed era of technology, wireless system is playing an important role in the way people and things communicate. Like its name explains, wireless means communication without use of wires, antennas or other materials used in the ground to wiring the wired communication. Wireless systems architecture is based on two types of devices; access point (AP) and wireless terminal. An access point (AP) is a device that allows wireless devices to connect to a wired network using WI-FI, Bluetooth or related standards while the wireless terminals are devices that make use of network services such as PDAs, cellular phones, notebook or other equipments that interface the standard IEEE 802.11 or consumer systems on Bluetooth technology.

Compared to the wired networks, wireless networks offer important advantages over the wired networks, it permits some services that might be impossible or impractical with the use of wires. Its advantages are very known and some of them are: flexibility, simplicity, reduced cost of ownership and scalability.

Nowadays wireless technologies include cellular telephones, PDAs, GPS units, garage door openers, headphones, radio receivers, satellite television, broadcast TV, cordless telephones, etc. All these wireless technologies are classified in four current wireless systems named as; *Wireless LANs*, *Wide Area Wireless Data Services*, *Broadband Wireless Access*

and Satellite Networks. Among the current wireless systems, Wireless LANs have become the preferred Internet Access used in many homes, offices and campus environments due to ease of installation, their convenience, mobility, expandability, cost and free from wires.

Despite the popularity of Wireless LANs, the Cellular telephone has been the most successful application of wireless networking all over the world.

2.1 Wireless System Generations

First Generation (1G)

The first generation wireless technology(1G) is the original analog, voice-only cellular telephone standard launched in Japan by NTT (Nippon Telegraph and Telephone) in 1980s. The cellular telephone had been launched initially in the metropolitan area of Tokyo and it has been expanded to cover the whole population of Japan within next five years.

The Nordic Mobile Telephone (NMT) system came next in 1981, this system was used in Nordic countries such as Denmark, Norway, Iceland, Finland and Sweden, as well as in its neighboring countries Switzerland, Netherlands, Eastern Europe and Russia. Different 1G standards were used in various countries in this period where RTMI (Radio Telefono Mobile Integrato) was used in Italy, TACS (Total Access Communication System) in the United Kingdom, France used the Radiocom 2000, AMPS (Advanced Mobile Phone System) used in North America and Australia, C-450 in West-Germany, Portugal and South Africa. TACS operates at a higher frequency and with lower bandwidth channels than AMPS [1].

The important disadvantage of 1G had been the impossibility to roam between European Countries with a single analog phone, and this reason had motivated the need for one unified cellular standard and frequency allocation throughout Europe. This motivation lead to the second generation (2G) wireless cellular mobile services that provides the roaming facility and short message service (SMS).

Second Generation (2G)

Contrary to its predecessor, 2G technologies are digital signals that allowed to their users to benefit certain services such as SMS (Short Message Sent), picture messages and MMS (Multimedia Messaging Service). SMS is a cheap and easy way to communicate by sending a text message to any mobile network at any time instead of calling. This second generation (2G) telephone technology was launched in Finland in the year 1991 and its technology is based on GSM (Global System for Mobile Communication) which support the international roaming. International roaming is one of the benefit of 2G compared to 1G, where mobile subscribers are enabled to use their mobile phone connections outside their countries. Second generation technologies are either time division multiple access (TDMA) or code division multiple access (CDMA). In TDMA, several users transmit at the same frequency but in different time slots while in CDMA users transmit at both same frequency and time, modulating their signals with high bandwidth spreading signals [2]. TDMA technologies are GSM which accounts for over 80% of all subscribers around the world, IS-136 (Interim Standard 136 known as Digital AMPS) used in Americas, PDC (Personal Digital Cellular) excursively used in Japan; and IDEN (Integrated Digital Enhanced Network) used by Nextel in the United States and Telus Mobility in Canada. CDMA technologies are IS-95 (Interim Standard 95) used in Americas and some part of Asia, nowadays this technology accounts about 17% of all globally subscribers.

Benefits of 2G are not limited to GSM or SSM services, the *"reduction of fraud"* is another advantage of digital systems while in analog systems it was possible to have more cloned handsets with the same phone number[3]. 2G phones prove an enhanced privacy with their protection against eavesdropping, which is the weakness of 1G phones.

The disadvantages of 2G technology include its occasional dropouts when the conditions are not good by failing completely, dropping calls or being unintelligible; and in the case of less populous areas when the digital signal is weak and not be sufficient to reach a cell tower.

Evolution

2,5 G

2,5 G describes a *"Second and a half generation cell phone technology"* that bridged 2G to 3 G wireless technology. This wireless system generation describes a 2G cellular system combined with General Packet Radio Services (GPRS). GPRS service provides data transmission rates of 28 kbps or higher, is based on packet-switched technology and this makes its infrastructure more efficient and improve the service delivery, and always on-capability[4] [5].

2,5 G can also provide data rate up to 144 kbps and support services such as MMS (Multimedia Messaging Services), WAP (Wireless Application Protocol), SMS mobile games, etc.

2,75 G

This term is occasionally used to refer to EDGE (Enhanced Data Rates for GSM Evolution) data connectivity. This technology is faster than GPRS but slower than typical 3G networks. Enhanced Data Rates for GSM Evolution (EDGE) also known as Enhanced GPRS (EGPRS), IMT Single Carrier (IMT-SC), or Enhanced Data rates for Global Evolution is an official ITU ratified 3G technology that delivers high bit-rates per radio channel, resulting in multiple increase in both capacity and performance compared with GSM and GPRS connections[6]. EDGE does not require any changes either hardware or software to be made in GSM core networks, the network can be upgraded to EDGE by activating an optional software feature.

GSM network topology is presented in the figure below:

In the graph,

UM represents the radio link, while A shows the interface between the base stations and base station controllers.

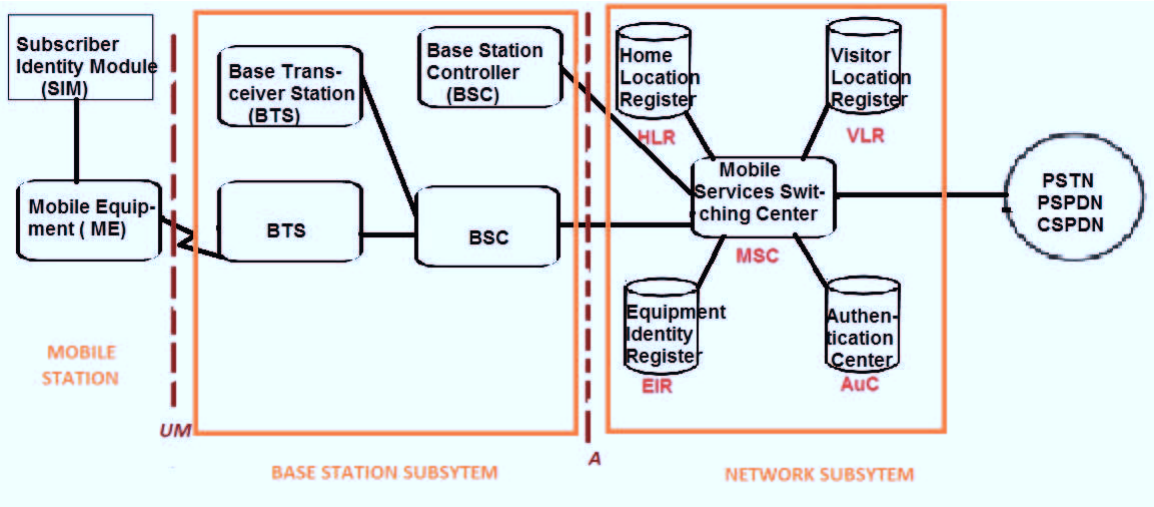

Figure 2.1: GSM network topology

Third Generation (3G)

As this generation era of cellular standards appears every ten years approximately, the third generation wireless technology (3G) is a generation of standards for mobile phones and mobile telecommunication services that fulfills the *International Mobile Telecommunications-2000* (IMT-2000) specifications defined by a set of interdependent ITU (International Telecommunication Union) recommendations in the mid-1980s, but the 3G research and development projects started in 90's.

The third generation (3G) networks is not limited in wireless network technologies, it uses a certain variety includes CDMA, GSM, WCDMA, CDMA 2000, TDMA, UMTS and EDGE. Compared to its predecessor, 3G networks offer greater security by allowing the User Equipment to authenticate the network is attaching to, this makes sure that the network using is the desired or the intended one and not the impersonator[7] [8]. Even if this wireless network generation offers more advantages, its difficulty in deployment has been one of the problem presented. The difficulty in deployment is the slowness to be adopted globally during the migration from 2G to 3G, where in some cases the radio frequencies

to be used in 3G networks are not the same as in 2G networks, so mobile operators have to build entirely new networks, license and frequencies for further achieving high end data transmission rates [9] [10]. It has also to be mentioned the delays due to the expenses of upgrading transmission hardware especially for UMTS, the one requiring the replacement of most broadcast towers for deployment.

The key features of 3G systems include the compatibility of services, use of small terminals with international roaming capability, Internet and so on. 3G system can determine geographic position of mobiles then report it to the network and the mobile terminal.

Characteristics of 3G:

Flexibility: The flexibility of 3G is founded in its capability to support a wide range of services and applications

Compatibility: The compatibility of 3G technology with existing systems like 2G technology makes ease the evolution of new technologies.

Affordability: Using the existing infrastructure as 2G networks, 3G networks become more affordable for deployment.

Modular Design: 3G networks are easily expandable, this permit its growing in capacity, coverage and new services with minimum initial investment.

3G evolution

3.5G

In the 3G era, 3G mobile phone platform has been the advanced form of mobile communication allowing users to stream video, send large files, have voice calls and receive TV signal using a mobile phone, but all these services got better with the arrival of 3.5 generation. The 3.5G solution assures a data download speed of up to 14Mbps and an upload speed of up to 1.8 Mbps.

3.5G denotes the continuation and upgrade of 3G technology, it banks on the *High-Speed Downlink Packet Access* (HSDPA) protocol which provides the download speeds more faster than earlier versions of 3G.

According a survey done in 2007, the number of commercial 3.5G networks (known as HSDPA) launched worldwide was grown by 69 percent which implicates that nowadays it has grown more than that. Commercial HSDPA networks are widely available in South-east Asia, Western and Eastern Europe, the Middle East and Africa, the Americas and the Caribbean.

3.75G

3.75G is a term occasionally used to refer to *HSUPA* (High-Speed Uplink Packet Access). 3.75G technology enables faster broadband services for its customers with its very fast Internet access, video streaming & calls, and mobile TV applications.

As the next step of HSDPA, HSUPA is a data access protocol for 3.75G networks that enhances the uplink speed of UMTS/WCDMA networks and advanced person-to-person data applications with higher and symmetric data rates such as mobile e-mail. The enhancement of the uplink speed will be benefited by traditional business applications and many consumer applications.

Comparing HSDPA and HSUPA, these two protocols are complimentary to one another, they both offer high voice and data performance as well as the success of mass-market mobile IP multimedia once together.

Some of the advantages of HSUPA mentioned are; connecting the advantages of UMTS-a wide range network coverage in the final development and an application for use while on the move like when driving cars, the system's advantages of radio-based local networks and WLAN in providing inexpensive broadband Internet. HSUPA should also be inexpensive thanks to its system based on software so that new development or installed infrastructure are no longer needed by mobile network providers, it is just a matter of updating the

existing network equipment with new software.

3.9G

Called a pre-4G technology, 3.9G is known as *3GPP LTE* (Third Generation Partnership Project / Long Term Evolution) often branded as 4G, is a collaboration between groups of telecommunications associations, known as Organizational Partners with the scope of making a globally applicable third-generation mobile phone systems specification based on evolved Global System for Mobile Communications (GSM) specifications within the scope of IMT-2000 project of the ITU. The project was established in December 1998 with these Organizational Partners: Alliance for Telecommunications Industry Solutions from North America, Association of Radio Industries and Businesses/Telecommunication Technology committee (ARIB/TTC) from Japan, China Communications Standards Association, European Telecommunications Standards Institute and Telecommunications Technology Association from South Korea.

The scope of 3GPP was later enlarged including the development and maintenance of the GSM (Global System for Mobile Communications), the evolution of 3GPP core networks and the radio access technology supported by the Partners, an evolved IP Multimedia Subsystem (IMS) developed in an access independent manner.LTE has a net bit rate capacity of up to 100Mbit/s in the downlink while for the uplink the net bit rate capacity is 50Mbit/s in the case a channel of 20MHz is used , and more if MIMO (Multiple-Input Multiple-Output) i.e. antenna arrays, are used[11].

Being an evolution of 3G, 3.9G technology is an advanced technology compared to 3G based on the frequencies of 2.1 GHz, that allows a fast data transmission which offer greater benefit to consumers.

Fourth Generation (4G)

Successor of 3G Technology, 4G is the fourth generation of cellular wireless standards defined by the ITU-R organization in 2009 specifying the IMT-Advanced requirements for 4G standards through setting up the peak speed requirements for 4G service at 100 Mbit/s for high mobility communication such as trains and cars and 1 Gbit/s for low mobility communication such as pedestrians and stationary users.

4G technology is the very latest and ultra fast technology aiming to provide fastest speed to all users such as users of mobile or smartphones, it is also expected to provide a comprehensive and secure all-IP based mobile broadband solution to Laptop Computers, Wireless modems and other Mobile Devices. The 4G facilities that may be provided to users while using it include Ultra-Broadband Internet Access, IP telephony, Gaming Services and Streamed Multimedia [12]. The word "MAGIC" has been referred to describe 4G technology which stands for Mobile multimedia, Any-where, Global mobility solutions over, Integrated wireless and Customized services. This word summarizes the characteristics of 4G technology.

The fourth generation (4G) will be based on OFDM (Orthogonal Frequency Division Multiplexing) which is its key enabler. Owing to its great benefits, OFDM is preferred because of its characteristics of sending data over hundreds of parallel streams thus increasing the amount of information to be sent at a time over traditional CDMA networks; the same for future broadband application such as wireless ATM, this technique is being considered.

OFDM technique

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission technique that allows the transmission of very high data rates over channels at a comparable low complexity .This technique divides the available spectrum into many carriers where each one is being modulated by a low rate data stream[13]. It is known that OFDM uses

the spectrum much more efficiently by spacing the channels much closer together and to achieve this, all the carriers are made orthogonal to one another preventing interference between the nearly spaced carriers.

Main features of 4G technology

- The entire network would be packet switched, IP networks based on Ipv6.
- The 4G technology will be able to support Interactive services like Video Conferencing (with more than 2 sites simultaneously), Wireless Internet, etc.
- All switches would be digital
- The bandwidth will be much wider (100MHz) and data will be transferred at much higher rates,the cost of the data transfer will be comparatively very less and global mobility would be possible, which would make cheap data transfer possible.
- The antennas will be much smarter and improved access technologies like OFDM and MC-CDMA (Multi Carrier CDMA) will be used.
- The network security features will be much tighter.
- The Quality of Service (QoS) will improve much more.
- More efficient algorithms at the Physical layer will reduce the Inter-Channel Interference and Co-Channel Interference.

Generations	1G	2G	3G	4G
Evolutions		**2.5 & 2.75G**	**3.5G & 3.75G**	**Pre-4G & 4G**
Technologies	AMPS, NMT, TACS, etc.	TDMA, GSM, PDC, GPRS, EDGE, CdmaOne(IS-95A), . etc	GSM, WCDMA, CDMA2000, UMTS, HSDPA, HSUPA, etc.	LTE, WIMAX, UMB, OFDMA, etc.
Characteristics	Middle Mobility	Roaming, Capacity & Quality, Medium Speed Data, etc.	More Capacity, High Speed Data, Global Roaming, High Mobility, etc.	Security, High data rates, Good Quality of Service, Cheap network, Multi-functionality, etc.
Year	1980's	1990's to 2002	From 2003 to 2010	From 2010 to 2015+

Table 2.1: Evolution of technology from 1G to 4G

WiMAX

Worldwide Interoperability for Microwave Access (WiMAX) is a wireless digital communications system that delivers high-speed Internet service to large geographic areas, also known as IEEE 802.16 standards that is intended for wireless "Metropolitan Area Networks". Described on its forum, WiMAX is a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL. According the low costs deployment of a WiMAX network, providing last-mile broadband Internet access in remote locations is economically feasible. As specified in 802.16 standards, WiMAX will support low latency applications such as video, voice, and Internet access at the same time. WiMAX technology provides higher speed connection of up to 70

Mbps over the area of 30 miles[14].

WiMAX applications

Wimax network enables the new era broadband service deployment providing a broad customer base while adding up a mobility feature to those services. As already mentioned, Wimax technology provides data, video, mobile and Internet access to the service providers, it also provides prospective cost saving and service efficiency to be able to allow VoIP calling, mobile devices, video making and high speed data transfer. Even if the previous cited applications are known as Wimax technology applications and look like the more important of all, Wimax technology offered the most important applications which are business, consumer connectivity and backhaul.

A part from these applications, Wimax technology provides exclusive applications such as Connectivity for SMBs, Wimax Backhaul, Nomadic Broadband, Broadband for developing countries, and Private Networks. Connectivity for Small to medium-sized businesses (SMBs) is the most effective application offered by Wimax progressing day by day thanks to Wimax technology connectivity that attract and facilitate clients with various types of services like hotspot and so on. Wimax backhaul refers the connectivity of one tower to another one by means of a line-of-sight (known as microwave link), it has the ability to cover up 3,000 miles since Wimax network covers rural or remote areas. Nomadic broadband is a service tailored for laptops which is under the marvelous plan of WIFI. Broadband for developing countries will provide to developing countries the ability to reduce costs, making wireless broadband affordable for these nations where mobile phone users continue to grow day by day in a a huge number. Private networks are expected to be the very last Wimax application which emphasizes the logical position of Wimax as the wireless technology for MAN (Metropolitan Area Network).

WiMAX deployment

After the rapid growth of Wimax technology in large business companies, multimedia project software and hardware manufacturer, large business corporations such as Intel, Motorola, Samsung and others have started worldwide deployment. After the progressing of cables and DSL technologies used to bring wireless broadband access to rural areas, wimax technology was spread to a great extent all over the world in the year 2009. Nowadays, the wimax deployments has been started in certain countries while in others is about to complete and covering whole world [15]. As claimed by Wimax forum in February 2011, wimax technology covered over 823 million people, and estimated over 1 billion subscribers at the end of the year.

WiMAX services

Wimax technology provides different services that change the way we leave, the services are including Mobility, Coverage, Maintainability, Roaming services, and other valuable services for the ease and multitenancy expansion. Wimax offers both fixed and mobile wimax, as well as point to point or point to multipoint network [16]. The high value services of wimax technology are Data and networks, CCTV surveillance, Access control, Home Automation, Intercoms and Security.

- *Data and networks* make available a customized network for home, business and others providing accurate proficiency in telecommunications and latest technology of routers and hub to get the best results when broadcasting.
- *CCTV surveillance*: Through security cameras, our businesses get secure as well as our home. Different cameras are provided such as Time lapse security recorder, spy security cameras and so on.

- *Access control system* permit the flow of personal data and encrypted unwanted visitors or others with bad intention to save your data. Other cited access control system offered by wimax services are pin codes, swipe card and proxy readers.

- *Home automation* offered by wimax services are home theatre technology, high quality sound, best quality DVD player and recorder.

- *Intercom system* is one of the wimax services used most in big hotels, restaurants, educational institute and universities where after a confirmed visit, a host allows a visitor to enter home by releasing electronic door. Another service provided by this system is permitting inhabitants to speak via a call station with visitor.

- *Security* is a significant wimax service that provides full security with well thought-out wiring for telephone, video and Local Area Network (LAN). This security in wimax is enhanced by its key aspects designed in its mind such as “Support for privacy” where user data is is encrypted using cryptographic schemes such as AES (Advanced Encryption Standard) and 3DES (Triple Data Encryption Standard); “ Authentication in wimax technology” offers a flexible means for authenticating subscriber stations and users in order to prevent unauthorized use; “ Flexible key management protocol” that transmits keying material securely from the base station to mobile station; “ Protection of control messages “ that uses the message digest schemes such as AES (Advance Encryption Standard) or Message Digest 5 to protect the integrity of the messages; “Support for fast handover” where wimax technology permits the mobile station to use pre-authentication with a specific target base station to assist accelerated re-entry.

Advantages of Wimax technology[17]

1. *Coverage* : The wimax coverage provided by a wimax single station can operate for hundreds of users at once as well as managing the sending and receiving of data at a

very high speed with the entire network security.

2. *High speed* : in scarcely populated area, the wimax high speed plays an important role as the desired one in these areas thanks to its connectivity over long distance and high speed voice.

3. *Multi-functionality* : Wimax is a multitasking technology that performs a variety of task at a time such as offering high speed internet, providing telephone service, transformation of data, video streaming, voice application and so on.

4. *Potential and development* : Being a new technology with enough potential for developing and opportunity to offer a variety of services, wimax offers the opportunity to be connected to internet wherever you are, browse any site and make online conference using mobile internet. There is a plenty of services offered by wimax.

5. *Stay in touch with end user* : Providing absolute communication service to end users, Wimax network helps in keeping in touch with friends and other users using the same wimax network.

6. *Wimax infrastructure* : is very easy and flexible thus provides reliability of network at a maximum extent and respond favourably to actual access to end users.

7. *Cheap network* : Wiamx provides a low cost network alternative to internet services offered through ADSL, modem or LAN.

8. *Rich features* : These rich features offered by wimax make it useful. The rich features told are separate voice and data channel for fun, the semantic connection that makes the network more secure than before, fast connectivity, license spectrum, etc.

9. *Wimax and Wifi* : The comparison of the two shows that the wimax network provides much higher speed and very long range compared to wifi technology.

10. *Smart antenna and Mesh topology* : In Wimax technology. The use of smart antenna provides high quality widest array that renders capable the communication on long route without any encryption. On its turn, the use of Mesh topology in wimax networks is an extensive spectrum of antennas for commercial as well for residential users.

11. *Ultra wide band* : The Wimax infrastructure design is providing a range from 2 to 10 GHz as well as outstanding time response.

12. *Homeland security* : Wimax technology offers high security through the encryption system used, it provides also exclusive homeland security. Wimax enables changing of data on whole network without any fear of loosing data.

13. *Lack of history* : Wimax has no history in mobile industry, it pushes the existing technologies and forward on steady stream, it is the first mobile transporter supporting wireless and wired networks including cable operator successful due to wimax core networks.

Disadvantages of Wimax technology

Wimax technology has not only the advantages but faces some disadvantages that we are going to discuss below.

1. *Lack of quality* : Due to heavy traffic caused by many users trying to get access through the same tower, wimax network becomes unable of providing the good quality of its services because it becomes hard to maintain high quality as the network is overloaded.

2. *Wimax range* : The range is another disadvantage of wimax network. This problem is caused by the speed provided by wimax network in moving station, this speed range of 70 Mbps is practically different because it is only possible in a specific or ideal

circumstances. The problem occurs when a user is staying away from the specified environment which may cause the drop of the speed.

3. *Bandwidth* : Wimax bandwidth tends to decrease in case lot of users are in one area.

4. *Expensive network* : The installation and operational cost of wimax network need heavy structure, tower, antennas and other appropriate equipments which further make the wimax network installation and operation very expensive.

5. *Bad weather* : During bad weather like rainfall season, the quality of service of wimax network may decrease because the weather condition could interrupt the signal that causes bad signal as well as stopping or interrupting of broadcasting.

6. *Wireless equipments* : The use of many wireless equipments at a time in Wimax network may cause interference or interfere the broadcasting data, or facing some compromised speed.

7. *Power consuming* : Wimax network needs much electrical support to run the overall network.

8. *Data rate* : Wimax data rate is very slow compared to other networks such as fiber optics, cables, satellite, etc.

The figure below shows how wimax works.

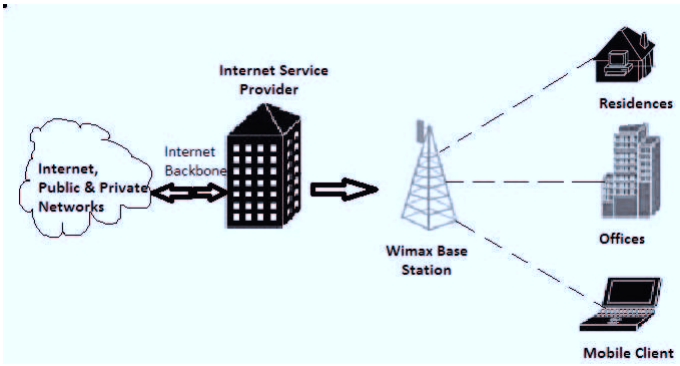

Figure 2.2: How WiMAX works

2.2 MAPPING OF WIRELESS SYSTEMS IN THE WORLD

Wireless systems are spread all parts of the world at different levels, certain continents or countries are more developed in technology while others are at their starting stage. In this section, we are going to select some countries and compare their mapping in wireless systems. The selected countries are Japan, Italy and some of the third world countries. Japan as one of the most developed countries in technology is a role model on how technology is growing fast that is why we took it in consideration during our studies. Italy as a country where my studies were going on, it has taken in consideration because it is one of European union countries where the technology is advanced and continue to grow up. Third world countries figured in our first work where we worked on its switching from one generation to another. The case study was Rwanda and its launching of GSM in previous years as well as the new strategies to reach the next generations of wireless systems.

Mapping of Wireless Systems in Japan

In Japan, mobile phones have become ubiquitous as the big number of the Japanese population own cellular phones. With the rapid growth of technology, the cellular phones owned by the Japanese people are well equipped with enhancements such as video, camera and games capabilities as well as other new enhancements as long as the technology continues to grow. Those cellular phones are of good quality and own some properties such as waterproof. Being one of the countries with advanced technology, Japan has been the first to launch 3G services on a large scale and the newest technologies are on track to be launched.

With the use of Internet, some cellular phones get access to Internet and this facilitates some services like checking train schedules and planning trips on public transit, sending e-mails using phones, navigation by GPS and so on. Massaging is very common in Japan because in public transportation, making a call is not recommended. The low per message-price and ample allowed length per message (10,000 characters per message), special characters to use, emoticons and pictures, and the use of astrological symbols, all these facilities are benefited by mobile phone users and enhance the use of cellular phones in Japan.

The rapid growth of Internet is relative to the growth of mobile devices such as services offered by mobile phones through Internet. One of many examples in Japan is the mobile phone wallet technology commonly know as “FeliCa”, this technology has been invented by Sony working with NTT DoCoMo and uses an RFID chip inside the handset that can communicate with reading devices when the phone is placed near them [18] [19]. Despite being a new technology, this system can be used in many locations such as convenience stores and some vending machines. It has to be noted that users must charge up their accounts with credits before making any payment using their phones. After seeing the popularity of the system, other manufactures are making the compatible phones. A cell phone novel was firstly published in Japan in the year 2003 and has spread to other countries like China, Germany and South Africa as long as in other European, African and East Asian countries. Cell phone novels gained its popularity through a virtual world created for

teenagers via the mobile phone or via text messages and virtual online computer games, its mobility and convenience save time as it is changing reading habits in a way that readers no longer need to physically go to a bookshop to buy a book, now it is just a matter of going online using mobile phone, download a novel then read it on their personal mobile phone any time and anywhere when desired.

The general overview of wireless systems in Japan is explained by different applications of wireless technology that summarize all types of wireless systems such as Wireless Local Area Network, Wireless Personal Area Network, Wireless Metropolitan Area Network and Wireless Wide Area Network. Even all types of wireless systems are present in Japan, the success of Wireless Personal Area Network that involves cellphones, laptop computer and wireless mouse; is such a success compared to other wireless systems through mobile phone technologies like PDC (Personal Digital Cellular), CDMA (code Division Multiple Access) and WCDMA. In Japan, there are over 80 million mobile phone subscribers today.

Mapping of Wireless Systems in Italy

Wireless system in Italy is achieving success in different modes, some of them are going to be cited to show how much is growing day by day. Microwave Systems are provided by different companies in Italy, among them there are Pasquali Microwave Systems that leads manufacturer of high precision waveguide devices and assemblies, RTW (Ride The Way) which is a group of specialized competences in microwave and electromagnetics engineering, and Galvanica Pasquali that provides surface treatments for defense, aerospace, electronic and commercial metal productions. VSAT satellite communication system for domestic and small business customers is present in Italy where it enables customers to connect to Internet from remote locations. WIFI (Wireless-Fidelity) floats elsewhere in Italy, you can find it in hotels and in different places as some cities provide and make access free to their residents, its connection is so fast. WIMAX technology is also in use in Italy and is provided by different companies [20]. Cell phones are also playing an important

role in wireless systems in Italy as many italians own a cell phone, these cell phones are enhanced so that the users can access Internet using their phones. These types of wireless systems and others not cited here are showing the level of technology in Italy and the way it continues to grow.

Mapping of Wireless Systems in Developing Countries

Wireless Systems is now everywhere in the world, and all countries such us developed as long as developing countries are enjoying the benefit of it from different applications. Like other countries, many of developing countries provide microwave systems services, VSAT Satellites are present in African, Asian and South American countries for providing Internet access to the customers form remote locations, WIFI is very present as cell phone users can get access to Internet through their mobile phones, GSM is there to favorise user travelers to be always connected to their families and others while traveling without changing a phone number neither the phone device. Technologies like CDMA, WCDMA, UMTS, WiMAX are also present thanks to Internet and cell phone providers that are going to invest in these countries and compete to supply the good services to their dear customers that also continue to increase every day.

The role of wireless systems in developing countries is detailed discussed with the aid of a matrix. The table below shows the level of each technologies in certain countries from I as the first level which represents the less used technology in the country to X that represents the more used technology in that country. The countries are taken randomly from developing countries list. Thanks to its roaming, GSM occupies almost the first place in technologies used in many countries thanks to its roaming that favorise the communication of cellular phone users while traveling or changing their current locations.

Developing countries are using and implementing mostly the third and fourth generations (3G & 4G) because their systems are new, so that they don't need to upgrade the old ones like 1G, but they are implementing the new technologies which is the contrary to the

developed countries where they are facing problems to migrate from old technologies to the newest ones. Sometimes the migration seems to be impossible or very expensive because the technologies used are totally different and it needs expensive requirements.

Technologies & Countries	GSM	TDMA	CDMA	GPRS	EDGE	UMTS	HSDPA	HSUPA	LTE	WiMAX
Brazil	X	II	I	VII	III	IX	VI	V	IV	VIII
Croatia	X	II	I	III	IV	IX	VII	VI	V	VIII
India	X	I	II	III	VIII	IX	VI	IV	V	VII
Kenya	X	VI	II	IV	III	VII	IX	VIII	I	V
Mexico	IX	VIII	X	II	I	IV	VII	V	III	VI
Poland	X	IX	I	VIII	II	VII	VI	V	III	IV
Russia	VII	I	II	VIII	VI	III	IV	V	IX	X
South Africa	X	I	IV	VI	II	VII	IX	VIII	III	V
Thailand	X	II	V	I	III	VII	IX	VIII	IV	VI
Uganda	X	IX	VII	VIII	VI	IV	V	III	I	III
Venezuela	X	IX	VIII	I	II	V	VII	VI	III	IV
Vietnam	X	III	IX	IV	V	VIII	VII	VI	I	II
Argentina	X	V	VI	IX	III	VIII	IV	II	I	VII
Bangladesh	X	VI	IX	I	III	VII	II	IV	VII	V
Cambodia	IX	VII	VI	I	II	VIII	III	IV	V	X
Iran	V	IV	IX	I	II	III	VIII	VII	VI	X
Malaysia	IX	VII	X	III	V	II	VI	I	IV	VIII
Kazakhstan	X	IX	VII	VIII	IV	V	III	II	I	VI
Azerbaijan	X	VIII	VII	VI	V	IV	II	I	III	IX
India	X	VII	VIII	III	I	II	IV	VI	V	IX
Afghanistan	X	VIII	IX	I	VI	VII	II	III	IV	V
Kyrgyzstan	X	IX	VIII	VII	V	IV	II	I	III	VI

Table 2.2: The use of wireless technologies in developing countries (a)

Technologies & Countries	GSM	TDMA	CDMA	GPRS	EDGE	UMTS	HSDPA	HSUPA	LTE	WiMAX
Mongolia	X	VII	IX	VIII	III	II	I	V	IV	VI
Ukraine	X	VI	I	IX	VIII	VII	III	II	IV	V
Tajikistan	X	IX	VII	VIII	II	III	IV	V	I	VI
Turkmenistan	X	VII	IX	VIII	I	III	IV	V	II	VI
Uzbekistan	X	IX	VIII	IV	III	V	VII	I	IV	VI
Mauritius	X	VII	IX	IV	VII	I	VI	II	V	III
Senegal	X	IX	VIII	VII	IV	VI	I	V	II	III
Moldova	X	IX	VII	IV	VIII	II	V	VI	I	III
Chile	X	IX	VII	VIII	VI	V	III	IV	I	II
Philippines	X	IX	VI	IV	I	II	VII	VIII	III	V
Ethiopia	X	V	IX	VII	I	VIII	II	III	IV	VI
Bulgaria	X	I	VII	IX	II	VIII	III	V	VI	V
Angola	X	I	II	IV	III	V	VI	VII	IX	VIII
Indonesia	X	IX	VI	VIII	I	VII	V	II	III	IV
Latvia	X	IX	VIII	I	VII	IV	V	VI	II	III
DR Congo	X	VIII	IX	VI	V	VII	IV	III	II	I
Romania	X	III	II	IX	I	VI	VIII	VII	IV	V
Haiti	VIII	IX	X	V	VII	VI	III	IV	II	I
Belarus	VII	I	II	VIII	VI	III	IV	V	IX	X
Cameroon	X	IX	VIII	VII	IV	VI	I	V	II	III
Ecuador	X	VIII	IX	I	II	V	VII	VI	IV	III

Table 2.3: The use of wireless technologies in developing countries (b)

Technologies & Countries	GSM	TDMA	CDMA	GPRS	EDGE	UMTS	HSDPA	HSUPA	LTE	WiMAX
Libya	X	II	I	III	V	IV	VI	VII	VIII	IX
Paraguay	X	VI	VII	VIII	I	IX	II	III	IV	V
Malawi	X	IX	VII	I	VIII	VII	II	III	IV	V
Guatemala	X	VIII	IX	I	II	IV	VII	VI	III	V
Cuba	X	VI	VIII	VII	I	IX	II	III	V	IV
Burundi	X	IX	VI	VII	V	VIII	II	IV	III	I
Honduras	X	IX	VIII	I	II	V	VII	VI	III	IV
Armenia	X	IX	VIII	VI	II	V	VII	I	III	IV
Sudan	X	IX	VIII	VII	VI	V	III	IV	II	I
Liberia	X	IX	VII	I	VIII	VII	II	III	IV	V
Serbia	X	I	VII	IX	II	VIII	III	V	VI	IV
Bolivia	X	VI	VIII	VII	I	IX	II	III	V	IV
Eritrea	X	V	IX	VII	I	VIII	II	III	IV	VI
Swaziland	IX	X	VII	I	VIII	VII	II	V	IV	III
Turkey	X	II	I	IV	III	VI	VII	IX	VIII	V
Lebanon	X	I	III	II	IV	V	VI	VII	IX	VIII
Burkina Faso	X	IX	VIII	VII	IV	VI	I	V	II	III
Peru	X	VI	VIII	VII	I	IX	II	III	V	IV
Seychelles	X	II	I	III	V	IV	VI	VII	VIII	IX
Botswana	X	IX	VII	I	VIII	VII	II	III	IV	V
Benin	X	IX	VIII	VII	V	VI	I	IV	III	II
Panama	X	IX	VIII	I	II	V	VII	VI	IV	III

Table 2.4: The use of wireless technologies in developing countries (c)

2.3 WIRELESS SYSTEMS: FOCUS ON DEVELOPING COUNTRIES

The rapid growth in technology is attending all the world crossing all borders even the one of developing countries. The wireless systems generations are implemented step by step in all continents and the use of mobile phones is the most succeeded in all technologies. The key success of mobile phones is based on every day growth of technology and the number of subscribers that continues to grow. Nowadays, the rapid growth of subscribers is especially noted in developing countries where people are experiencing the good of the technology and are thirsty to know more about the technology. These developing countries are gaining an important advantage compared to the developed countries as the developing countries are implementing the new technologies that we have on today market and they do not face any problem of migrating from the old technologies to the newest ones, while some of the developed countries may face those problems to update their technologies from the existing to the new technologies.

Going back on on the developing countries, we are going to discuss about the case of Rwanda [21] [22], one of the African countries which is on a good way towards the communication technology. Rwanda is a thousand hills country situated in the central of Africa, it has been devastated by the genocide which took place in 1994, but despite the totally destruction of the country during that period, it is among the African countries that settled up a good telecommunication policy that aims to meet ITU(International Telecommunication Union) standards and goals.

Before 1994, Rwanda owned one telecommunication company called Rwandatel s.a, Rwandatel had been the only player till 1998 where Terracom purchased the company and introduced CDMA (Code Division Multiple Access) technology. Further, Terracom failed to meet financial obligations and the government of Rwanda decided to buy back the company. Therefore, another telecommunication company MTN Rwandacell has opened its

doors in Rwanda with new technologies like GSM (Global System for Mobile Communications) [23]. MTN Rwandacell got the success on the market because of monopoly as it was the only one company that supplied the mobile phones when Rwandatel s.a got some stucks, this period was before 2008. It has to be noted that before the end of 2008, Rwandatel s.a supplied the landlines phones and mobile phones based on CDMA technology. CDMA phones introduced by Terracom didn't get success in a country of thousand hills because of geographic situation of the country that does not favor an easy implementation of CDMA network and the way CDMA network does not offer telecommunication roaming. Another disadvantage to CDMA uses is deactivating the old phone and activating the new one because CDMA carriers are not card-enabled, and this makes the useless of the old mobile phone.

Even CDMA technology provides some advantages such as: increased cellular communications security, simultaneous conversations, increased efficiency, low power requirements, etc..., international roaming is a big advantage to mobile users especially when they are abroad.

However, at the end of 2008, Rwandatel s.a has decided to increase its services by launching its GSM and 3G network for its mobile telephone, replacing its CDMA platform to GSM technology [20]. GSM is a mature technology that permits the international roaming as well as the availability of SIM cards. SIM (Subscriber Identity Modules) cards provide secure data encryption and facilitate users to change their phone numbers when desired without changing the mobile device.

With the launching of GSM technology and 3G network, Rwandatel signed up hundreds of subscribers thanks to its good tariffs, and this brought the Rwanda mobile tariffs low.

The launching of GSM by Rwandatel made the mobile phone market very competitive, MTN Rwandacell also launched seamless roaming services with MTN Uganda, Safaricom in Kenya and Vodacom in Tanzania to facilitate their clients when traveling in neighboring countries. MTN Rwandacell also reduces its tariffs and is improving its technologies day

by day.

Another new Multi National Telecommunications Company is awarded the third national telecommunications license of Rwanda in November 2008, the company is called Millicom International Cellular but known as Tigo Rwanda, it aims to deliver Affordability, Accessibility and Availability to its customers. The company launched its network in November 2009 with new technologies such as 3.5G HSPA network and Value-Added Services innovations such as CRBT, Mobile Internet and enhanced content [24].

The coming of a third telecommunication company with new technologies in Rwanda has led the country to more competition, lower prices for subscribers, the introduction of new products and services and a surge of investment in the communication infrastructure. This case of Rwanda shows how telecommunications and wireless systems are growing on a rapid level in developing countries and the way those countries are on a good way to meet ITU standards.

Chapter 3

Wireless System architecture

3.1 How do Wireless Systems work

The wireless technology is applied to portable electronic devices such PDA, mobile phones, laptop computers and many other electronic devices we may note cited all here. Throughout bluetooth or WIFI, this technology permits those devices to be connected to internet. The benefits of wireless systems are well explained by different applications, some of them are going to be cited in order to explain the way this system is working. Cellular phones known as mobile phones are a good example of the functionning of wireless systems where mobile users can communicate using their mobile hand phones anywhere and everywhere as long as base stations are implemented in the area. The mobile phones are different from fixed phones where users cannot benefit the mobility as for mobile phones.

Wireless home security systems are rapidly increasing in popularity due to the facility of keeping homes, offices or buildings secure by installing different alarms or other systems of security proposed in this system. The advantages of the system include its *"Easy installation"* as it does not need wires, its installation does not require experts so that everyone can set the system alone. The *"Versability"* of the system gives the freedom to place the devices where you think there are most effective in monitoring your home, and the *"portability"*of

the system gives an advantage of moving from a place to another with your system as the devices are not fixed to a certain place.

The wireless technology plays a big role while using internet permitting computer laptops or PDAs phones to get connected and perform different jobs as desired. The use of internet through electronic portable devices permit users to check and send e-mails wherever they are, to buy train tickets using their mobile phones and many other applications. It can also be noted that using wireless system we can make free call through skype, voip and so on... as well as keeping in touch with friend using charts.

New wireless technology improves audio communication to people with hearing loss allowing the use of hearing aids in both ears rather than just one. The wireless technology will also allow people in museums, galleries or conference centers to receive audio descriptions and requesting descriptions in their specific language.

3.2 The user capacity

The main advantage of wireless systems is facilitating the communication of electronic devices with no need to be physically connected, in other words it explains the mobility of the system that is changing the way we are living in a better a way. For being connected everywhere, the user must have some capacities that permit him/her or it(in a case it is an object) to maintain the connectivity besides some changes may occur like changing the geographic location, being in a train with high velocity or conducting in a highway route. Those capacities are measured in a sense of queries and presenting in a mobile network which is more in need of user capacities to manage the changes occurring during the use.

The graphic below is going to outline the queries that are going to be explained in details after the graphic:

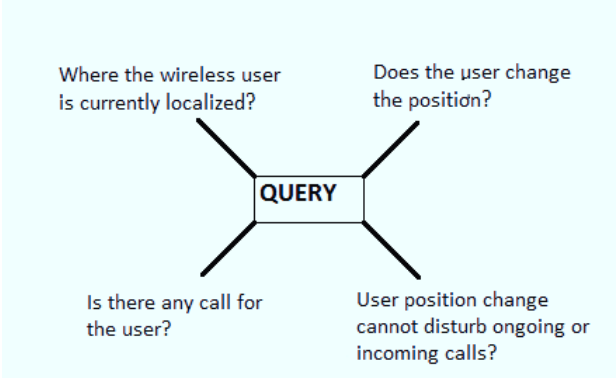

Figure 3.1: User capacity

- *Where the wireless user is currently located?*

ROAMING indicates the location capability of the user in a network and stores it in a network database as long as updating the movements of each user when are done. Roaming can also indicate the transit between networks of two nations or within the same nation between networks of two different operators [25].

- *Does user change the position?*

LOCATION UPDATE takes care of updating the user position by its procedure of updating the localization database. This process is done by an identifier that broadcasts periodically the Location Area within the cells belonging to the same Location Area, then the terminal receives regularly the identifier of the Location Area in which is located.

- *Is there any call for the user?*

PAGING is the procedure on which the system inform the terminal that is receiving a call. At that time, the paging message is broadcastingly sent to all cells of the Location Area where the user is located.

- *User position change cannot disturb the ongoing or incoming calls?*

HANDOVER helps to maintain an active call during the position change of a user from one cell to another without interrupting the service and the user will not be aware of what is going on. This process is somehow complicated because it requires to realize that the user is coming from a cell, to identify the cell in which the user is entering in, to shift the channel and to release the resources abandoned in the cell [26].

3.3 Case study: A Client/Server architecture for intelligibility tests

The development of technology is playing a role in all study areas and continues to be a big deal in a way of rendering things very easy and portable. Different studies in different areas are carried on, day by day new things are coming from researches and change the way we work and live. Coming back in the days, forty years ago the computer used was a mainframe that occupied the whole room, then after some personal computers started to be spread and the arrival of first cellular phones on the market gave a push to technology researches to improve much better the way to communicate using those terminals. The use of cellular phones gives to the people the possibility of communicating independent of the place and the time, they can communicate wherever they are and whenever they want. With the years passing, the development of cellular phones reached a good level and provide different applications such as social networking, shopping, internet connection through Bluetooth and WLAN, and many other applications. This device that owns the capacity of providing those applications is known as a smartphone and can also install other applications like *Java Mobile Edition J2ME*, etc.

3.3.1 The project aim

The purpose of the project was to create an architecture for the submission of DRT questionnaires on mobile devices through wireless systems which will be followed by the collecting of data and submit data to the server. The designed client/server architecture will be based on a wireless server and a number of simple Java-enabled clients such as mobile phones or PDAs (Personal Digital Assistant). The architecture will be able to be run in any environment with more than one user for satisfying the demand of conducting the test with multi-user system.

3.3.2 Diagnostic Rhyme Test (DRT)

The DRT is an ANSI standard for measuring speech intelligibility (ANSI S 3.2-1989), composed of words that differ only in their initial consonants. The procedure of the test is done showing a word pair to the listeners then asking them to identifier which word is presented by the talker. The test evaluates nasal, continuity, coronal and novelty sounds, and can be presented in a short period of time and may also be scored in several different ways. Among the parameters taken in consideration during DRT there are difficulty in understanding or difficulty with which a word is perceived in different conditions of signal to noise and reverberation, the subjective is measured to a scale of four or five points [27]. Further studies have considered another parameter derived from audiologist in submission of test, the parameter is known as *"response time"*. This value indicates the time elapsed between the end of audio playback and selection of the answer to the question submitted, this additional parameter helped in improving intelligibility test [27][28].

The acoustical team at the department of engineering at the university of ferrara has conducted intelligibility test using DRT for pupils of primary schools, the tests were run in the laboratory of acoustic, at this time it was needed to perform an intelligibility test in a classroom with pupils of primary schools using mobile devices familiar to them. The

technology used in the project suggest the development of an architecture that allows the submission of DRT questionnaires on mobile devices and satisfied the demands of the acoustical team at the department of Ferrara. In our case, a sample DRT was prepared in italian language as the test was done with pupils speaking italian as the mother tongue.

```
nizza , lizza , 1 , audiotest_1_1.wav
sciocco , ciocco , 2 , audiotest_1_2.wav
zaino , daino , 1 , audiotest_1_3.wav
doccia , goccia, 1 , audiotest_1_4.wav
sisto , scisto , 2 , audiotest_1_5.wav
galli , calli , 2 , audiotest_1_6.wav
melo , pelo , 2 , audiotest_1_7.wav
```

Figure 3.2: A sample of a file test created in TestBuilder

3.3.3 Introduction of the project

In the realm of acoustical engineering, several studies have been conducted to improve the intelligibility tests in order to test the capacity of listening and its difficulties from different people. These tests have been conducted in acoustically treated or untreated rooms with a single listener at a time, and in this field the acoustical engineering team at the Department of Engineering of Ferrara has conducted the same test which aimed to measure the *"Listening difficulty"* experienced by users while listening; it has to be mentioned that this team worked in the same context as previous researchers, it means with a *"one-user-at-a-time prototype system"* [29]. The intelligibility tests conducted by the team measured the listening difficulty on a five item scale, and objective measures (intelligibility scores, response times) were obtained and their inter-relations were investigated. Therefore, we were proposed to develop a multi-user solution to be used in in different environments, either acoustically or non-acoustically developed. The *"response time"* measurement was added to improve the overall understanding and effectiveness of intelligibility tests.

To choose the architecture of the project, the general client/server architecture is referred , and the designed architecture fell on a WIFI client/server system given its low cost and easy setup. *Fig. 3.3* shows a general client/server architecture and gives an idea of the devices compose the future architecture design.

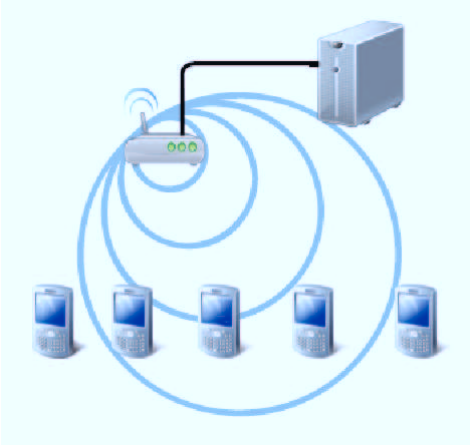

Figure 3.3: General Client/Server architecture

During the setup phase, three fundamental devices are selected: a server, a client and an access point.

Client, as a client, it has been chosen a device with the capabilities of being connected through WiFi and installing J2ME applications that will facilitate the realization of the project. Nokia N95 has been recognized for its WiFi connection capability, the widespread use of it , its simplicity and the capability to install and execute Jar application (MIDP 2.0, J2ME)[30][31].

Server, the server is an ordinary laptop which acts both as data collector, provider and coordinator of the network and experiments. The server performs the functions of *Http Server* setting static ip address and installing the necessary softwares. The laptop used as a server has http server version 2.2.15 and Dual server open source software

that provide a DHCP (Dynamic Host Configuration Protocol) and DNS (Domain Name System) servers. A DHCP server assigns IP addresses to all clients while a DNS server converts hostname to the numerical IP addresses. The server plays two important roles: (1) To host the webpage where users can download Intelligo mobile applications and run Intelligo server application that permit to act with mobile devices, (2) Collect data from the mobile devices.

Access Point, a Netgear Prosafe Access Point WAG 102 has been selected according its realibility, security and high performance on wireless LAN [32] [33]. To set the necessary conditions of the AP, it has been determined an open WiFi network with SSID "acustica" and a static IP address was given to the laptop served as a server. The WiFi network has been kept open because there was no reason to protect it.

3.3.4 Message format

To facilitate easy management and interpretation of messages from the clients and server, a flexible format has been chosen to set a reliable messaging format. XML(eXtensible Markup Language) format has been selected for its portability, simplicity and easy management both in Java SE and in J2ME. The XML is a textual data format similar to HTML(HyperText Markup Language) designed to store , transmit data, view and manipulate informations hidden in text files. *Fig. 3.4* shows a sample question message sent by the server to mobile devices, the message format is in XML. This XML message sent by the server contains a "question test" and the proposed answers for the asked questions, the level difficulty of the test and the ability to know if the selected answer is correct or false. The id of the client will be sent to the server together with the results of the test. Both the listening difficulty and the evaluation of the test are measured on scale of 5, the end user will select the scale by pressing the button on his/her mobile device.

The above part of figure 3.4 shows the answer message sent by the client to the server,

the message is also in XML format and is sent at the end of each question. This XML message contains the following data:

- the user identifier (user id) which is the age, the class attended and genre of the end user, and it is written as *id_sex_age_class*;
- the user's answer, which is a number correspondent to the answer selected by the user, it has a scale of three which are three possible choices such as *correct_answer*, *wrong_answer* and *not_selected*;
- the response time which express the time taken by the end user to answer the questionnaire, the time is expressed in milliseconds;
- the listening difficulty has a four scale and explains the difficulty encountered by the user to listen the talker.

```
<?xml version='1.0' ?>
<message type="101" difficulty="true">
 <question test-id="1">
  <question-text>What did you hear?</question-text>
  <answers>
   <answer answer-id="1.1" correct="true">
    dardo</answer>
   <answer answer-id="1.2" correct="false">
    tardo</answer>
   <answer answer-id="1.3" correct="false">
    None of the above</answer>
  </answers>
 </question>
 <difficulty>
  <question-text>This test was:</question-text>
  <answers>
   <answer>Very easy</answer>
   <answer>Easy</answer>
   <answer>Average</answer>
   <answer>Difficult</answer>
   <answer>Very difficult</answer>
  </answers>
 </difficulty>
</message>
```

```
<?xml version='1.0' ?>
<message type="202" difficulty="true">
 <user-id>1_M_3_3</user-id>
 <user-answer>1</user-answer>
 <time>2110</time>
 <difficulty>2</difficulty>
</message>
```

Figure 3.4: A sample question message (above) send by the server to all mobile devices, answer message (below) send by a client to the server.

The connection between the client and the server was established through a datagram connection necessary to exploit its broadcasting capability.

3.3.5 Design and development of GUI

To ensure the functionality and simplicity of the system, a graphic user interface (GUI) has created to facilitate the technician in his/her work and the clients that may not be much familiar to mobile devices. On the left side of *figure 3.5*, a server GUI is presented and on the right side of the figure there is a client GUI. Both graphic user interface screens permit

the phases of the test step by step and here is the summary of the steps:

- Step 1 – Startup : This step shows the number of clients connected, i.e. Number of clients ready to do the test.
- Step 2 – Send a DRT test : In this step, the technical choses a DRT question and sends it in broadcast to all clients when they finished to be connected, the DRT questionnaire contains the possible answers to be proposed to the clients. Before leaving this step, the technical selects an audio playback on which clients will be based on to select the correct answer, i.e the pronounced word by the talker. Selection of the word by the client will be accompanied by an evaluation of the test where the user will chose her/his level of difficulty in understanding the test.
- Step 3 – Save the test results : After receiving the users' answers, the technician may decide to end the test or go ahead with the test

To reduce mistakes and focus the users' attention during the test, end users will be informed step by step how the architecture works and to reduce the distractions, other functions of the mobile device are blocked and users will be able to press any button when it is requested to answer.

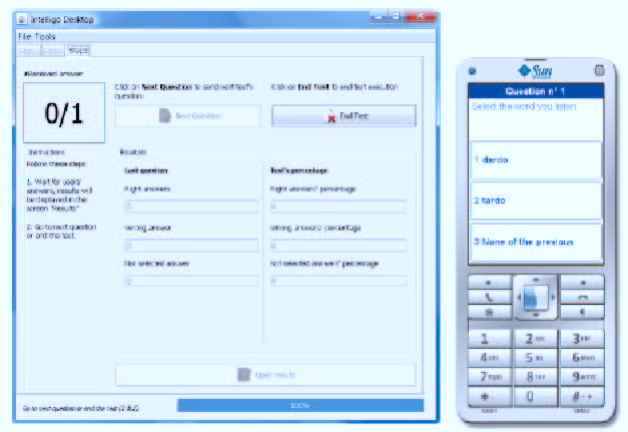

Figure 3.5: The Graphic User Interface screen, both on the server (left) and on the mobile (right), simulated by a convenient Sun tool.

3.3.6 Message exchange and data collection

To identify the various stages of data collection process and the interaction between server and clients, this section will describe step by step each phase of the test. The first step absolute must be done by testers downloading the software on their mobile devices. The tester will be connected to the local network, then through the browser of the mobile device will access the page *www.acustica.it* from which will download the J"ME application that will be installed to the terminal. The download and installation phases are managed by the operating system of the terminal. The whole lifecycle for the server and clients all over the test is explained in details, this lifecycle explains the process of message exchange between server and clients, and how data are collected along the six phases of the process.

- Phase 1 – **Startup phase**

- The technician starts up the server and Intelligo Desktop application, then inserts the number of test participants, after that the technician waits for acknowledgement from all

users . The “acknowledgements” ensure the communication between the server and all clients.

- After the startup of the server, the users start the Intelligo Mobile application on their own devices.

- Phase 2 – **Acknowledgements**

- The end user fills the form inserting the age, class attended and sex for being identified from others.

- The client is notified to the server sending an acknowledgement “WELCOME_ACK” then waits for reply.

- The server replies sending a notification message to all clients to notify the technical about the connection of each client. The notification message message sent by the server is “WELCOME_REPLY”, this message is repeated until the number of user participants is equal to first inserted in phase 1.

- While waiting for a DRT test, the client is in a”waiting state”.

- Phase 3 – **Sending a DRT question**

- After receiving notification messages from all clients, the technician opens a test file, selects a question then sends it in broadcast to all user participants. At its turn, the server will creates the corresponding XML message which will be sent in broadcast to all clients then waits an acknowledgement from them. The technician will also select the parameters for each question, among the parameters there is listening difficult parameter.

- Intelligo Mobile Client receives decode message, create the Question screen to avoid every possible delay caused by screen construction, and replies with “QUESTION_ACK” to ensure the receiving of the question to all clients.

- Phase 4 – **Sound reproduction and Question display**

- The sound reproduction is the next step made by the server after receiving the notification messages from all the clients. The sound accompanies the question sent previously and complete it. After the reproduction of the sound , a “START_ACK” acknowledgement is sent in broadcast to all mobile devices to notify the display of the question on mobile devices screen .

- Upon the reception of the “START_ACK” acknowledge, a screen containing the question and three possibles reply is displayed, simultaneously a timer is activated to record the time response.

- Phase 5 – **Answer selection and sent**

- The user judges the difficulty lo listen to the word pronounced by a selecting one of the 5 scales displayed on mobile device screen. When a listening difficulty scale is selected, an XML answer message is created with user_id, listening difficulty and response time. The three proposed answer are “right, wrong and not selected answer”, the listening difficulty represents a scale of five “ very easy, easy, medium, difficulty and very difficulty”, the response time is expressed in milliseconds.

- The client waits for an “ANSWER_ACK”, and once received waits again for an acknowledgement which could be either a next acknowledgement “NEXT_ACK”nor an end acknowledgement, “END_ACK”.

- After receiving each “ANSWER_MSG” Intelligo Server sends at each client a notification “ANSWER_ACK” to notify the reception of the answer.

- Phase 6 - **The termination phase**

- After receiving all responses, Intelligo Desktop displays results to the technician and permits him/her to send the next question or to terminate the test. In the case it is decided to continue the test, the process returns to phase 2 and passes through the next phases. When it is decided to end up the test, the technician has the possibility to display the results in MS Excel File (.xls). The results are saved as excel file(s).

- In the moment the technician terminates the test, Intelligo Mobile application terminates the execution displaying a “thankful message” to the user participants, otherwise a “welcome message” is sent by the client to the server to restart the process from phase 2.

Figure 3.6 represents schematically the process of collecting data and how the messages are exchanged between clients and server. The figure explains the necessary synchronization between clients and server, the broadcasting messages sent between server and clients, and the acknowledgement messages that ensure the reception of the messages sent.

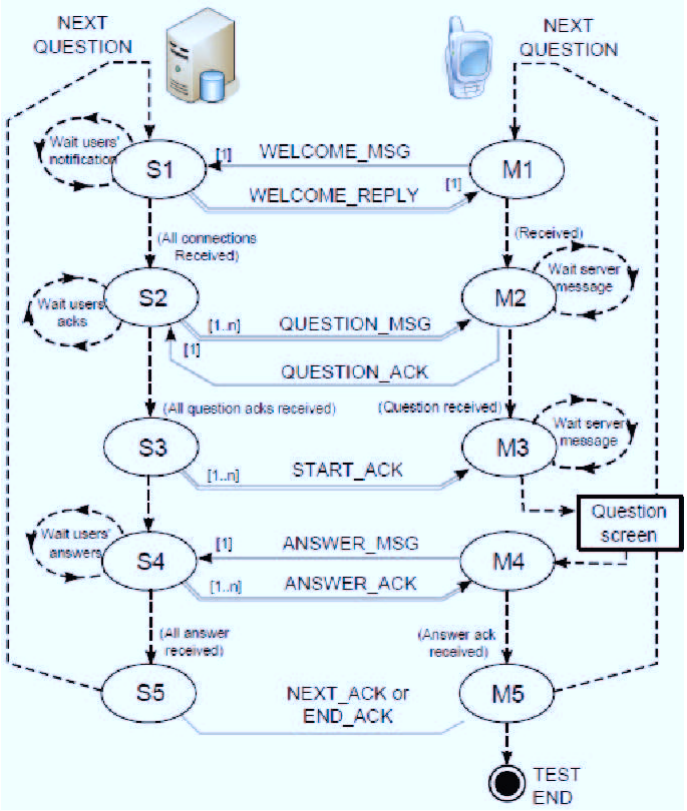

Figure 3.6: Message exchange and data collection : the grey lines show the connection between server and clients; the double lines represent the messages sent in broadcast; while the dotted lines show the state steps.

3.3.7 Results file

At the end of the test, the data collected must be saved and displayed in a clear format and easy to handle. This format has been chosen after consulting the Acoustical team at the department of Ferrara, and in agreement with them, xls sheets are used to save and display data, the production of this file is done by the technician through Intelligo Desktop at the end of the test.

The results on the output file are divided in four tabs: the answers, response time, listening difficulty and the summary of all results on the same sheet.

- The *"Answer"* sheet of the results file contains the results pf each answer for each question and each client.
- The *"Response time"* sheet of the results file contains the time taken by each client to respond to each question.
- The *"Listening difficulty"* of the results file represents the difficulty indicated by each client for each question asked and answered.
- The *"Summary"* sheet of the results file includes the summary for all clients and for all questions. This sheet represents at the same time the answers, response time, and the listening difficulty.

3.3.8 Results

The realization of both GUI (Graphic User Interface) has been done with a particular attention in order to realize understandable interfaces and easy to be used, on the technician side, an Intelligo Desktop that permits the construction of DRT tests and sending the questionnaires to the mobile terminals while for the user and Intelligo Mobile able to install the necessary softwares in order to perform its work such as collecting and sending back the data to the server.

The architecture designed satisfies the desires of the team of the Department of Acoustics at the University of Ferrara by its simplicity and portability characteristics. The simplicity of the design will permit the performance of Intelligibility tests of non familiar people with mobile devices, in this case the first test will be done with children of 6 to 10 years old in one of Ferrara primary schools.

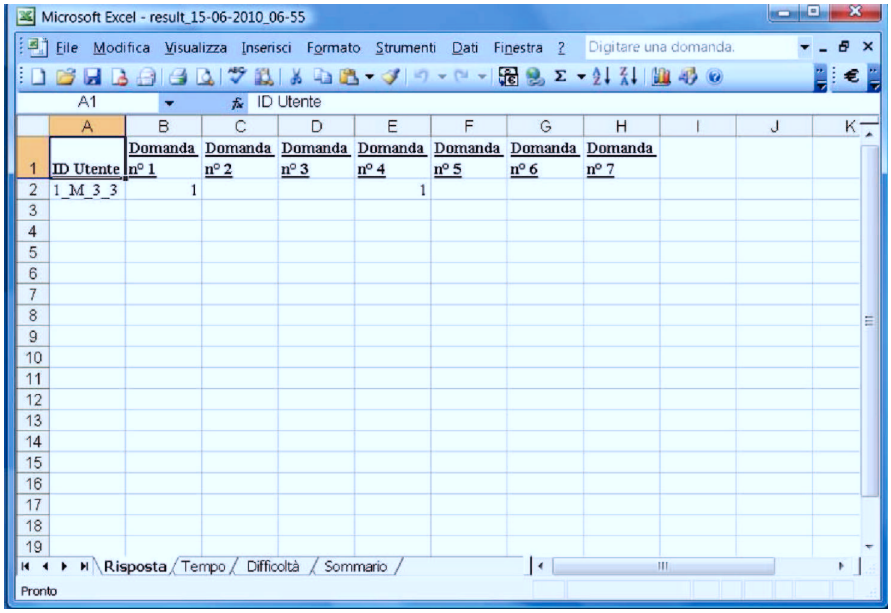

Figure 3.7: A sample of the results file. The file represents the "answer" sheet of one user, but the proper test will be done with more done one user (around 25 pupils in a classroom) during the testing of the architecture in a non acoustical environment

It will be more exploited the "portability" property of the design as it will be used anywhere especially in non acoustical environments to test intelligibility. The design portability comes from the wireless system that will make all the architecture usable everywhere.

The last advantage of the design but not least is the "multi user" property. This architecture resolves a problem of "one user" system used in previous researches during Intelligibility tests. Thanks to wireless technologies, wireless devices used (such as Nokia N95) facilitates the design of a multi user architecture and Intelligibility test with more than one person at a time.

It has to be mentioned that previous Intelligibility tests have been done in only acoustically environments, with one person at time, while this new design permits Intelligibility tests in any environment, with a group of people simultaneously.

3.3.9 Problems encountered

To reach the final results of the project some problems have been presented but they have also been resolved in proper manner to avoid any single problem or complications during the tests. The problems we faced and the way they have been solved are cited here:

- THE INSTALLATION CERTIFICATE. The installation of J2ME applications on mobile devices in the case of unsigned applications causes the display of pop-up confirmation. To solve this problem, the first proposition has been trying to generate a self signed certificate, but this one has not solved the problem. So it has been decided to ignore the warning that may be eliminated by purchasing a signed certificate (Verisign) in the future.

- WLAN CONNECTION. The test on the emulator and on the real devices has not been easy on the same way because the test on emulator didn't face any problem while on mobile devices the selection of an access point through a pop-up has been required. It was not possible to eliminate this request as it is in Symbian Libraries, but through the maintenance of a single connection pipe it has been reduced to a unique request at the application startup.

- SYNCHRONIZATION. In the alpha testing phase we faced some synchronization problems server and clients. The problem has been solved using the acknowle-dgement system to ensure the "unlocked" state of the receiver during its waiting state.

3.3.10 Conclusions

The aim of the project is to design and develop an architecture for the submission of the questionnaires on mobile devices such as smartphones, PDAs. The goal of the project has been successfully reached and improves the way intelligibility test are done in these days using new generations of technologies. The design solves the problem of multi users and

gives the Intelligibility tests the simplicity, the completion and usability. The prototype works well and and opens a series of further works :

- *Image display*. In the place of words image can be used and may simplify the test. This development is easy to implement thanks to the structure of XML messages that allows the insert of URL images in the post of a question message and downloading the file from the server.

- *Retransmission system*. With the growing in number of user participants may occur some errors and messages loss. To solve this problem, it may be implemented a retransmission system of sent messages.

- *Results file management*. It may be useful to extend the software to manage the test files previously created.

Chapter 4

Multiple users of the same services

4.1 Multicast

Today market in technology field is improving and continue to improve day by day. One of the most developed and more interested field nowadays is wireless communication. Thanks to wireless communications, iphone, ipad, android and different kind of cellular phones are the success products on today's market and facilitate the way to communicate. To send and receive an electronic mail doesn't need to be behind computers, with wireless it can be done irrespective of location and time. Internet cable is not indispensable to use internet as wireless systems give an easy way to be connected which facilitates the mobility and portability.

The development of technology touches all part where multicast communications continue to grow and succeed. Multicast is a network addressing for delivery of information to a group of destinations simultaneously using the most efficient strategy to deliver the messages over each link of the network only once, creating copies only when the links to multiple destinations split. Multicasting is useful because it conserves bandwidth by replicating packets as needed within the network, thereby not transmitting unnecessary packets.

Multicasting is the most economical technique for sending a packet stream (like audio,

video or data) from one location to many other locations on the Internet simultaneously. Multicasting commercial applications are webcasting over the Internet, multiparty computer games and conference calls, communication between devices behind the scenes.

Multicast like unicast or broadcast sends packets using protocols. The known protocols used to send packtes are TCP (Transmission Control Protocol) and UDP (User Datagram Protocol). Based on these protocols properties, multicast uses UDP as its underlying transport protocol. UDP is a simpler protocol where there is non acknowledgement of the success or failure of the transmission of any packet, and no retransmission, at the transport layer. The inconveniences of TCP in multicasting communication are, frequent transmission of acknowledgement (ACK) packets between the sender and the receiver of flow control and to determine if packets have arrived safely in order to retransmit the dropped packets. This form of feedback and retransmission does not scale well into the "‘one to many"’ case, although some forms of reliable multicast do use negative acknowledgements (NACKs) to signal the need for retransmission.

The *“multicasting”* model is an intermediate between unicasting and broadcasting models. Unicast is the simplest and most used method where the transport of data packets is done between single sources and destinations while “Broadcasting” is the method used in mass distribution media such as Radio and TV due to its properties of sending packets data to all destinations connected to a certain network.

4.1.1 IP Multicast addressing

Multicast is the transfer of messages to multiple selected destinations simultaneously, a simple example of multicasting is sending an e-mail to a mailing list, teleconferencing and videoconferencing. Sending multicast packets need also internet protocol (IP) address. *“Class D Address”* is multicast address and includes addresses from 224.0.0.0 to 239.255.255.255. The first four bits “1110” differentiate an IP multicast datagram to others while the remaining 28 bits identify which multicast group the datagram is sent to.

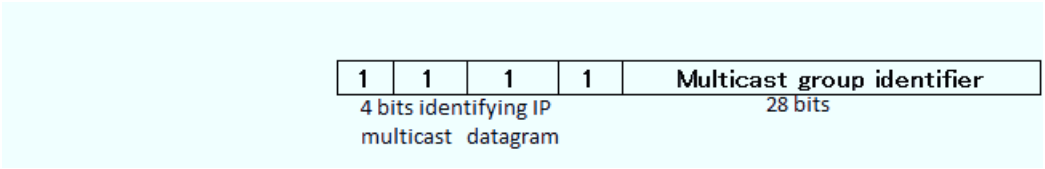

Table 4.1: Multicast IP address

The IP addresses of multicast groups are allocated differently from unicast IP address, some addresses are allocated by IANA for well-known services (IPv4), other are delegated for allocation by network administrators while others are intended for local use.

Range start address	**Range and address**	**Description**
224.0.0.0	224.0.0.255	Reserved for special “well-known”
		multicast addresses
224.0.1.0	238.255.255.255	Globally-scoped (internet wide)
		multicast addresses
239.0.0.0	239.255.255.255	Administratively-scoped (local)
		multicast addresses

Table 4.2: IP Multicast Address Ranges and Uses

Like other Class IP addresses, the 32 bits of IP multicast are all used. The first four bits “1110” are unchanged, this means that the least-significant 28 bits identifying multicast group host are assigned to various group and differentiate *“well-known”* multicast addresses to *“globally-scoped”* and *“administratively-scoped”* multicast addresses [34].

As shown by the below figure, the “Well-Known” multicast addresses are differentiated from others by “0000” following the unchanged first four bits, “1111” represent “Locally-Scoped” multicast addresses while the “Globally-Scoped” multicast addresses are represented by all other addresses from “0000” (other than the well known addresses) to “1110”.

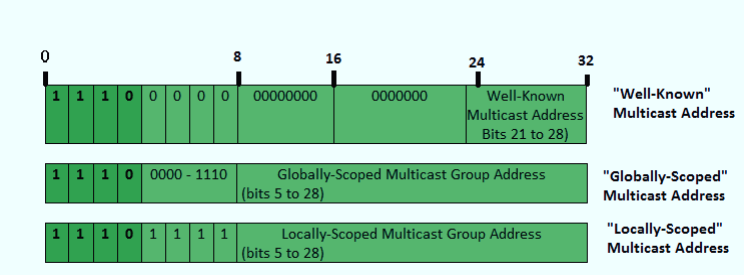

Figure 4.1: IP Multicast Address Ranges and Uses

4.1.2 Multicast advantages & disadvantages

ADVANTAGES

The “Multicast” technique is preferred in most case because of the advantages that present:

- Efficiency: Multicast assures the network efficiency reducing unnecessary packet duplication.
- Distributed application: Compared to unicast, multicast supports distributed applications, this is the case of distance learning, telemedecine, Webcasting, Web radio, Web TV, real-time videoconferencing, etc.
- Performance: Multicast optimizes the performance avoiding the data flow redundancy.

DISADVANTAGES

Multicast applications use UDP (Unreliable Datagram Protocol), this may cause some problems due to UDP protocol properties:

- Multicast group loss: UDP protocol may cause multicast group loss, it is for that reason the multicast application has to consider the unreliable factor.

- Congestion : the protocol used in multicast (UDP) does not have congestion control function, therefore when the protocol becomes more popular on the network lead to the congestion of the network which will result to the drop of the network.
- In a case the network topology changes, the redundant multicast group may appear.
- Security risk: This risk may present during a conference call when a hacker finds a way to be part of the multicast group.

4.1.3 Multicast wireless

Multicast wireless refers to multicasting used over wireless networks such as cellular telephones. In multicast wireless, the information is delivered to each of the links once, then the copies are created when the links to the destinations split. To ensure secure transmission in wireless multicasting, packet loss detection can be done in one of the following ways:

- Sender initiated: Receivers send an acknowledgment for every packer received correctly
- Receiver initiated : Receivers send negative acknowledgment to sender when a packet is lost.

Compared to wired multicasting, wireless multicasting aims to maximize the security levels that results frequently lacking in wired multicasting, to reduce bandwidth and power consumed. With the rise of in number of mobile service providers and the new functions and applications that get integrated into mobile networks and service and wireless Internet connections, multicast wireless is replacing wired multicasting due to the quality of service offers to users.

4.1.4 Multicast wireless applications

Multicast communication can support different applications, some of them are here listed:

1. Conference meetings or calls
2. Distance learning / Distance education
3. Intelligent transportation system
4. Military control operations to multicast tactical information
5. Mobile commerce applications such as mobile auctions
6. Rescue and disaster recovery
7. Sensor networks

The above cited applications require continued connectivity, high bandwidth, minimal delay, secure and reliable multicast.

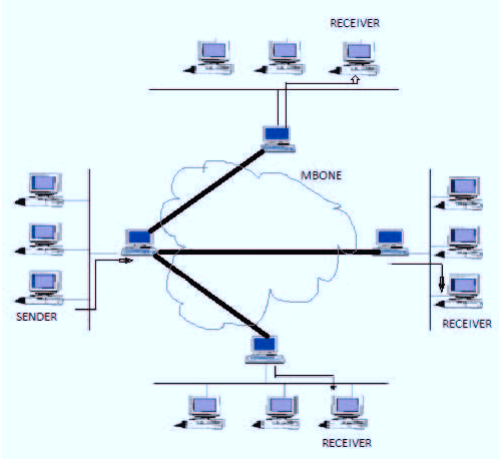

Figure 4.2: Basic multicast wireless

4.1.5 Multicast models

Any-Source Multicast (ASM), Source-Filtered Multicast (SFM) and Source-Specific Multicast (SSM) are three multicast models.

- ASM Model

ASM is a model of multicast data transmission where receivers request all data sent to a multicast group, regardless of its source address. In this model, any sender can be a multicast source and send information to a multicast group, also the receivers can join or leave the multicast group at any time.

- SFM Model

In the SFM model, the receivers can only receive the data from part of the sources necause some sources may be filtred. It should be noted that not all multicast sources are valid in this model.

- SSM Model

SSM Model is a multicast data transmission model that delivers multicast packets originating from a specific source address requested by the receiver.

4.2 The Spread of Multicast Wireless

As new technologies are propagating in the whole world and the suitable ways to use them are arriving in all the countries, there are some applications that need appropriate technologies and methods for a better use. In that case, there are technological applications such as conference meeting, distance education, rescue and disaster recovery and many other cited that require wireless multicasting, therefore this lead to the diffusion of this technology all over the world and each country adopt it according its demands.

4.2.1 In Developing Countries

With the rapid growth of wireless communications in emerging countries, certain wireless applications are becoming very useful in development of those countries and some of those

applications need appropriate technology like multicast wireless to operate in a certain environment. This is the case of “Distance Education” and “Telemedecine” applications that are necessary to improve both health and education environments in those countries.

In order to face the lack of professionals and experts in health and education sectors, distance education and telemedecine are an option to take for solving a problem when there are no experts present at the time.

Distance Education is becoming more popular due to the flexibility it offers to students to take classes from any location in the world the same for professors when giving courses, this technology favorise the people of all ages across varied professions to enhance their knowledge.

In health care sector, sometimes lacking of experts may lead the to serious problems, therefore telemedecine is an alternative solution where the doctors may intervene from any location to another in the world and give their support to solve the health problem.

Not only the cited examples are multicast applications used in developing, also othe applications are present even these two are more helpful, useful and exploited in these countries.

4.2.2 In Developed Countries

In the developed countries, multicast applications are more in use and most utilized applications are different to those for developing countries. Conference meetings are one of the most used applications to facilitate meetings between people from different locations, Intelligent Transportation System (ITS) is another multicast application used in developed countries, this technology improves transport outcomes with its various systems like car navigation, speed cameras to monitor applications such as CCTV systems, parcking guidance and information systems, and other advanced systems. Wireless Sensor Network is also a multicast wireless application of great importance in developed countries where it consists in monitoring physical or environmental conditions such as temperature, sound,

vibration, pressure and so on. All multicast wireless applications are in use in developed countries but their utilization varies from a country to another according the country needs.

4.3 Multicast Routing Protocols

The process of routing aims to transfer data in the form of packets from one network to another which means from the source to the destination. Routing protocols allow routers to determine the most efficient routes to a destination. Some of the characteristics of routing protocols are:

1. To prevent routing loops from forming or break them up if they do
2. To select the most efficient routes using hop costs information
3. The time taken to converge
4. The way they scale up well

Multicast routing protocols are four and play a role of enabling a collection of multicast routers to create distribution trees when a host on a directly attached subnet desires to receive traffic from a multicast group.

The five multicast routing protocols are the following:

- **DVMRP** (Distance Vector Multicast Routing Protocol)

DVMRP is the first routing protocol that implements flood-and-prune, the “flooding technique” is done by sending out a copy of received packet through each interface except the interface at which the packet arrived and the “prune message” is sent by a router along the source path of the multicast when it does not want to be of a multicast group. The protocol computes next hop information as well as a list of dependent downstream routers for prunning purposes. A DVMRP prune message includes a prune lifetime that shows the duration

a pruned branch will remain pruned before being automatically restored. Same as other distance-vector protocols, one of the troubles meet using this protocol is “network scaling” caused by periodic reflooding to detect new hosts and DVMRP’s flat unicast routing mechanism used to determine the source interface of a data stream.

- **MOSPF** (Multicast Open Shortest Path First)

MOSPF extends the unicast routing protocol OSPF for multicast use, then as in unicast OSPF each router calculates routes independently, MOSPF calculates shortest-path trees for each sender in multicast group. It should be noted that a router computes a shortest-path tree for a source only if there is traffic from that sender.

- **CBT** (Core Based Tree)

CBT was the first core-based tree routing protocol for the Internet that took a core based tree approach. Distribution trees in CBT are bidirectionnal which means that routers are able to forward multicast packets downstream away from the core as well as upstream towards the core. In CBT, different multicast groups may use different core-bases trees.

- **PIM** (Protocol Independent Mode)

PIM is a multicast routing protocol that consists of two multicast routing protocols: PIM Dense Mode (PIM-DM) and PIM Sparse Mode (PIM-SM). PIM-DM builds source-based trees using flood-and-prune while PIM-SM builds core-based trees as well as source-based trees with explicit joins, it is for that reason that these two protocols are in several aspects similar to DVMRP and CBT. The advantage of PIM is to be independent of unicast routing protocol present on the network and its two modes make it more used and spread widely.

- **PIM Dense Mode**

PIM-DM is similar to DVMRP as both refer to dense mode protocols and in their operational environment multicast sources and receivers are located in the same area such as Lan.

DVMRP and PIM-DM operate using a broadcast and prune methodology, in this methodology multicast routers make an assumption that everyone wants to receive multicast traffic. In addition of that, these dense mode protocols also assume that bandwidth is not a limiting factor. DVMRP and PIM-DM create source-based delivery trees to connect each particular multicast source with each downstream receiver. The source trees are created for each source using Reverse Path Forwarding (RPF) technique.

As a difference, DVMRP uses a built in multicast routing protocol while PIM-DM relies on the configured unicast routing protocol, this explains the compatibilty of other IP routing protocols such as RIP, IGRP, EIGRP and OSPF with PIM-DM. Even though the compatibility of PIM-DM with other IP routing protocols, PIM-DM is not suitable for large and medium size networks. PIM-DM differs from PIM-SM in two essential ways:

1. There are no periodic joins transmitted, only explicitly triggered prunes and grafts.
2. There is no RP (Rendezvous Point).

- **PIM Sparse Mode**

PIM-SM is a type of sparse mode multicast protocol operating in an environment where the multicast sources and receivers are not nearly located, thus the distribution of PIM-SM nodes is sparse. This does not explain that PIM-SM cannot used in LAN but means that sparse mode protocols are most efficient over *Wireless Area Networks* (WAN). Contrary to the model used by dense mode protocols in their "broadcast and prune" methodology, sparse-mode protocols use an explicit join model in which multicast traffic is exclusively forwarded to an interface if receivers downstream have joined the group.

PIM-SM uses shared trees for the delivery of multicast traffic and that tree contains a central point to which all senders of a specific multicast group send their traffic, each sender routes traffic along the shortest path to the central point which distributes the traffic to all receivers of the group along the shortest path. PIM-SM builds unidirectional shared trees

rooted at a Rendezvous Point (RP) per group, and optionally creates shortest-path trees per source.

The following terms have special significance for PIM-SM,

Rendezvous Point (RP) is a router that has been configured to be used as the root of the non-source-specific distribution tree for a multicast group. Join messages from receivers for a group are sent towards the RP, and data from senders is sent to the RP so that receivers can discover who the senders are and start to receive traffic destined for the group.

Designated Router (DR): A shared-media LAN like Ethernet may have multiple PIM-SM routers connected to it. A single one of these routers, the DR, will act on behalf of directly connected hosts with respect to the PIM-SM protocol. A single DR is elected per interface (LAN or otherwise) using a simple election process.

PIM-SM is the most widely used multicast protocol suitable for large and medium size networks with sparsely and widely distributed multicast group members.

4.4 Multicast algorithms

*Multichannel Multicas*t (MCM) and *Level Channel Asiignment* (LCA) algorithms has been proposed to be used in multicast wireless because they have been found appropriate for a Wireless Mesh Networks (WMN). A Wireless Mesh Network (WMN) is a communication network made up of radio nodes organised in a mesh topology, the network consists of mesh clients, routers and gateways where mesh clients are ofthen laptops, cellphones, PDAs and other wireless devices which access the Internet through the mesh routers in the way that the mesh clients are normally within one hop of the mesh routers. A mesh network offers reliability and redundancy, hence when one node can no longer operate, the rest of the nodes can still communicate with each other, directly or through one or more intermadiate nodes. WMN presents an advantage of being implemented with various wireless technology such as 801.11, 802.15, 802.16, cellular technologies or combinations of more than one type.

The advantages of WMN in addition to the performance evaluation shown by the simulation of the 2 algorithms have led us to suggest the use of LCA and MCM algorithms both in developing and developed countries in order to improve the throughput and reduce delay in multicast communication.

In order to construct a system model for both algorithms, the network is modeled as a weighted graph:

$G = (V,E)$ where V represents the set of gateways and mesh routers, and E represents the physical links among neighboring nodes

If node u can transmit directly to v, there is a link (u,v) in E, so that $E(u,v)$. Each node is able to be equipped with $k(k \geqslant 2)$ network interface cards (NICs). The value of k normally equals to 2, 3 or 4 due to economical reasons.

The two algorithms are below explained in details:

Level Channel Assignment (LCA) algorithm

To build a multicast tree using using the LCA algorithm, firstly the nodes must obtain their level information. All the nodes are partitioned into different levels according to the hop count distances between the source and the nodes. Secondly, a multicast tree is built based on the node level information (The source and all the receivers are included in the tree). For each multireceiver v, if one of its parents is a tree node, then connect it with that parent, and stop. Otherwise, choose randomly one of its parents , say fv , as relay node on the tree, and connect v and fv. The process repeats until all the multireceivers are included in the multicast tree [35].

Multicast tree construction for LCA

Algorithm 4.1 LCM algorithm

Data: M: multi-receivers; s: source node;

Result: T: multicast tree

$\mathrm{V}(T) = M \bigcup \{s\}$;$\mathrm{E}(T) = \phi$;

for $\bigvee$ node $v \in M$ **do**

$p = v$;

while none's of p's parents is included in $\mathrm{V}(T)$ do

Randomly select one of p's parents, say f_p

$\mathrm{V}(T) = \mathrm{V}(T) \bigcup \{f_p\}$;

$\mathrm{E}(T) = \mathrm{E}(T)$ U $\{f_p\}$;

$p = f_p$

end

$\mathrm{E}(T) = \mathrm{E}(T)$ U $\left\{\left(p, f_p^{'}\right)\right\}$; ($f_p^{'}$ is the parent of p, and it is a tree node)

end

- The source node (level 0) only uses one interface , which is assigned channel 0. This interface is responsible for sending packets to the tree nodes in level 1.
- The internal tree node in level $i (i \geq 1)$ uses two interfaces: one is assigned channel *i-1* which is used to receive packets from the upper level ; the other is assigned channel i, which is used to forward packets to tree nodes at level *i+1*.
- The leaf in the level $i (i \geq 1)$ uses two interfaces: one uses channel *i-1* to receive the packets from level *i-1* , the other uses channel i to forward the packets to the mesh clients within its communication range that desire to receive the packets.

The LCA algorithm offers to users two advantages, *"simple implementation"* and *"throughput improvement"*.

Multichannel Multicast (MCM) algorithm

The proposed *MCM algorithm* minimises the number of the relay nodes and the hop count distances between the source and the destinations, and further reduces the interference by exploting all the partially overlapping channels instead of just the orthogonal channels[35]. The MCM tree construction is described in this algorithm:

MCM tree construction algorithm

Algorithm 4.2 MCM algorithm

Data: T: tree mesh of the network

Result :T': multicast tree

Use BFS to partition nodes into different levels;

for node $\lhd v \in \mathrm{V}(T)$ do

c$[v]$ = true if and only if v is a multi-receiver or the source.

end

for l = LevelNum – 1; l $\geqq$ 1; l = l -1 do

$\mathrm{S}_i = \{nodev | v_j belongstolevell - 1\}$;

S_j= {node v_j|v_j belongs to level l and c$\left[v_j\right]$ = true};

while S_j != do-Find v_{i1}, v_{i2}, …..... in S_j with the minimal number of parents,

Among the parents of v_{i1}, v_{i2},....., find note tf with the maximal number of children;

c$\left[t_f\right]$ = true;

$\mathrm{S}_i = \mathrm{S}_i - \{t_f\}$;

The children of tf record tf as their relay node;

$\mathrm{S}_j = \mathrm{S}_j$ – {the children of t_f};

end

end

$\mathrm{V}\left(T'\right) = \phi$; $\mathrm{E}\left(T'\right) = \phi$;

for$\lhd$node v $\in \mathrm{V}(T)$ do

$\mathrm{V}\left(T'\right) = \mathrm{V}\left(T'\right) \cup \{v\}$ if and only if c$[v]$ = true;

edge e = (v,vs relay parent);

$\mathrm{E}\left(T'\right) = \mathrm{E}\left(T'\right) \cup \{e\}$;

end

The goal of this algorithm is to discover the minimal number of relay nodes needed to construct a multicast tree. Both multicast algorithms (LCA and MCM) have been found efficient to be used in multicast wireless both in developed countries as well as in developing countries due to their properties of using multiple channels and multi-interfaces which led to a multicast structure able to minimize the number of relay nodes and the communication delay, the multiple channels serve to reduce the interference and hence the throughput improves.

Chapter 5

The cost of the spectrum

5.1 Introduction

With the rapid growth of technology, wireless services continue to come in most technological used services thanks to the switching from a generation to another one. Wireless technology improves access and connectivity on wireless services in remote ares, areas of difficult terrain and in developing countries where the use of wires may not be a benefit. Indeed, the boost of wireless communications is becoming a factor in economic development as well as increasing the demand of spectrum too. Spectrum is a vital natural resource that provides considerable benefit to the economy of a country when it is well used.

Being a limited resource and more likely scarce in the future, the spectrum must be utilized efficiently and economically setting up regulations that favor its best use. The regulations regarding spectrum allocation have resorted to different known ways and each country choses one which fits the country regulations and obligations. The very known ways are : *"Auction"*, *" No free spectrum"* and *"Beauty contests"*.

The best practice for appropriately structured and organized regulations suggest the characteristics for a better regulation such as fair management, financial sustainability and effective and transparent regulatory processes.

The regulations regarding spectrum prices, spectrum assignment, license spectrum and other duties related to spectrum are established by the adequate legislation and regulatory framework taking in considerations different factors but the goals are same for all regulators: *"Economic efficiency & Raising of revenues"* Assigning spectrum licenses for developing and developed countries has led to rapid development of wireless communications as the spectrum users pay for spectrum use, spectrum efficiency, covering management costs as well as for achieving economic and social development goals.

5.2 Spectrum Pricing

This method used the pricing as a spectrum management tool refers to the task of setting either the price floor and the price ceiling of the spectrum. The spectrum pricing plays an important role in the development of a country ensuring that the spectrum resources are used efficiently by users, it also refers to a range of spectrum management activities and tools such as spectrum usage, spectrum prices and administrative fees. To determine the spectrum price, there are main factors to be based on such as: types of services, bandwidth, frequency location, geographical location, coverage area and some technical parameters [36]. The revenues raised from the spectrum are divided in three categories:

1. Partial cost recovery
2. Full cost recovery
3. Greater than full cost recovery

For the *"Partial cost recovery"* , the amount raised is not the set regulation cost while for the the *"Full cost recovery"* all costs are covered. The last category of *"Greater than full cost recovery"* generates a surplus compared to the costs of regulation. With the implementation of new technologies, there are different challenges ahead to be taken in considerations for a better use of new technologies. Among those challenges, there are [37]:

1. Valuation and Pricing Spectrum;
2. Set the regulatory framework;
3. Synchronization of digital switchover

The spectrum pricing uses certain methodologies and approaches to set prices, those methodologies are going to be explained in details.

- ***Administrative Price Methodologies*** **:** is one of the spectrum pricing form where different tasks concerning the spectrum are set by the spectrum manager. Those tasks may include "Equipment license fees" or "Charges for spectrum rights". Administrative pricing may also includes such types: shadow pricing, incentive and regulatory pricing [36]. Administrative Price Methodologies : is one of the spectrum pricing form where different tasks concerning the spectrum are set by the spectrum manager. Those tasks may include "Equipment license fees" or "Charges for spectrum rights". Administrative pricing may also includes such types: shadow pricing, incentive and regulatory pricing [36]. The aim of administrative pricing is to contribute to spectrum management making the users utilization of the spectrum more efficiently.

- ***Market-Based Prices*** **:** Normally, this is the process of bargaining among many buyers and sellers in a competitive market. In the context of spectrum, this methodology emerge through an authentic market transaction such as an auction or secondary trading. Auctions are fundamentally a method of assigning spectrum at a time of its first issue by the spectrum regulator to those who value the spectrum most highly [37]. This method will be explained later in this chapter as it plays a remarkable role in spectrum pricing.

- ***Administrated Incentive Prices*** **:** is another tool available to the regulator well suited to fixed links developed in the UK based on the method developed by NERA

Economic Consulting and Smith System Engineering Limited in 1996. AIP contributes to spectrum efficiency and able to be used in administrative regime for spectrum assignments as well as applied either to private or public sector users reflecting the opportunity-cost and regulating tariffs to be paid by licensees. AIP is already used by some regulators like Ofcom in the UK, ACMA in Australia, etc..., and encourages efficient spectrum use within a framework of administrative spectrum management as a method which reflects the scarcity of spectrum and encourages economy in its use.

APPLICATION OF AIP

Before being extended to other services that are going to cited, Administrated Incentive Prices were solely applied to mobile and fixed services cause of their most acute congestion problems. It should be remembered that this method was introduced in 1998 and started to expand its services from that year [38]. Nowadays, AIP is applied to some or all spectrum allocated to:

1. Defense
2. Fixed links
3. Maritime & Private business radio
4. Program making and special events
5. Public mobile networks
6. Public safety services including police, fire and ambulance services
7. Satellite uplinks (permanent and transportable earth stations and VSATs)
8. Scanning telemetry for national channels only.

5.3 Auctions

This mechanism provides a fast and effective method of assigning spectrum to users especially in a case an excess of demand exists. This method works well in promoting spectrum efficiency giving the spectrum to those best able to use it, it also helps the government raise non-tax financial resources. Even though auctions are effective method of assigning resources, they should be well-designed considering the geographic area and frequency bands Auctions are more preferred compared to lotteries, first-come-first-served and beauty contests method that demonstrated different weakness such as slowness and lack of transparency and other different problems that may favorise the bad use of the spectrum.

However, spectrum auctions are regulator instruments to enhance competition used by governments to assign and price licenses for wireless communications and improve market outcomes. Many countries have conducted several auctions to assign wireless licenses to wireless operators and this stimulates the competition which led to a rapid development of wireless telecommunications [39].

This part of our work focused on previous auctions done in certain developed countries, in order to understand how auctions are proceeding in those countries specifically for new technologies.

5.3.1 Italy Spectrum Auctions in 2011

Recently, the Italian Government has done very well with spectrum auctions of 4G frequencies raising more than the expected amount, while was expected to receive a minimum overall amount of €3.1 billion, the total yields go beyond expectations reaching €3.5 billion the last September 2011.

During the auctions, the participants were four italian operators (H3G, Telecom Italia, Vodafone and Wind) , offers or single raises were also allowed for a single generic block of bandwidth, it means for 800 MHZ frequency only. The below table explains more the

Italy's 4G spectrum auction.

Operator	Band assigned	Number of blocks	Total Cost in EURO
H3G	2.6 GHZ	2 TDD blocks	74.0 million
	2.6 GHZ	2 lots of FDD spectrum	72.4 million
	1800 MHZ	1 block	158.9 million
Telecom Italia	800 MHZ	2 blocks	992.2 million
	1800 MHZ	1 lot	159.0 million
	2.6 GHZ	3 lots of FDD spectrum	109.1 million
Vodafone	800 MHZ	2 blocks	992.4 million
	1800 MHZ	1 block	159.1 million
	2.6 GHZ	3 lots of FDD spectrum	108.18 million
Wind	800 MHZ	2 blocks	977.7 million
	2.6 GHZ	4 lots of FDD spectrum	142.2 million

Table 5.1: Italy's 4G & LTE Spectrum Auction

FDD (Frequency Division Duplex) and TDD (Time Division Duplex) are 2 duplex schemes supported by LTE (Long Term Evolution), LTE FDD will be widely used while LTE TDD will support many operators thanks to its higher spectrum efficiency. It should be noted that the operators will gain access to the 2.6 GHZ band by the end of 2012 while for the 800 MHZ band will be at the beginning of 2013.

5.3.2 Kenya's spectrum pricing

In a bid to ensure the efficient use of the spectrum, the Frequency Spectrum Management (FSM) department of Kenya takes in charge different roles concerning the frequency license

such as planning, assignment, licensing, monitoring and coordination of Kenya's radio frequency resource and geostationary satellite orbits. The services that require frequency licenses are aeronautical and maritime radio services, cellular mobile telecommunications, emergency and disaster communication services and TV and FM radio broadcasting.

The below tables show the spectrum fees of different services in Kenya today and in the future:

Service	**Annual fees per station per frequency in Kshs. (up to 30th June 2012)**		**Annual fees per station per frequency in Kshs. (effective 1st July 2012)**	
	MF / HF	***VHF / UHF***	***MF / HF***	***VHF / UHF***
AERONAUTICAL STATION LICENSE	Kshs . 4,800	Kshs . 4,800	Kshs . 4,800	Kshs . 4,800
AIRCRAFT STATION LICENSE	Kshs . 4,800	Kshs . 4,800	Kshs . 4,800	Kshs . 4,800
LICENSE FOR FIXED STATION OPERATING IN MOBILE SERVICE	Kshs . 18,700	Kshs . 5,000	Kshs . 18,700	Kshs . 5,000
MOBILE STATION LICENSE	Kshs . 5,610	Kshs . 2,900	Kshs . 5,610	Kshs . 2,900
PORTABLE STATION LICENSE	Kshs . 5,610	Kshs . 2,900	Kshs . 5,610	Kshs . 2,900
COAST STATION LICENSE	Kshs . 5,610	Kshs . 2,900	Kshs . 18,700	Kshs . 5,000
SHIP STATION LICENSE	Kshs . 5,610	Kshs . 2,900	Kshs . 5,610	Kshs . 2,900
RADIO AMATEUR LICENSE	Kshs . 2,000	Kshs . 2,000	Kshs . 2,000	Kshs . 2,000
CITIZEN BAND RADIO LICENSE	Kshs . 1,000	Not applicable	One time license fee of Kshs. 1,000	N / A
PRIVATE PAGING SERVICE	N / A	Kshs . 25,000	N / A	Kshs . 25,000
PUBLIC PAGING SERVICE	N / A	Kshs . 140,000	N / A	Kshs . 140,000
RADIO PRESS RECEPTION LICENSE	Kshs . 10,000	Kshs . 10,000	Kshs .	Kshs .

Table 5.2: Kenya's Frequency Spectrum Fee schedule

Broadcasting stations (spectrum fee up to June 30th 2012)

The fee payable for broadcasting stations are charged depending on the amount of base ERP power. The methodology used to calculate the fee payable for the license is based on the power and the occupied bandwidth.

The fee payable for broadcasting stations =

$[K_1 \log_{10}(P_{nom} inwatts/25watts) + K_2 \log_{10}(P_{tot} - 1000/25watts)] \times (Bw(kHz) * 574.10 * K_3)/8.5\ kHz$

where

K_1 =1 for the first 1 kW of radiated carrier power

K_2= 0.2 for additional power above 1 kW

K_3 =0.4 for TV broadcasting stations

K_3 =5 for Radio broadcasting stations

25 watts is the maximum power allowable for VHF base stations.

8.5 kHz is maximum allowable RF bandwidth for VHF base stations.

P_{nom} is the first 1 KW of the effective radiated power (ERP)

P_{tot} *is the total effective radiated power in watts*

BW is the bandwidth of the frequency band sufficient to ensure the transmission of information at a rate and with the quality acceptable under specific conditions.

Service	**Amount in Kshs & USD**	**ERP Power conditions**
TV BROADCASTING	360,000.00	ERP Power <= 10KW
	The minimum is of Kshs. 360,000.00	ERP Power > 10KW
RADIO BROADCASTING	30,000.00	ERP Power <=2KW
	65,000.00	2KW < ERP Power <= 5KW
	130,000.00	5KW < ERP Power <= 10KW
	The minimum is of 130,000.00	ERP Power > 10KW

Table 5.3: Kenya's broadcasting spectrum fee

The spectrum pricing in Kenya is calculated in consideration of the parameters established by the CCK (Communications Commission of Kenya) [40], and a proper formula is used to calculate the spectrum fee of each service. The fee payable may change as shown in beyond tables where the today fee payable will change from July 1st this year even if many services will remain on the previous rate. It is also noted that the spectrum auctions are not yet used in Kenya.

5.3.3 Case study of Rwanda

5.3.3.1 Economic overview

Almost 20 years ago, Rwanda's economy was mostly based on agriculture, industry sector had a low level and ICT services were nearly absent. Even though, Rwanda today is among the top African countries welcoming investors encouraging them by economic liberalization and civil stability as reflected by the last World Bank survey in which Rwanda comes in at 58 out of 183 nations surveyed, up from 143 in 2009. The survey explained how now is easy, fast and less expensive to operate a business in Rwanda thanks to its "Ease of Doing Business" plan.

After a genocide of 1994 that brought Rwanda to its knees, the government faced serious problems to rebuild the country either socially or economically. Learning from its history, the government of Rwanda emphasizes on women empowerment, education for all, health insurance and other key bases of a durable development. A giant progress step was made as shown by the Real GDP growth overview of 2010, the overview shows a Real GDP growth of 4.1 in 2009 and 7.4 in 2010. CPI inflation was 10.3 in 2009 and 2.3 in 2010.

5.3.3.2 Telecommunication Sector

Rwanda is also stimulated economically by the growth of ICT sector that boosts rapid changes in Rwanda's economy and transforming Rwanda into a regional high-tech hub. To

keep on growing the ICT sector, the Government initiated the five-years "National Information and Communication Technology (ICT) plans" known as NICI plans, where each "five-years plan" aims to accomplish its goal.

The goals of the four NICI plans[41] are as follows:

- *The first NICI Plan (2001 – 2005)*

GOAL: To support the development of an economic base and environment for accelerated growth and development towards transforming Rwanda into an information-rich, knowledge-based society and economy.

- *The second NICI Plan (2006 – 2010)*

GOAL: To support the strengthening of the economic base and improve the economic environment to accelerate the development and growth towards achieving an information-rich, knowledge-based society and economy.

- *The third NICI Plan (2011 – 2015)*

GOAL: To facilitate the process of sustaining economic development and growth towards improving national prosperity and global competitiveness.

- *The fourth NICI Plan (2016 – 2020)*

GOAL: To consolidate the process towards achieving a middle-income status and an information-rich, knowledge-based society and economy.

With the spread of wireless technology, the population of Rwanda exploits different wireless services mostly the mobile phones. In 2010, about 2.4 million Rwandans (it means one in four) owned a mobile phone, and the Rwanda Utilities Regulatory Agency (RURA) forecasts to top 6 million by 2015. The use of mobile phones increases by the competition of three mobile phone operators (MTN, Rwandatel and Tigo) that brings down the cost of a handset as well as the cost making a call or sending an SMS.

According ITU information and RURA data, mobile phone subscribers in Rwanda are increasing rapidly. The below table reflects the results from 2003 to 2011. The number of subscribers are expressed in “Millions”.

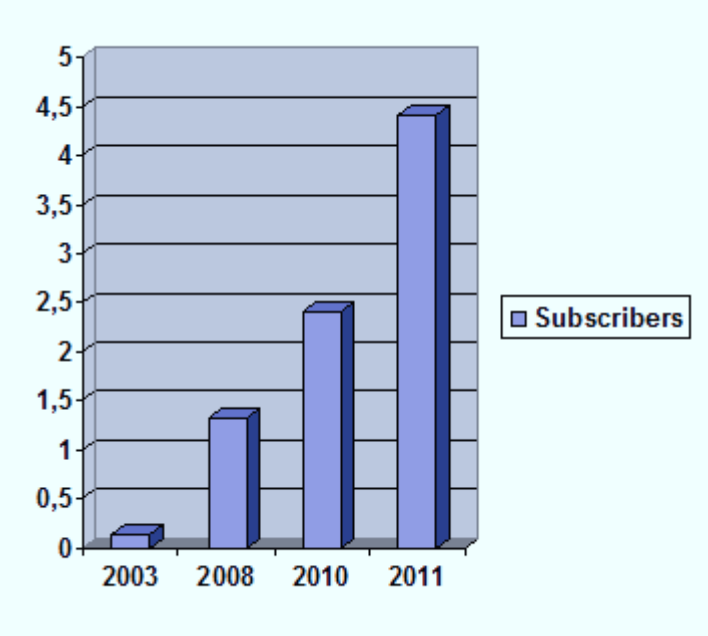

Table 5.4: Mobile phone subscribers in Rwanda from 2003 to 2011

The telecommunication sector of Rwanda covers also the spectrum management but this task is given to the Rwanda Utilities Regulatory Agency (RURA) which is an agency that provides the Telecommunications Law relating to Spectrum in Rwanda. Like in other countries, Rwanda’s regulator (RURA) needs to set spectrum prices that respond to market conditions. It is in this context that RURA with the assistance of the International Telecommunication Union (ITU) has initiated an exercise to review the frequency spectrum utilization and fee.

Before setting the spectrum fee, RURA defined the frequency ranges and their services:

Frequency Range	Service
87.5MHz-108MHz	FM Radio Broadcasting
136MHz-174MHz	VHF Mobile(1-way or 2-way communication)
174MHz-230MHz	TV Broadcasting
300MHz-306MHz	STL Frequencies
404MHz-414MHz	STL Frequencies
470MHz-862MHz	TV Broadcasting
862MHz-869MHz	STL Frequencies
890MHz-915MHZ/935MHz-960MHz	GSM 900
880MHz-990MHZ/925MHz-935MHz	E-GSM 900
1710MHz-1785MHZ/1805MHz-1880MHz	GSM 1800
1922.4MHz-1977.4MHz/2112.4MHz-2167.4MHz	UMTS
2205-2395	WIMAX
2486-2686	WIMAX
3401.25-3599.25	WIMAX
3400MHz-4200MHz/5.850MHz–6.725MHz	VSAT C Band
11-12GHz/14GHz	VSAT Ku Band
1.4GHz	Microwave
6GHz	Microwave
7GHz	Microwave
8GHz	Microwave
10GHz	Microwave
11GHz	Microwave
13GHz	Microwave
15GHz	Microwave
18GHz	Microwave
23GHz	Microwave

Table 5.5: Rwanda's current frequency ranges and their services

An approach used by RURA to determine spectrum user fees is the “Universal System Performance Model”.The basic principle for this model is to identify various technical parameters in order to measure spectrum volume used of a radio system as a common basis for establishing spectrum fees.

The formula is described in more detail below [42].

$P=\frac{V}{M}$ x $\frac{K_f K_s}{K_m}$ x C_sx K_p

Where

P = spectrum price;

V = volume of space or geometric area occupied;

M = useful results obtained from the radio equipment considered, for example the number of channels to be provided or users to be served;

K_f = coefficient reflecting specific characteristics of range used; Ks = coefficient taking into account the region of the radio station installation; Km = coefficient reflecting social benefit of radio system;

C_s = annual spectrum management costs;

K_p = coefficient reflecting the level of spectrum access demand in the band in question.

As mentioned above, this formula has been used by RURA making a simple modification [37].

The modifications are as following:

SP is the spectrum price, it will be expressed in Rwandan francs (RWF)(UNIT FEE), the unit varies by band and by service;

RF is the volume of space or geometric area occupied, for example the number of assigned frequencies to be provided or users to be served;

Unit-fee is simple Fee for the defined unit, for example 50,000 RWF per MHZ.

This technique chosen by RURA has advantages and disadvantages, the advantage is the spectrum use efficiency while the disadvantages are various problems with the practical

use of such formulas, but those problems can be resolved. The big difficulty that may be encountered using this formula is to choose the proper coefficients to be used which may vary in effectiveness on a case by a case basis in taking into account specific features of service such as spectrum demand and others.

5.3.3.3 The Spectrum Cost in Rwanda

Spectrum price determination for radiocommunication licensees in Rwanda has been defined by the Ministerial Decree n. 03/RURA/2005 of 14/07/2005, the fees defined by the decree are payable to the Rwanda Utilities Regulatory Agency (RURA) to contribute to different missions regarding radiocommunications planning, management, monitoring and control.

RURA provides an actualization of the payable fees at the beginning of a year according the evolution of exchange rate of the national currency. In that case, the schedule of fees are updated by applying the following formula:

$F_n = F_0 \times USD_n / USD_0$

where

$\boldsymbol{F_0}$ is the amount of same fee applicable during year n;

$\boldsymbol{F_n}$ is the amount of a specific fee appearing in the Schedule of Fees appended to the Ministerial Decree n.03/RURA/2005 of 14/07/2005;

$\boldsymbol{USD_0}$ is the value in Rwanda Francs of one United States Dollar on December 31st, 2003;

$\boldsymbol{USD_n}$ is the value in Rwanda Francs of one United States Dollar on the last working day of year *n-1*.

In order to stimulate technology services in rural areas, RURA guarantees a 50% reduction to both initial and annual fees to radiocommunication systems exclusively dedicated to rural areas. The reduction of 80% is also granted to radiocommunication systems used for

general interest services like security & emergency public services, humanitarian assistance services, public administrations, non governmental organizations for general interest, and to the diplomatic missions and assimilated agencies habilitated to operate in Rwanda.

For a proper schedule of fees, the agency classified telecommunication services in 7 categories (Mobile Services, Fixed Services, Broadcasting, Amateur Service, Short Range Applications, Non Commercial Satellite Services and Commercial Services). Pursuant to article 34 of Law n.44/2001 of 30/11/2001 governing telecommunications[44], the fees payable by radiocommunications licenses holder are of two categories: initial fees and annual fees. The article is here cited:

Article 34

All radiocommunications licenses are valid for a period of years commensurate with the term of any accompanying telecommunications license provided that the fees specified are paid by the telecommunications operator. If the telecommunications license is renewed, the radiocommunications license may also be renewed for further periods on the same or different conditions. Paragraph (1) of this article must be subject to any other provisions of this law relating to radiocommunications licenses.

On proposal by the Regulatory Board The Ministerial Decree determines , the fees for radiocommunications licenses. Fees may be initial application fees and annual fees. Failure to pay any fees within the specified time may result in the withdrawal of the radiocommunications license and reallocation of the relevant frequency.

The Regulatory Board has the right to change the terms and conditions attached to any license and specific contract. The change of general term is applied to all licenses. Licenses may be surrendered to the Regulatory Board at any time and are surrendered at the expiry of the period set out in paragraph (1) of this Article. Failure to surrender a license is punishable in accordance with the provisions set out in paragraph (4) of Article 62 of the law.

Initial fees

According the Ministerial Decree n.3/RURA/2005 of 14/07/2005, initial fees are paid at the first delivery of a radiocommunications license. In the case of license without any modifications, initial fees are not generate except when there are some modifications compared to the initial application. In the case of modifications, only new stations or new frequencies are considered to calculate the initial fee.

Annual fees

Contrary to initial fees, annual fees are paid by radiocommunications licenses holders at the beginning of each year, before March 31^{st}. As established by RURA, if a license starts or ends throughout the course of a year, the annual fee to be paid is reduced in ratio with the license duration during this year, rounded to the upper number of months. This means that, if a license begins during the course of a year, the annual fee for the first year and the initial fee will be paid at the same time. The case of license termination happens before the end of a year is also aforethought by Rwanda Utilities Regulatory Agency (RURA).

5.3.3.4 Schedule of Rwanda's Radiocommunications Fees

The schedule is prepared in categories indicating the services covered by each category, initial and annual fee of the radiocommunication service.

Category 1: MOBILE SERVICES

SERVICES	STATIONS	INITIAL FEE	ANNUAL FEE
Land Mobile	Base Station or Relay Station	Per each base or relay station and per each assigned channel either simplex or duplex, whatever the number of mobile stations, the cost is of 50 000 frw ≈ 83.33 USD	Per each assigned channel (simplex or duplex), and whatever the number of mobile stations:
			Mobile private networks including non commercial trunking cost 250 000 frw ≈ 416.66 USD per base or relay station
			Mobile stations only networks (without any base station or relay) cost 200 000 frw ≈ 333.33 USD per network
			Private paging networks cost 150 000 frw ≈ 250 USD per base or relay station
Aeronautical Mobile Services	Aeronautical Station	Lump sum for all communications channels 20 000 frw ≈ 33.33 USD per station	Lump sum for all communications channels 50 000 frw ≈ 83.33 USD per station
	Radionavigation or Radar Radiodetection Station	Lump sum for all communications channels: 10 000 frw ≈ 16.66 USD per station	Lump sum for all communications channels: 10 000 frw ≈ 16.66 USD per station
	Aircraft Station	Lump sum for all communications channels: 20 000 frw ≈ 33.33 USD per station	Lump sum for all communications channels: 25 000 frw ≈ 41.66 USD per station

Table 5.6: Mobile Services

Notes:

- Examples of “Base station or Relay station” are Commercial networks and Low-range networks. Commercial networks include paging, trunking, GSM, etc... while Low-range networks are model remote control and low power domestic applications.
- According RURA planning purposes, the emitted power and/or the antenna height may be limited.
- It has to be mentioned that the “Aeronautical Station” is for air traffic control or for services to airlines or aero clubs.
- For annual fee, if a network uses various channels, the referable amount for a given base or relay station is the indicated amount multiplied by the number of channels transmitted by this station. In a case of networks without fixed stations, the indicated amount is multiplied by the number of used channels.

Category 2: FIXED SERVICES

STATIONS	INITIAL FEE	ANNUAL FEE
Fixed stations	Whatever the number of channels, the initial fee is 50 000 frw ≈ 83.33 USD per station	For MF-HF frequency bands (0.3 – 30 MHz): Transmitter output power < 1 kW 250 000 frw ≈ 416.66 USD Transmitter output power > 1 kW 350 000 frw ≈ 583.33 USD
	Additional fee for International co-ordination: 75 000 frw ≈ 125 USD	For upper frequency bands 50 000 frw ≈ 83.33 USD per station Per occupied bandwidth : **Frequency band | Unit | Amount per unit** VHF | 50kHz | 20 000frw≈ 33.33 $ UHF | 100kHz | 6 000frw≈ 10$ SHF<12MHz |1MHz | 30 000frw≈ 50$ SHF>12MHz | 1MHz | 15 000frw≈ 25$

Table 5.7: Fixed Services

Note:

When frequency bands are segmented in channels, the occupied bandwidth is equal to the difference between the reference frequencies of two adjacent channels.

Category 3 : BROADCASTING

STATIONS	INITIAL FEE	ANNUAL FEE
Private Sound Broadcasting Station	Per station, whatever the number of channels: 50 000 frw ≈ 83.33 USD	Per station and per channel: Emitter power < 500 W : 960 000 frw ≈ 1 600$ Emitter power ≥ 500 W : 1 200 00 frw ≈ 2 000$
Private Television Broadcasting Station	Per station, whatever the number of channels: 100 000 frw ≈ 166.66 USD	Per station and per channel: 1 200 000 frw ≈ 2 000 USD

Table 5.8: Broadcasting Services

Category 4 : AMATEUR SERVICE

STATION	INITIAL FEE	ANNUAL FEE
Fixed, Mobile or Relay Station	Awarding of the radio amateur certificate : 10 000 frw ≈ 16.66 USD Per station :10 000 frw ≈ 16.66 USD	10 000 frw ≈ 16.66 $ per station

Table 5.9: Amateur Service

Category 5 : SHORT RANGE APPLICATIONS

APPLICATIONS	INITIAL FEE	ANNUAL FEE
Model remote control	Transmitter power < 10 W : license exemption Power ≥ 10 W : 5 000 frw ≈ 8.33$	Licensed transmitters : 20 000 frw ≈ 33.33$ per station
Low-power domestic applications	License exemption	Exemption

Table 5.10: Short Range Applications

Category 6 : NON COMMERCIAL SATELLITE SERVICES

SERVICES	INITIAL FEE	ANNUAL FEE
Private Dama or VSAT Networks	Any type of station : 100 000 frw ≈ 166.66 $ per station	* The annual fee is : 3 500 000 frw ≈ 5 833.33 USD per station * Per network, according to the occupied : bandwidth (transmitter side) - ≤ 0.2 MHz : 1 000 000 frw ≈ 1 666.67$ 0.2 < - ≤ 1 MHz : 1 500 000 frw ≈ 2 500$ 1 < - ≤ 5 MHz : 2 000 000 frw ≈ 3 333.33$ 5 < - ≤ 25 MHz : 2 500 000 frw ≈ 4 166.67$ - > 25 MHz : 3 000 000 frw ≈ 5 000.00$
Transportable Earth Stations	Voice or voice + data : 200 000 frw ≈ 333.33$ Low rate data only : 100 000 frw ≈ 166.66$	Voice or voice + data : 600 000 frw ≈ 1 000.00$ per station Low rate data only : 250 000 frw ≈ 416.66$ per station

Table 5.11: Non Commercial Satellite Services

Category 7 : COMMERCIAL SERVICES

SERVICES	INITIAL FEE	ANNUAL FEE
Paging	Per base station and per assigned channel 50 000 frw ≈ 83.33$	Per assigned channel, the annual fee is: 250 000 frw ≈ 416.66$ Per base station, the annual cost is : 10 000 frw ≈ 16.67$
Trunking networks	Per base station and per assigned channel, the initial fee is : 50 000 frw ≈ 83.33$	Per base station : 10 000 frw ≈ 16.67$ Per assigned channel : 1 000 000 frw ≈ 1 666.67$
Mobile Phone Service	Per network, the initial fee is : 1 000 000 frw ≈ 1 666.67$	Per assigned MHz : 1 200 000 frw ≈ 2 000.00$ Per base station :15 000frw ≈ 25$
Terrestrial Fixed Links	Whatever the number of channels, the initial fee is : 50 000frw ≈ 83.33$ per station	* For MF-HF frequency bands (0.3 – 30 MHz): Transmitter output power < 1 kW : 250 000 frw ≈ 416.66 USD Transmitter output power > 1 kW : 350 000 frw ≈ 583.33 USD * For upper frequency bands: 50 000 frw ≈ 83.33$ per station Per occupied bandwidth : Frequency band ǀ Unit ǀ Amount per unit VHF ǀ 50kHz ǀ 20 000frw≈ 33.33 $ UHF ǀ 100kHz ǀ 6 000frw≈ 10$ SHF<12MHz ǀ 1MHz ǀ 30 000frw≈ 50$ SHF>12MHz ǀ 1MHz ǀ15 000frw≈ 25$

Table 5.12: Commercial Services (a)

SERVICES	INITIAL FEE	ANNUAL FEE
Satellite	Per station, whatever the number of channels,	- The annual fee is : 3 500 000 frw
Fixed	the initial fee rate is :	$\approx$ 5 833.33$ per station
Links	100 000frw $\approx$ 166.67$	Per network, according to the occupied
		bandwidth (transmitter side) :
		- $\leq$ 0.2 MHz : 1 000 000 frw $\approx$ 1 666.67$
		0.2 < - $\leq$ 1 MHz : 1 500 000 frw $\approx$ 2 500$
		0.2 < - $\leq$ 1 MHz : 1 500 000 frw $\approx$ 2 500$
		0.2 < - $\leq$ 1 MHz : 1 500 000 frw $\approx$ 2 500$

Table 5.13: Commercial Services (b)

Notes:

- Example of mobile phone service cited in this category is GSM network.
- To calculate the number of assigned MHZ, the two bands (transmit mobile to fixed and transmit fixed to mobile) are added.

After a general observation of the spectrum cost in Rwanda, it is remarked that the methodology chosen by RURA to determine the spectrum cost should take into considerations some parameters such as geographical location, population coverage and the amount of assigned spectrum currently used. It may also be better if the chosen formula differentiate shared and exclusive use of bands.

Seeing the mechanism opted by RURA to assign the spectrum and set the spectrum cost, the mechanism like “auction” is not yet used by the regulator while it should be a better solution to assign scarce and highly valued spectrum such as Broadband Wireless (Fixed Wireless or WIMAX).

5.3.3.5 Conclusion

After studying the spectrum pricing of these countries (Italy, Kenya and Rwanda), it is realized the spectrum is a scarce resource for the government in developed and developing countries even if the methodologies adopted by those countries for the spectrum efficiency are different. In developing countries, are now in use methods such as AIP, Universal System Performance Model, etc... for establishing the fee payable for the spectrum frequency even in the case auctions are more preferable. This is contrary for the developing countries as shown by the case study of Italy where "Auctions" are more used and their results are more advantageous than other methods. According one of the spectrum auctions done in Italy in September 2011, the auction has been a great success where the government earned more than the expected money. This method should also adopted by developing countries where it is necessary as it is more advantageous than the existing methodologies.

5.4 Conclusions

This thesis was focused on wireless technology in developing world even though developed countries appear in this work for a constructive comparison which further led us to fruitful suggestions for a better utilization of wireless systems.

The work done took in consideration diverse wireless system applications with the scope of establishing an overall image of wireless technologies in emerging world. With the aid of table, it has been noted that the *Global System Mobile* (GSM) technology is the most used wireless technology in developing countries (even it does the same for developed countries) thanks to its "roaming" property that allows to cellphone users to make and receive phone calls.

According the case study discussed in this thesis regarding the wireless system architecture, the use of wireless devices in designing and implementing the architecture for intelligibility tests makes the new architecture efficient, simple and portable compared to the

previous ones also enabling the multi user services thanks to mobile phones used known as *Personal Digital Assistant* (PDAs).

While studying the multiple users of the same services, two algorithms *Level Channel Assignment* (LCA) algorithm and *Multichannel Multicast* (MCM) algorithm have been found appropriate for a better application of multicast wireless services in developing world thanks to the previous studies done on these algorithms.

Regarding the cost of the spectrum, the methodologies adopted by some developing countries seem to be inappropriate for some services, therefore it has been suggested to adopt developed countries system "auction" when it looks necessary for a better use of the spectrum. In a case of Rwanda, it is better to reset the spectrum cost for some services that would have cost more than the current cost.

After this work, we have noted that new technologies are easily implemented in developing word in comparison to the developed world where it calls for upgrade from old to new technologies which sometimes seems impossible or requires a lot of money while for developing countries some technologies have to be implemented from the first step as the old technologies are not currently in existence, and this alleviates the developing countries to use and implement new technologies.

Conclusions

This thesis focused on wireless technology in developing world even though developed countries appear in this work for a constructive comparison which further led us to fruitful suggestions for a better utilization of wireless systems.

The work done took in consideration diverse wireless system applications with the scope of establishing an overall image of wireless technologies in emerging world. With the aid of table, it observed that the Global System Mobile (GSM) technology is the most used wireless technology in developing countries (even it does the same for developed countries) thanks to its "roaming" property that allows to cellphone users to make and receive phone calls.

According the case study discussed in this thesis regarding the wireless system architecture, the use of wireless devices in designing and implementing an architecture for intelligibility tests makes the new architecture efficient, simple and portable compared to the previous ones also enabling the multi user services due to mobile phones used known as Personal Digital Assistant (PDAs).

While studying the multiple users of the same services, two algorithms Level Channel Assignment (LCA) algorithm and Multichannel Multicast (MCM) algorithm are found appropriate for a better application of multicast wireless services in developing world thanks to the previous studies done on these algorithms.

Regarding the cost of the spectrum, the methodologies adopted by some developing countries seem to be inappropriate for some services, therefore it is also suggested to adopt

"auction" methodology mostly applicable in developed countries when it looks necessary for a better use of the spectrum. In a case of Rwanda, it is better to reset the spectrum cost for some services that would have cost more than the current cost.

After this work, we noted that new technologies are easily implemented in developing word in comparison to the developed world where it calls for upgrade from old to new technologies which sometimes seems impossible or requires a lot of money while for developing countries some technologies have to be implemented from the first step as the old technologies are not currently in existence, and this alleviates the developing countries to use and implement new technologies.

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