FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

CELLULAR MOBILE COMMUNICATIONS: Connecting the World and Empowering the People

By

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1. Introduction

Inaugural lecture is a very good opportunity in the sense that it gives one time to pause and look back on the academic trail through which one has passed. In so doing, one is able to take stock, evaluate the past, compare it with the present and plan the future. Therefore, in discussing cellular mobile communications and how it connects and empowers our people, it is only pertinent to shade a little light on where this technology is coming from and how it got us where it have us today.

1.1 Man's Need for Communication

Man's need for communications is as old as man, the only difference between now and the origin of man is the technique (or the technology) used in communications. It is also very clear that communication drives civilization and develops society by empowering individuals via connectivity because, people need people. Without having the possibility to communicate and talk to other people, no individual, community, group or any other institution would be able to exist or prosper, that is, there will be no society. From the beginning till now, communication remains a key to survival and success. History has documented various techniques man has invented to communicate with one another.

Man is endowed with the ability to talk. Therefore, communication begins with language, the ability which has made possible the evolution of human society. With language, messages/information are conveyed over limited distances. The longer the distance the more people are reached. Town criers used to compete on who can shout a clear message the longest distance, the world record is less than 100 meters. Considering the short distance, it was more efficient to run with the message [1], but running with the message is expensive. Funny as it may sound, the whole developments in communication technologies hinges on the search for ways to improve upon shouting in order to get the message across to the people (the destination). Note that efficiency is all about getting better quality at lesser cost. This is the driving force which has progressively taken mankind through various techniques of communications. The more communications techniques improved, the more society developed.

1.2 Communication in the Early Age

Prehistoric man, in his effort to communicate with his fellows at a distance made use of such techniques as, fires, smoke signals, beacons, talking drums, and town criers [2]. Since the shouting distance was very short, an alternative was to run with the message. In this case it is better to do it yourself because a second hand may introduce errors (remember the magnitude of error in the spread of rumor). This problem was solved by the invention of writing. Now, messengers can run with messages, this marked the beginning of postal services. In the ancient civilization (2nd to 11th century BCE), written messages are standard feature of governments. There is a great advantage to a ruler who can send and receive messages quicker than his rivals [1]. At this time, focus was on increasing the speed of communications. Attempts to achieve this was made by improving on the transportation networks – developing the roads, using relays of horsemen, coaches, and good horses etc. In another development, from the 11th century, pigeons were used to take messages home (hinging on the fact that pigeons always find their way home from any location), this was a one way postal service. The rapid and widespread dissemination of message was achieved with the advent of printing in the West. Printing, though originated in the East, was put to more effective use in the West between 1439 – 1457. The Marathon race is a historical offshoot that stresses the need for communications. Phidippides, a Greek soldier ran from Marathon to Athens in 3 hrs., a distance of 26.2 miles (about 42km), to announce the Greek victory over Persia, and to warn Athens that the Persians planned to attack Athens before the Greek soldier could regroup and come there, but he collapsed after delivering the message [3]. The Marathon race was instituted in his memory.

1.3 Important Definitions

(i) *What is Telecommunications?:*

Telecommunication derives from the Greek word *tele* (meaning, at a distance), and the Latin word *communicare* (meaning share). Newton's telecoms dictionary defined telecommunications as the art and science of communicating over a distance by telephone, telegraph, and/or radio. The transmission, reception, and switching of signals such as electrical or optical, by wire, fiber, or through the air. Wireless communication is telecommunications that happens through the air, without wire or fiber.

It is interesting to note that the earliest type of telecommunication was wireless. The first wireless network was a line of sight link consisting of smoke signals, torch signaling, flashing mirrors, signal flares, or semaphore flags. Observation stations were built on hilltops and along roads to relay these messages over large distances. These early communication networks were replaced first by the telegraph network (invented by Samuel Morse in 1838) and later by the telephone. In 1895, a few decades after the telephone was invented, Marconi demonstrated the first radio transmission from the Isle of Wight to a tugboat 18 miles away, and radio communications was born. Radio technology advanced rapidly to enable transmissions over larger distances with better quality, less power, and smaller, cheaper devices, thereby enabling public and private radio communications, television, and wireless networking [4].

(ii) *What is Mobile Communications?*

Mobile and wireless communications are often used interchangeably but they connote two different meanings. While wireless communication is the ability of terminal devices to receive and transmit messages through the air (without wires), mobile communication is the ability for terminal devices to receive and transmit messages while on the move, therefore devices that are used for this are called mobile devices. It then means that, all mobile devices are wireless devices, but all wireless devices are not mobile devices. It is also important to differentiate between mobile and cellular communications: cellular communication devices are a subset of mobile devices, they are devices designed to transmit and receive messages in a cellular network. It then again means that all cellular devices are mobile but the reverse is not the case. The cellular network will be introduced in the course of this lecture.

2. Developments in Mobile Communication Technology

Developments in telecommunications was fueled by the invention of wireless transmission, which ushered in mobile communication. It all started in the mid-1860s when the Scottish mathematician James Clerk Maxwell produced a pair of equations whose solutions predicted electromagnetic waves propagating at the speed of light. In 1889, the Italian born Guglielmo Marconi achieved radio telegraph transmission from a ship in New York Harbor to New Jersey. Shortly after, radio telegraph started to be used for sea to shore communications instead of homing pigeons. In fact, it was used to report the sinking of the Titanic in 1912, which facilitated the saving of some passengers.

Voice transmission was introduced by 1905, and the first "land mobile" radio system was put into operation by the Detroit police in 1928, usually installed in the boot of a car (see Fig 1). By 1934, there were 194 municipal police systems and 58 state police radio stations serving more than 5000 radio-equipped police cars [5, 6] these early systems were manually switched (an operator was needed to make a connection), they used half duplex channels (push to talk), and were spectrally inefficient (due to poor filtering), as a result, only few connections could be made. These radios were therefore mostly devoted to military and emergency services. It was until 1960 that automatic switching was introduced, this means that a user can dial a number from his car radio.

Fig.1: Field communication radio

Early mobile telephone systems resembled broadcast systems, in that powerful transmitters were used to cover large distances from high towers or rooftops. The reuse of any channels for a different call required equally large separation distance [7]. Only few lines could be connected, the demand for service was great, resulting in severely overloaded channels and long waiting lists for service. This is not surprising because mobile communications, with its flexibility and convenience, is quite attractive to users. It should be noted that spectrum scarcity has always been a challenge to capacity in wireless communication system even to this day.

2.1 The Cellular System

The cellular system was born out of necessity for better spectrum management in order to increase the capacity of the mobile communications system. As early as 1946, Bell system researchers had already conceived the idea of using a cellular radio system to improve capacity. This means replacing the high powered transmitters, covering wide geographic areas, with low powered transmitters that will cover smaller geographic areas called cells as shown in Fig.2. This will enable frequencies to be reused within shorter distances (which implies more often) than the earlier system, and without interference. However, this dream did not come true till late 1970s, due to inevitable techno-politics and various business level conflicts. After these initial hitches, and with many supporting technological developments that emerged within that interim, such as stored program controlled switches, integrated circuits, minicomputers, synthesizer, microprocessors, etc., cellular system was achieved. Now mobile communications industry has become the fastest growing industry in recent history [5]. The various mile stones in mobile technology development is usually categorized in what is known as generations of mobile technology [7].

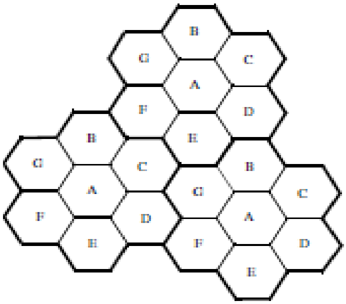

Fig.2: cellular system structure (cells of same letter use same frequency)

2.2 Generations of Mobile Technology

(i) *First Generation (1G)*: The first generation cellular wireless mobile systems (1G) before the 1990s were analog and were based on frequency division multiple access (FDMA), which is a technology that lets multiple users access a group of radio frequency bands and eliminates interference of message traffic. It operated on the 900 MHz frequency band. Mobile terminals were large and weighty (see Fig.3), and mostly mounted in vehicles. This system was spectrally inefficient, and therefore could not accommodate many subscribers. The system was usually congested and slow, and a long waiting queue of subscribers formed. Researchers and vendors worked to improve the system capacity, all their efforts plus favourable government policies in various countries gave rise to the second generation of mobile technology.

Fig.3: early mobile phone

(ii) ***Second Generation (2G)*****:** The second generation of the wireless mobile network was based on digital technology. The most popular 2G wireless technology is known as Global Systems for Mobile Communications (GSM), which was developed in Europe and is deployed almost all over the globe. It uses time division multiple access (TDMA) technology to manage multiple users on a single frequency channel. Other mobile technologies in the second generation include TDMA-136 and cdma-one both developed in North America, a 2G mobile technology developed in Japan is called the Personal Digital Cellular (PDC). These are different mobile communication systems because they are designed differently with different radio access technology, and were standardized in the country of development. These 2G standards have not only improved voice quality and transmission security, but also lay the foundation for the future value-added services, especially for data transmission.

(iii) ***GSM Enhancement for higher data rate (2.5G):*** The GSM standard was originally a circuit-switched, voice-centric system with modest data speed of up to 9.6 kbit/s e.g, for SMS. Due to demand for higher data rate (i.e., higher speed), GSM was enhanced to give 56.7 kbit/s data rate using high-speed circuit-switched data (HSCSD). The need to access the internet with the GSM terminal (handset) led to development of general packet radio service (GPRS), which is a kind of interface network, interfacing between a voice network (GSM) and a data network (the Internet). Wireless application protocol (WAP) was also designed to enable web pages to be transmitted through a voice channel and be displayed on a small screen of the handset. Theoretically, GPRS supported speed of up to 115 – 171.2 kbits/s. A further upgrade in GSM was enhanced data rate for GSM evolution (EDGE). The resulting maximum EDGE bit rate is 384 kbit/s.

(iv) ***Third Generation (3G):*** The need for further improvement in data rate, in order for users to take advantage of the internet through wireless access, drove the mobile technology to 3G. the International Telecommunication Union (ITU) under their IMT2000 (International mobile telecommunication) project gave specifications for the design of 3G, which was to provide data rates of 144 kbit/s for vehicular, 384 kbit/s for pedestrian, and 2 Mbit/s for indoor environments. Their plan was to have an international standard for mobile communications. 3G did emerge not with a unified standard as planned, rather there were many standards, the most popular being wideband CDMA (W-CDMA).

(v) ***The fourth Generation (4G)***: One of the aims of 4G mobile technology is network integration. This means to integrate the various wireless, mobile, and personal communication networks such as GSM, WLAN, Internet, Bluetooth etc., such that a user can access each of these networks using the same terminal device. This means that a user will be always be well connected.
The Fifth Generation (5G): the fifth generation of mobile technology is currently on the drawing board, this is the mobile network of the future.

3. Cellular Mobile Communications System

It is necessary, at this juncture, to present a brief over view of the cellular system, so that readers will have some appreciation of the network that serve them on daily basis, and also have some appreciation of the type of research work that is done in this area.

3.1 Cellular Architecture

The cellular system layout is shown in Fig. 4. It consists of three major segments: the Mobile station (MS), the base station subsystem (BSS) and the network subsystem (NS). The mobile station is the mobile equipment or the handset that users interact with. It connects to the BTS via an air interface. An MS is generic (could be used for any network) until a SIM card is inserted, the SIM card maps it to a given operator network. The BSS consists of base station controller (BSC), which controls a number of base transceivers station (BTS). The BTS is the major component of a cell, it connects the MS (which is the subscriber unit) to the cellular network. The range of space where its transmission power is designed to reach is called its coverage area. BTS connects to BSC via cable or microwave links. The network subsystem consists of the mobile switching center (MSC) and its associated databases. The MSC coordinates the cellular network, it controls many BSCs, routes calls through them to MSs, controls handoff between BSSs and connects the cellular network to other networks such as public switched telephone network (PSTN) and the Internet via cable or microwave links [8].

The MSC is connected to four databases: The home location register (HLR), the visitor location register (VLR), the equipment identity register (EIR), and the authentication center (AuC). The HLR stores the profile of users that are registered in its domain on a permanent basis. The VLR stores the information of mobile users who have currently moved into its domain, the information lasts as long as the user remains in the domain of a given VLR. The EIR keeps track of the type of equipment that exists in a given cellular network. While the AuC stores information used for authentication of subscriber stations. The data bases are very useful in managing the mobility of mobile users in the network.

3.2 Mobility Management

An important and inevitable function in a cellular mobile system is mobility management. Mobility management enables mobile wireless networks to locate mobile stations (MS) for call delivery and to maintain connections as the terminal is moving into a new service area. Thus, mobility management supports MSs, allowing users to move while simultaneously offering them incoming calls and supporting calls in progress. Mobility management consists of two processes: location management and handoff management [9].

Location management consists of two main functions, see Fig.5. In this operation the network tracks and locates roaming stations for call delivery of incoming calls. This is because the wireless network consists of many small service regions called cells (see Fig. 2). Each cell is served by a base transceiver station (BTS) that assigns radio frequencies, or channels, to each MS within the cell. For location management, a cellular system is logically divided into groups of cells called location areas (LA), the network keeps track of the approximate location of an MS by storing its location profile in a location database. When a roaming MS crosses an LA boundary, it performs location update, to explicitly notify the network of its new access point and store changes to its user location profile.

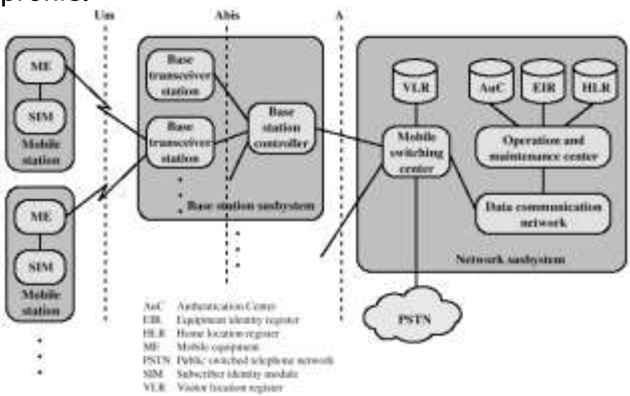

Fig.4: GSM architecture source: [8]

Then, when incoming calls arrive, the network performs call delivery by querying the location database to identify the current LA where the MS is residing. A paging signal is broadcast to the cells in this LA, in order to locate the exact cell where the MS is residing. Some research problems here include designing optimal sizes of LA and cost-effective paging in order to reduce the overall cost of location management [10, 11, 12, 13].

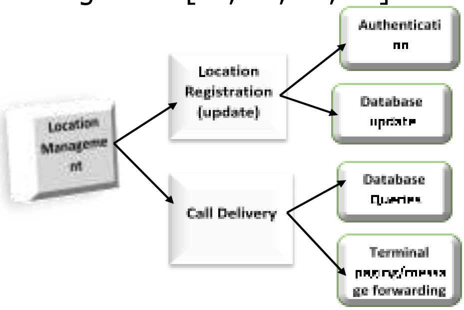

Fig. 5: Location management

In handoff (or handover) management the network ensures that a call in progress continues as the MS changes channels or moves between cells. Note that the signal strength drops as the distance between the transmitter and the receiver increases. Therefore, as the mobile terminal moves away from the serving BTS (cell) to a new one, the signal from the BTS weakens, the MS is handed over to a new BTS in time enough for the on-going call not to drop. This type of handoff is called horizontal handoff. Some research issues here include reducing handoff delay, minimizing handoff signaling [14, 15]. For acceptable quality of service (QoS) level, all network management activities should be seamless, i.e., the user should not be aware of it.

With the proliferation of wireless networks with different underlying technologies, called heterogeneous networks, which offer different services and require different wireless terminals for access, such as GSM, WLAN, UMTS, Wimax etc., research is looking into network integration. This aims at integrating the heterogeneous wireless networks such that a user can access them with the same user terminal device [16, 17]. This means that a mobile terminal can automatically switch to any network that best serves the user’s needs. Switching across heterogeneous networks, while in active connection, is achieved by vertical handoff process.

3.3 Mobility Management in the Internet

The Internet has always been described as a victim of its own success. It all started as a project in the US department of defense as Defense Advanced Research Projects Agency (DARPA), a project to aid the US military improve their communications, especially in enemy zone. The general idea was that, since the enemy can destroy the communication link thereby disconnecting the field soldiers from their commander, it was necessary to design a communication system that is intelligent and can send information through multiple routes. The system should be able to decide on availability of a route before sending information through it. It should get acknowledgement of sent messages, if it fails to get an acknowledgement, it should consider that route unavailable, and should decide on another available route to continue sending messages. It must also resend any message for which it did not receive an acknowledgement. All this means that the system cannot send messages as a single stream as is done in analogue systems. The message must be digitized, and broken up into packets, each packet must have originating (or source) and destination addresses, it will be transmitted from router to router (a router is a machine that can receive, store, process, and transmit a packet) based on the destination address until it gets to the destination. This technique of transmission was based on the internet protocol (the popular IP) and supported by another protocol called transport control protocol (TCP). A protocol is, generally speaking, a rule-set that guides a given operation, it is usually implement in software. In designing the internet, a lot of idea was borrowed from the existing and well established postal system. The project managers of the internet project collaborated immensely with the academia. The internet emerged and was easily accepted by users. The use of the internet became wide spread when the World Wide Web (WWW) application was created. Every internet node must have a unique IP address, the address consists of two parts – prefix and suffix. The prefix indicates the subnetwork where the node is attached, while the suffix is the node identifier. Therefore, IP address serve dual purpose – location identifier and node identifier. Since the internet routes packet based on the IP address, it logically means that the receiving node must be found at the designated address for the message to be delivered. Any packet that cannot be forwarded, for whatever reason, will normally be returned to sender using the source address. Internet routing was therefore described as 'location dependent'. This was not a problem then because internet nodes were basically desk tops, mini computers and mainframes – there were no mobile devices.

By the mid 90's, the internet has gained a lot of popularity and also, many innovations were taking place on the technological plane. The computer industry was fast developing, laptop and notebook computers and PDAs were becoming common place. The mobile communication industry was not left behind, 2G systems which was based on digital technology has been launched, it offered higher capacity, smaller-sized and intelligent handsets, secured communication etc. It was then envisioned that this developmental progress will likely continue and that vendors would likely produce more miniaturized terminal devices that can access the internet, and that users would like to access the internet on the move (i.e., as they move about). Then researchers began to think on how to introduce mobility into the internet. This means designing a protocol that will allow internet devices to transmit and receive packets as they move from place to place, which otherwise, means manipulating the 'location dependent routing' idea to accommodate mobile terminals. This protocol was called mobile IP protocol (MIP) [18]. It was then a daunting task, because this has to be achieved without affecting the existing internet system, with cost efficiency, and adequate security.

Again, due to the success of the internet, at this point in time, another challenge was rearing its head up, and that was depletion of internet address space, generally referred to as IP addresses. Recall that every system connected to the internet must have an address for it to receive or transmit messages, it them means that as many devices as connected, so will addresses be assigned. The internet was designed based on IP version 4 (IPv4), and the address was a 32-bit number, which affords as many as 2^{32}

different addresses. It appeared enormous at the beginning, but with the celebrated success of the internet, these addresses were fast depleting, and technology has to move to address it. Researchers then began to define a new internet protocol called IP version 6 (IPv6) [19]. All the problems of IPv4 was corrected in the IPv6, prominent among them being the address space issue. Therefore, the IPv6 address is a 128-bit number, which can afford 2^{128} addresses. IPv6 has been designed and standardized, what is currently happening is figuring out how to marry the two versions of IP without affecting users, businesses and applications. Following this developmental trend, researchers thought it wise to also design mobility protocol for IPv6 (MIPv6) [20]. These initial designs naturally had some limitations. I hope a brief description will not bore the reader.

3.3.1 Mobile IP version 4 and 6

In MIPv4 [18], each mobile node (MN) is identified by its permanent IP address (called home address). When the MN moves to a foreign network it obtains a temporary address called care-of-address (COA), which is a foreign network address, managed by a node called foreign agent (FA), that identifies the location of the MN. The MN registers this COA with a mobility agent in its home network known as the Home Agent (HA). The HA stores the COA in a binding cache. Correspondent Nodes (CN) send packets to the MN using its home address. These packets are routed to the MN's home network, where its HA intercepts them, encapsulates them and forwards them to the MN's COA (a process termed tunneling) using conventional IP routing. Whenever the MN changes its location by moving to another subnet, it sends a binding update (BU, i.e., location information update) containing the latest COA to its HA. It must also periodically refresh its address binding with the HA. When the MN returns home, it must deregister with its HA and then resume communication like any other node on the network, the architecture is depicted in Fig.6.

The mobility support defined in IP version 6 (MIPv6) [20], is based on the same basic principles as Mobile IP version 4. But MIPv6 is more robust than MIPv4 because it incorporated some of the more robust features of the IPv6 [19]. For example, in MIPv6 an MN is able to create its own COA using its link local address and automatic address configuration. Therefore, there is no need of foreign agents. Mobile IPv6 makes use of two of the new IPv6 Destination Options Header [19,21], namely a Binding Update (BU) and a Binding Acknowledgement (BA) options headers. The destination options header is one of the IPv6 extension headers, which is treated only by the final destination. Therefore, MN can directly send a BU in the same packets carrying effective traffic to the CN. The CN can then learn and cache the MN's new COA. As a result of this mechanism, when sending a packet to any IPv6 destination, a node must first check if it has a binding cache for this destination. If a cache entry is found, the node sends the packets directly to the COA indicated in the binding using an IPv6 Routing Header. The routing header is an extension header that forces the datagram to follow a predetermined route, which has two hops. The first hop is the COA and the second hop is the MN's home address. This eliminates triangular routing. On the other hand if no binding is found, the packet is sent to the MN's home address. The HA intercepts the packet and tunnels it to the COA address as usual, creating the triangular route.

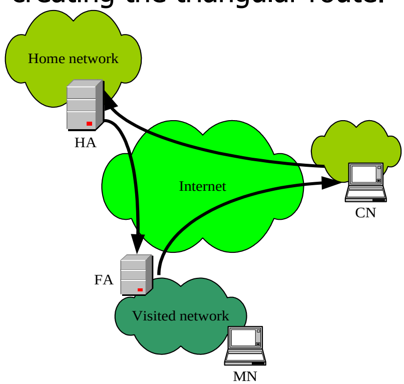

Fig.6: IP macro mobility architecture showing the triangular routing.

Mobile IPv4 and Mobile IPv6 both present a simple mobility support protocol that provides global roaming capability to the MN, they are classed as macro mobility. However, besides the triangular routing problem, they are also prone to some scalability and performance problems such as large handoff delay, generation of spurious control signaling etc., A lot of work has been done and is still being done in literature to address these limitations, some examples are [22, 23].

3.4 Convergence of Computing and Communications (ICT)

Convergence of computing and communications has been a subject for discussion in the past few decades. At the present time, it is becoming more and more obvious to industry players that these two, initially standalone technologies are better, more efficient, more productive, and more cost effective when together than when standing apart. In fact, the marriage between computing and telecommunication is a natural one, as will be explained in what follows.

Man's need for communication arose from his need to be informed about his near and remote environments, which in turn affects his decision and actions. Effort to improve in the techniques for doing so through technology has, over time, necessitated the convergence between computing and communications. This convergence benefits from three key technologies, which are communications, processing, and storage, and one basic commodity, which is information. Information has been defined as "recognizable patterns that inform us or affect our actions", and comes by way of different *media*, such as the printed word, pictures, audio, and video. The technological roles are distinct: *processing* modifies information, *communications* conveys it over distance, and *storage* conveys it from one time to another [24]. Before now, these technologies have been evolving independently as information technology (IT) and communication technology (CT). While IT refers to hardware and software used to store, retrieve, and process data, CT includes electronic systems used for communicating or sharing information between individuals or groups [26]. Due to advances in technology, these two technologies evolved on a converging evolution line. A brief look at the developments is in order.

Early telecommunication system was manually switched, advancement in technology brought about automated switching driven by relays. Eventually, stored-program controlled switching emerged together with digital representation of telephone signal. This marked the beginning of convergence between communication and computing. Computers became telecom switches, and were used for signaling and control – enabling more sophisticated services. Digital representations of audio, image, and video signals allowed them to be stored and manipulated by standard computational hardware. Next, computer networking was developed, telecom borrowed this technology to enhance its core network. A keen reader will notice the complementary roll the two technologies play, that is, the telecommunications industry made extensive use of computer and software technologies in the implementation of the configuration and control of the network. The computer industry made use of the telecommunications infrastructure to network computers, which enabled networked applications [25]. The strongest drivers of convergence are programmability of computers and digitization of signals. While digitization provides the same format for computer data and telecom signals, which enabled transmission via common media, thereby converging them at the lower level (the physical layer), programmability converged them at the higher level by enabling diverse applications that can be shared through the telecom network.

Traditional IT centers on data, whereas traditional CT centers on connection-based networks. Convergence of IT and CT produced ICT, which is the cornerstone of what we often refer to as cloud computing - a technology focused on interaction and collaboration between users and systems. Before now, real-time voice services played a dominant role in CT, today, the telecommunications industry focuses on the customer need for seamless services supported by integrated mobile networks [26], (see Fig.7).

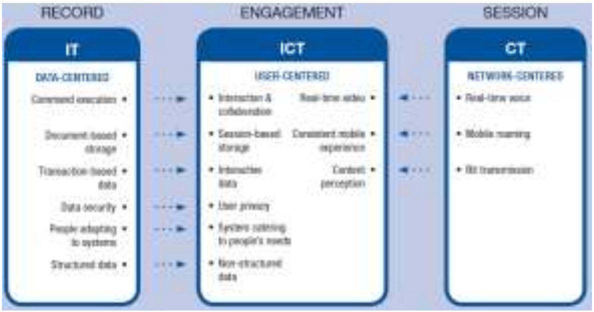

Fig.7: Dynamic connections of ICT services
source: [26]

4. Economic Empowerment via Mobile Connectivity

All the discussion before now has hinged on technological layout for mobile communications. One should stop to ask, 'why the fuss?' 'What is the essence of all these?' Recall that we have pointed out man's need for communication, and that communication drives civilization, we should add that civilization drives economy and therefore better quality of life. Also recall that it was mentioned earlier in this lecture that since prehistoric times, the innate need to communicate has driven mankind to seeking convenient ways to communicate further and more effectively so that he can socialize and do business on the globe. This intuitively supports the fact that telecommunication connectivity is strongly related to economic empowerment. Technically, connectivity level in a given country or region is measured in terms of tele-density or number of telephone lines per 100 population.

It has also been scientifically proven that countries with more number of telephone lines perform economically better than countries that are less connected. This supports the fact that investment in telecoms generates a growth dividend because the spread of telecommunications reduces costs of interaction, expands market boundaries, and enormously expands information flows [27]. According to Roeller and Waverman [27] in the OECD (organization of economically developed countries), the spread of modern fixed-line telecoms networks alone was responsible for one third of output growth between 1970 and 1990. However, development of fixed telecoms lines is a slow and expensive process, and normally takes a long time to develop, every access to homes and firms needed physical lines to be built. For example, France, which had 8 fixed line telephones per 100 persons in 1970, only doubled this by 1976, and reached 30 lines per 100 population in 1980. on the other hand, developing countries could not afford more than minimal fixed line access (figures of about 0.02 fixed-line per 100 persons are obtainable), therefore, at the dawn of mobile telephony, they heartily embraced it because it is cheaper and quicker to rollout, more convenient for users and very flexible. While mobile telephony supplements connectivity in the developed world, in the developing world it forms the major communication network. As a result, statistics abound on the fast growth of mobile communications in the developing countries. In addition, arrival of mobile broadband on the scene, which allows access to data network, has fueled the growth of mobile technology. A few statistics will throw more light.

4.1 Connectivity Statistics

While mobile telephony is connecting the world and empowering the people, mobile broadband promises to be a greater driver of economy globally. Broadband refers to the bandwidth for transmission or reception of data, measured in the number of bits transmitted per second (bps). This terminology came from the fact that telecom network was originally designed for transmission of voice, which uses narrow bandwidth and does not require more than that, but the network was later required to transmit video and data formats which require as much bandwidth as can be afforded. In fact, the wider the bandwidth the faster the transmission and the better the user experience. Exact definition of broadband changes with technological advancement, and with the group defining it. For example, Bold and Davidson in [28] defined it as any mobile (or cellular) technology that delivers minimum data rates in the hundreds of kilobits per second (kb/s) to end users and peak rates in the Megabits per second (Mb/s).

The international telecommunication union (ITU) and the organization of economically developed countries (OECD) have defined broadband as a capacity of at least 256 kbps in the uplink or downlink speed. The Broadband Commission for Digital Development has defined broadband using a cluster of concepts, as high-speed Internet access which is always-on and capable of multiple service provision simultaneously [29]. Whichever way it is defined, the aim of broadband technology is to drive data speed as high as it could go in order to satisfy user demand.

4.1.1 Global connectivity Figures

The world's population is currently estimated to about 7.4 billion people. How many of this population are connected? According to the ITU facts and figures for ICT, by end 2015, there were more than 7 billion mobile cellular subscriptions, corresponding to a penetration rate of 97%, up from 738 million in 2000. Mobile broadband is the most dynamic market segment; globally, mobile broadband penetration reached 47% in 2015, a value that increased 12 times since 2007. However, fixed-broadband uptake is growing at a slower pace, with a 7% annual increase over the past three years and reaching 11% penetration by end 2015. Within this period global Internet penetration grew 7 fold from 6.5% to 43%. The proportion of households with Internet access at home increased from 18% in 2005 to 46% in 2015. The proportion of the population covered by a 2G mobile-cellular network grew from 58% in 2001 to 95% in 2015 [30]. These facts are summarized in Fig.8, while Fig.9 shows global subscription by region.

4.1.2 African Connectivity Figures

In spite of all the report that says Africa is the fastest growing mobile market, the continent is still under subscribed with less than one billion subscription and about half a billion subscribers as shown in Fig.10. The disparity between number of subscription and subscribers is due to multiple subscription by a single subscriber. It is easy to predict that many Africans will not be connected by end of 2016. This is attributable to the poor economic standing of average African. It is expected that connectivity will improve per capita income, which will in turn improve connectivity.

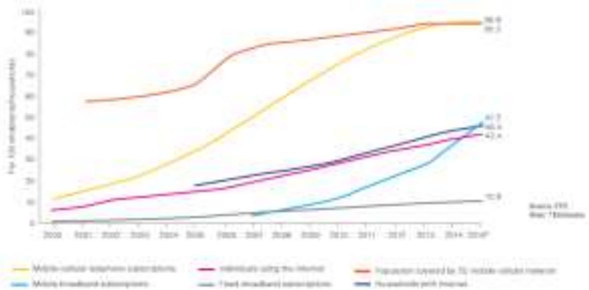

Fig.8: 15 years of ICT growth
Source: [30]

Coming closer home, Sub Saharan Africa (SSA) stands out like a sore thumb in the global economic space. It is expected that this region, more than any other, should leverage ICT to leap-frog development. It is reported that this region has been the fastest growing in mobile connectivity both in terms of unique subscribers and in connections. The unique subscriber base was growing at a compound annual growth rate (CAGR) of 17% per annum. By mid-2014, there were 329 million unique subscribers, equivalent to a penetration rate of 38%. Consumers, governments and businesses across SSA are rapidly adopting mobile, not only as basic communication tool but also to access information and a growing range of new applications and services. The mobile subscriber base is forecast to grow at a CAGR of 7% per annum, reaching just over half a billion unique subscribers by the end of 2020 (see Fig.11). Despite this growth, by 2020 less than half the population of SSA will have a mobile subscription, compared to a global average of six out of 10 people by the same date [33].

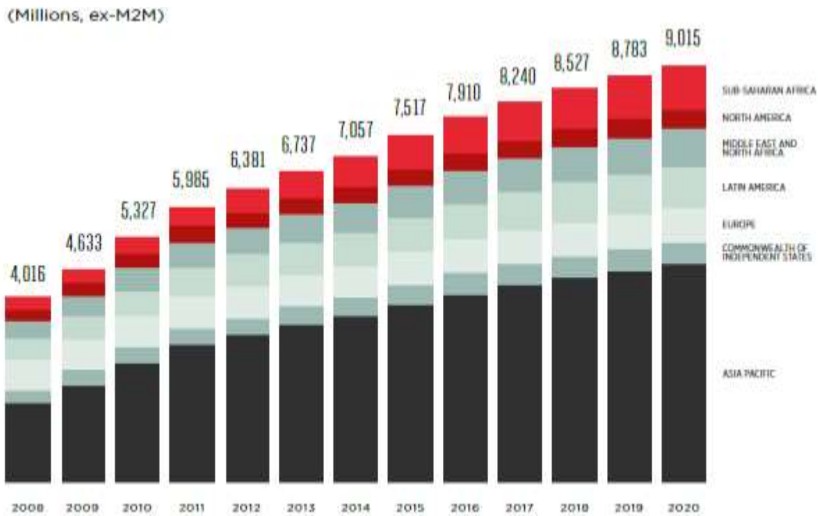

Fig.9: Global mobile connection by region, Source: [31]

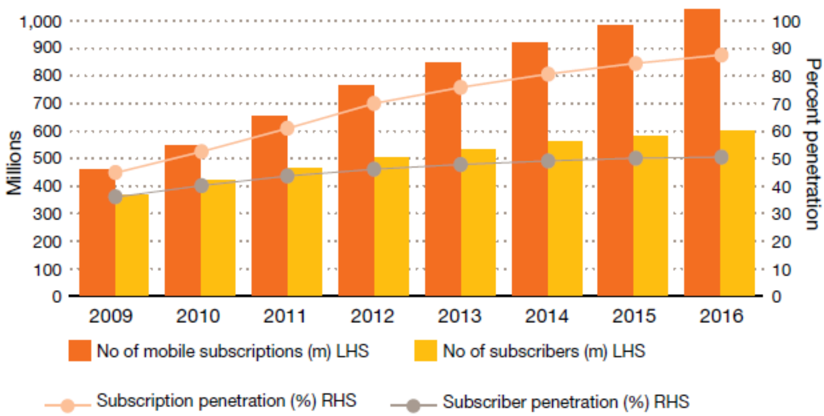

Fig10: Mobile subscriptions in Africa, 2009-2016
Source: [32]

Fig.11: Unique subscribers and penetration rates for SSA
Source: [33]

4.1.3 Mobile Connectivity in Nigeria

Before 1985 telecommunications in Nigeria was managed by NET (Nigerian External Telecommunication and NP&T (Nigerian post and telecommunications). There was one telephone line to 440 inhabitants (i.e., teledennsity of 0.02), quite below the ITU specification of one line to 100 inhabitants. Services were poor, congested, and expensive. By 1985, government split P&T into postal services and telecommunications services, it then merged the later with NET to form NITEL (Nigerian Telecommunications Limited) [34]. Nigerians quest for connectivity was not achieved with NITEL – a state monopoly. Deregulation of the telecom sector was started in 1992 with the formation of Nigerian Communications Commission (NCC), but was completed in 1999 [35]. NCC's task is to auction licenses to private mobile operators and to fairly regulate operations in the sector. The first batch of licenses were issued to MTN, Econet wireless, and M-Tel. It was from this point that connectivity in Nigeria started making steady progress. From teledensity figures of 0.4 lines per 100 inhabitants recorded in year 2000, by October 2008, Nigeria had recorded teledensity figures of 42 lines per 100 inhabitants, and an active subscriber base of nearly 59 million lines [36]. This is a brief story of how Nigeria joined mobile connectivity train, Fig.12 provides a summary. Being the most populous country on the African soil, coupled with poor wireline network, Nigeria has been reported to be the largest mobile telecom market. Nigeria is reasonably well connected in 2G technology, however, with favourable regulatory practices and spectrum availability, Nigeria's growth in broadband connectivity is predicted to be substantial by the year 2020 as shown Fig.13.

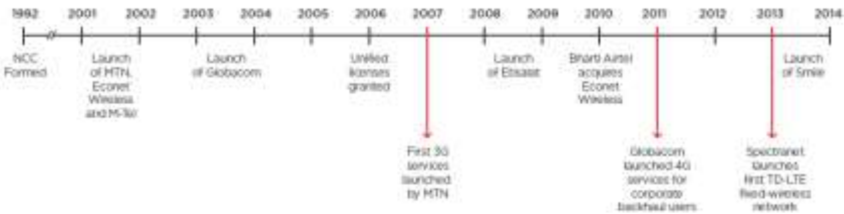

Fig.12: Mobile network operator launch timeline
Source: [37]

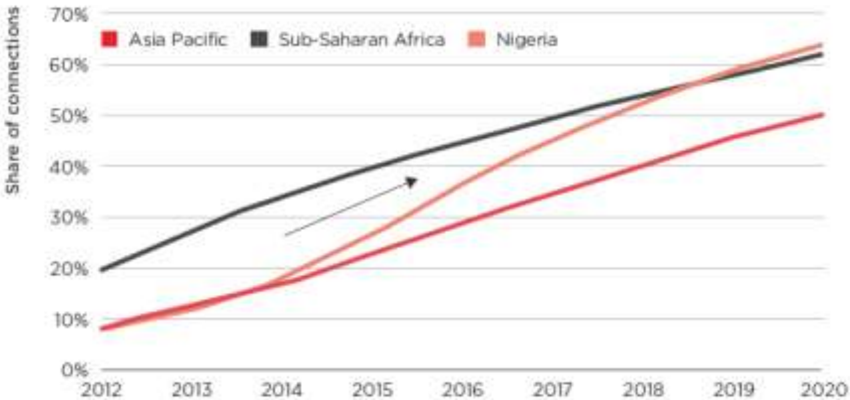

Fig.13: Mobile broadband impending rise
Source: [37]

Despite a great potential for growth in the mobile market, Nigeria is currently undersubscribed (see Fig.14) due to high cost of subscription. This is attributable to a number of challenges, which include, very unstable power supply, multiple taxation, poor distribution of backbone network etc.

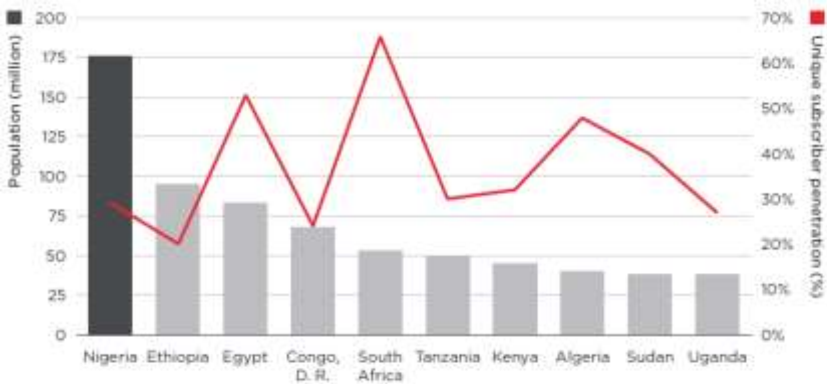

Fig.14: Nigeria, the largest country in Africa, but underpenetrated in mobile [37]

4.2 The Reach of Mobile Empowerment

Mobile connectivity brings economic empowerment in many dimensions. Besides direct employment by mobile company, and mobile services related businesses (usually called mobile ecosystem), mobile connectivity enhances every other business by bridging distances, reducing the cost of contact and provides information at cheaper rates. All of this drops the cost of running businesses and increases profit. Studies assessing the direct and indirect impact of mobile broadband in economies such as India; South Africa; Nigeria; Taiwan, China; and the United States show that a 10 % increase in mobile broadband penetration is likely to yield an impact of between 1 and 1.8 % in GDP. More specifically, it was estimated that for South Africa, mobile broadband and related industries could generate about 28,000 new jobs and 1.8 % of GDP by 2015 if sufficient spectrum is allocated. In Nigeria, mobile broadband could contribute over 1 % of GDP (and 1.7 % of non-oil GDP) in 2015, supporting diversification of the country’s economy [28]. These supports the World Bank studies which estimated that a 10 % increase in mobile phone penetration correlates to a 0.8 % increase of per capita GDP, while a 10 % increase in Internet penetration increases per capita GDP by 1.4 % in developing countries [31]. It will interest the reader to see a few specific examples of how mobile communications is empowering people, especially in developing nations.

These statistical estimates are pointers of how mobile connectivity is empowering individuals, communities, nations and regions by providing access to information. The reader must have observed that there are applications that assist farmers, fishermen, small businesses, etc., to increase efficiency and improve customer satisfaction. Connectivity generally improves income levels; job creation; poverty reduction; better education; improved healthcare; and social inclusion, all of which increases quality of life. Some specific examples from [38] are summarised below:

(i) Increase in productivity: The ability to send complex information and data via mobile phones and the internet reduces travel time and costs and increases organizational efficiency. Being connected enables individuals to receive information and new ideas on the business the individual is engaged in. For example, researchers get new ideas, farmers get informed on new farming methods, disease control, market prices etc., even live stocks can be tracked using mobile technology, the street water hawker (*mai ruwa*) connects with his customers via mobile phone.

(ii) Supports Enterprise and Innovation: SMEs are amongst the biggest beneficiaries from access to mobile technology. By reducing transaction costs and the constraints of distance, mobile phone reduces barriers to market entry and allows SMEs to reach a broader market, and customer base. Mobile banking enables ease and quick payment to suppliers. Access to mobile broadband encourages innovation by helping innovators share ideas and connect with investors across the world. We can listen to our search FM online and even NTA points listeners to online news clips.

(iii) Increases Employment: Mobile technology creates new jobs through numerous avenues: directly through the demand for labour from new technology-based enterprises; and indirectly through the demand from the wider ecosystem of companies that are created to support technology-based enterprises; for example, network installation and maintenance providers and providers of other skill-based services such as mobile phone repairers and app developers.

(iv) Increases Economic Growth: Through increases in productivity and innovation throughout the economy, mobile technology leads to additional economic growth. Growth is also driven by increases in demand in the sectors associated with telecommunications and internet service provision, together impacting the wider economy through increases in demand, spending and government revenues. This is summarized in Fig.15.

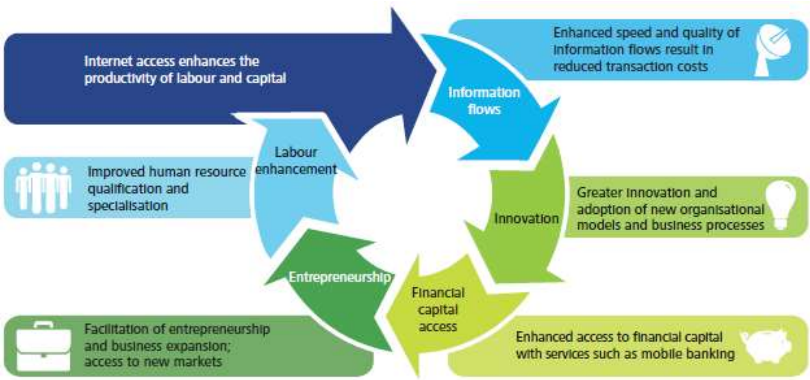

Fig.15: Economic impact of mobile connectivity [38]

(v) Creation of Knowledge-based Economy: our economy and economies of most developing nations are dependent on either oil or agriculture. The internet via broadband connectivity can unlock a knowledge-based economy whereby information is shared without barriers. In a knowledge-based economy, people and enterprises increasingly have the ability to develop specialized expertise and adopt new business methods. Skills such as software development will increase the demand for high skilled labor.

(vi) Impacts on Healthcare: Lack of access to basic health services in developing countries remains a major social concern causing hundreds of thousands of deaths every year. Access to the internet via mobile technology can improve health conditions by reducing the incidence of diseases through better information for both patients and health practitioners. In addition, mobile and internet technologies have the potential to improve medical behaviors for patients and healthcare professionals by reminding individuals of their due treatments or medications; and enabling connectedness between patients and doctors, and between doctors in different locations. This impact is likely to be particularly significant in rural communities, where the traditional health infrastructure is harder to reach. Healthcare impact of mobile technology is illustrated in Fig.16.

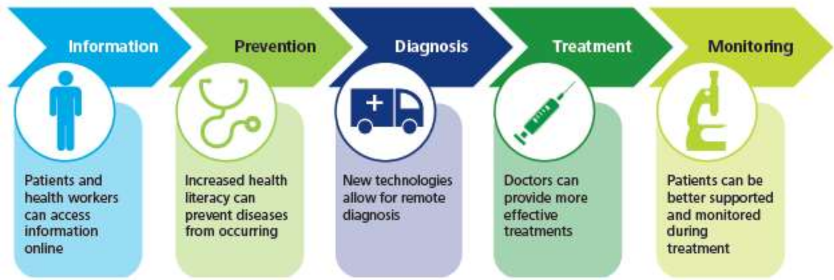

Fig.16: impact of mobile communication on healthcare [38]

(vii) Impacts on Education: Education is a major catalyst for human and economic development and its role is paramount in delivering sustainable socio-economic growth. While providing access to formal education for all requires investment in physical infrastructure, training of teachers, and adequate teaching resources, the internet is already proving one of the most powerful means to extend access to educational resources and improve lifelong learning with potential outcomes, reaching even the most disadvantaged populations and in a cost-effective way. According to the secretary general of the ITU, "a student in a developing country can now access the library of a prestigious university anywhere in the world; unemployed persons can retrain and improve their job prospects in other fields; teachers can gain inspiration and advice from the resources and experiences of others. With each of these achievements, the online world brings about another real-world victory for education, dialogue and better understanding between peoples." See Fig.17.

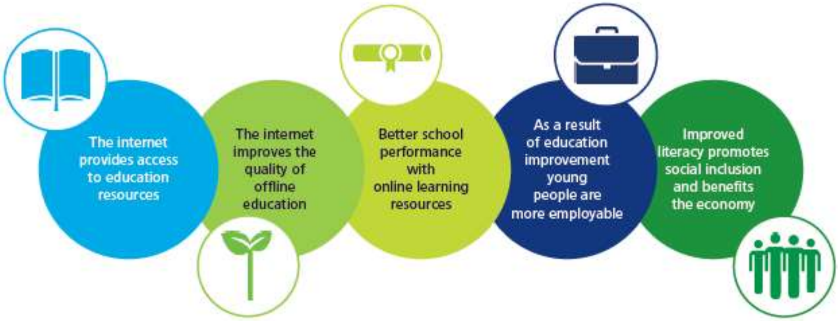

Fig.17: Impact of mobile communication on education [38]

(viii) Impact in Promoting Social Inclusion: Social inclusion means the participation of individuals and groups in society's political, economic and societal processes. These often intangible benefits can have strong impacts at the personal and community level and the economic and social transformation promoted by mobile and internet access can improve a number of other social issues currently affecting developing countries. For example getting information around when disaster occurs; participation in governance and societal issues especially by marginalized groups; promotion of social cohesion and sharing of problems; sharing of information on environmental preservation etc. see Fig.18.

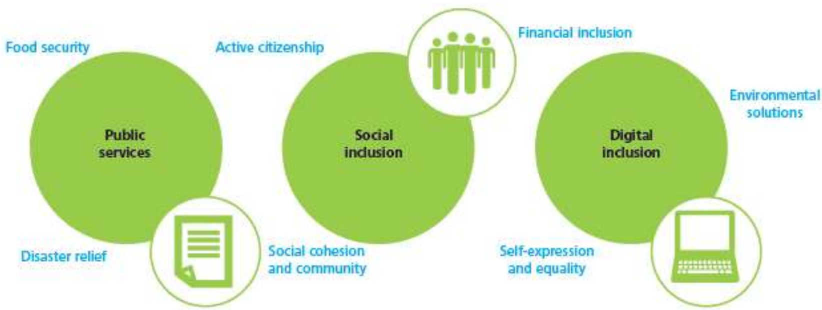

Fig.18: Impact of mobile communication on social inclusion [38]

5. Our Humble Contributions

From the foregoing, the avid reader must have seen the importance of communications to societal empowerment, he must have also seen some of the stages of development of the systems that enable man to interact with his environment. Of all the technological communication systems, the one that has positively impacted society most immensely is the mobile communication system. We are therefore justified to continue investigating this system – creating new ones and improving on the old systems, in order to help man enjoy his short stay on planet earth.

It should be noted that the genesis of mankind's challenges on earth is insufficient resources (of any kind). No resource is ever enough for man to do all he wanted to do. This insufficiency is indeed a blessing from God Almighty, because it keeps us in motion, spiritually, mentally and physically. It helps man to be alert, to keep investigating and exploring in order to find better ways of using the available resources to provide for his needs. It is this challenge that forced us to go to seek education, cultivate farms, …, and to design mobile communication systems.

The mobile communications network consists of two major parts: the fixed part and the mobile part, connected by the wireless interface. The mobile part is the mobile terminal or mobile node (MT or MN), which move with the user from place to place, while the fixed part consist of the peripheral and the core network nodes that do not move, example is the base transceiver station (BTS). The fixed part of the network does the job of connecting the mobile users and controlling their calls and transactions. These connections are done through the wireless spectrum (wireless frequencies). The architecture of a network (node & signal architecture) impacts the management of the network resources, which in turn determines the quality of service (QoS) derivable from such network.

In mobile communication network, the wireless spectrum, being a natural resource that cannot be increased at will, constitutes a bottle neck in the system. Therefore, most research efforts in mobile communication is driven by the objective to improve performance while conserving the spectrum through efficient utilization. Another very important and scarce resource in mobile communication is power, especially the mobile terminal power. System designs (either the mobile node, fixed node or the entire network) are usually geared towards power preservation, to ensure that the mobile terminal signaling load is minimized. Bandwidth and power consists the two most important resources in mobile communication.

In the design of the communication network, an important performance measure is transaction delay, another important measure is capacity i.e., how many users the network can support. Network delay and capacity are related in the sense that poor capacity will increase delay. A number of factors can affect network capacity, examples include design of network switches, memory space and database management of network nodes, network signaling design etc. Poor design of the fixed part of the network will usually affect the mobile part that it supports.

Network signaling refers to control signal transmissions used to manage user movements and transactions in a mobile network. Mobility management, earlier introduced, is a core function of mobile network and it is heavily dependent on signaling. Therefore, poor design of mobility management functions such as handoff, location management and paging will result to a poorly performing network. Note that these functions are designed on the underlying network architecture, therefore a faulty architecture will impact negatively on the design of mobility management functions.

My supervisors, students, and I have tried to make some contributions in the area of mobile network architecture design, mobility management, spectrum management, and recently big data analytics for counter terrorism. I will briefly discus a few that may interest the reader.

5.1 Scalable IP Micro Mobility Management:

Recall the background of mobile IP laid earlier, and the fact that it has a number of performance challenges. This is because it was designed to manage user movement across the globe. It was therefore difficult to effectively manage user mobility on such wide space. Other works introduced what is called micro mobility management, which is to manage mobility in smaller regions. Two of the most prominent works in IP micro mobility management [22, 23] were thoroughly examined, though they solved some of the problems inherent in the macro IP mobility management, they did not consider scalability of the network. Scalability of mobile IP network is very important for three reasons: 1. the fixed internet is already highly subscribed such that the huge address space is near depletion, 2. mobile technology is also highly subscribed especially in regions with poor fixed network infrastructure coupled to the enormous positive impact it is making in society, and 3. the emergence of internet of things where more machines than humans will eventually connect to the internet. It is therefore not difficult to predict that mobile IP network will be heavily subscribed. It is important to point out that network scalability implies sustainable capacity growth.

In considering scalability we recognized the fact that hierarchical design enhances scalability. Although there was a work on hierarchical mobile IPv6 [39], this work considered hierarchy with respect to network node topology only, this type of hierarchy neither considered the signaling load on the network nor distribution of mobile node information on network database. Unlike the mobile voice network, in the IP network, database of mobile node information is collocated in the router. In a hierarchical architecture, higher level routers/databases are the bottle neck, because once these routers are saturated the segment of the network under them will no longer scale, which means no new user will be accommodated. Putting all these into consideration we designed a completely hierarchical micro mobility architecture that has distributed signaling load, which gave rise to distributed database loading (it is hierarchical in both node topology, signaling, a and node address). This was achieved using a hybrid of routing techniques – prefix routing and host-based routing. To achieve this, advantage was taken of the IPv6 broad address space and classless inter domain routing (CIDR), which allows flexibility in routing hierarchy by masking selected groups of address bits. This architecture was supported by the fact that 70% of time, mobile users move around only in their home domain [43], therefore, keeping their location information in every database, many of which are far-away, is not only unnecessary waste of network resources but also introduction of unnecessary delay. The architecture is shown in Fig.19 and the signaling flow is illustrated in Fig.20.

From Fig.19, it could be seen that any MN at home has location information entry only in its home router/database, which is the access router (AR). Only when it moves to another coverage area will it have a mobility binding stored in the respective sub-domain router (SDR) and the AR. This means that only MNs away from home will have location information in the SDR or GR (gateway router) for the purpose of routing traffic to them using host-based routing (i.e., mobility binding). Once an MN returns home, the mobility bindings are cleared, thereby freeing the storage space, and traffic will be routed to it using traditional IP routing (prefix based).

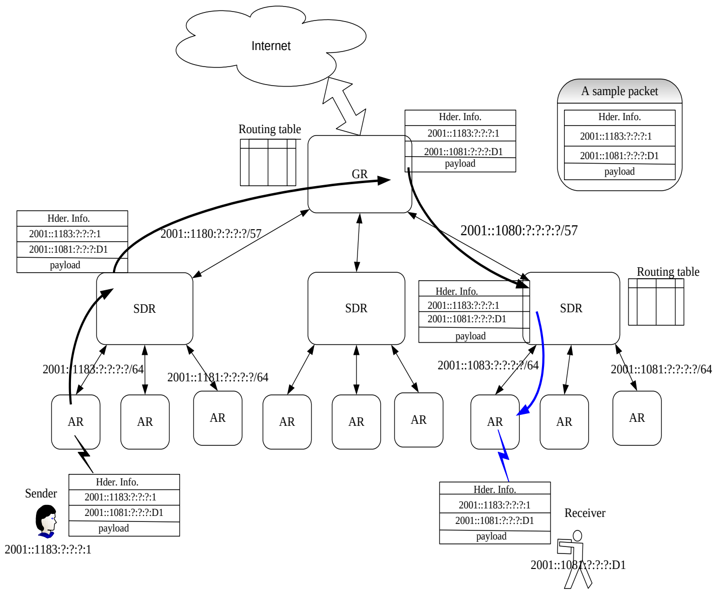

Fig.19: The hierarchical micro mobility architecture illustrating the hybrid routing mechanism

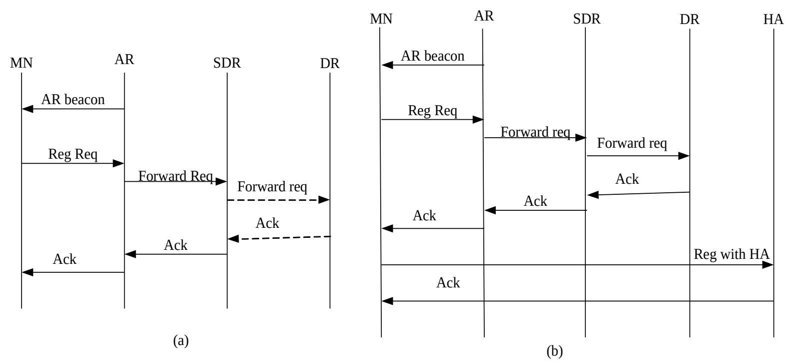

Fig.20: Signal flow for MN updating: (a) in home domain, (b) in foreign domain (dashed lines in (a) means that this does not happen at every move of the MN)

From Fig. 20, it could be seen that spurious signaling is avoided, which drastically reduces network congestion when many nodes are in the network. The system was evaluated to assess the scalability under different scenarios such as: 2, 3, 4 levels of hierarchy against when only topological hierarchy is used, it was also evaluated under high user density scenario. In all these scenarios, the architecture showed excellent scalability performance, meaning the network has a reasonable sustainable capacity. The system was compared with the two prominent architectures in the micro mobility category of mobile IP, the result showed an excellent scaling behavior for our hybrid architecture, for two different scenarios. Queueing theory and tele-traffic engineering technique was used for the analysis. The result shows that the network can conveniently support many users. It is also interesting to note that this network can easily be expanded by adding access routers at the leaf level of the hierarchy. Figs 21 – 24 show some of the results. Other results were obtained but space will not permit displaying all of them. Interested readers are pointed to [40] and [41] for details of the analysis. This work has a European patent [42].

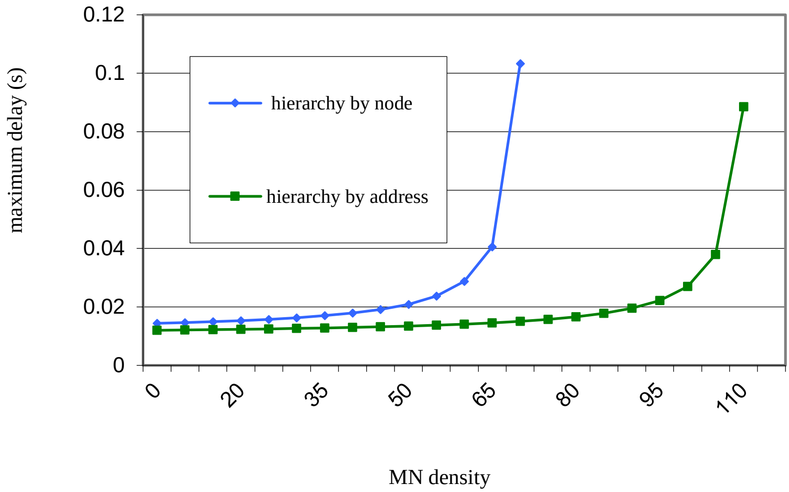

Fig.21: Scalability performance for 2-level system for scenario 1and 2 (l=800m, v=5.6Km/hr)

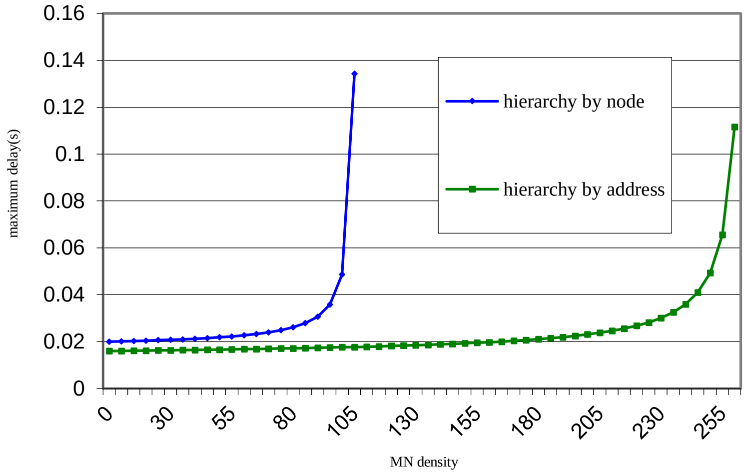

Fig. 22: Scalability performance for 3-level system
for scenario 1and 2 (l=800m, v =5.6Km/hr)

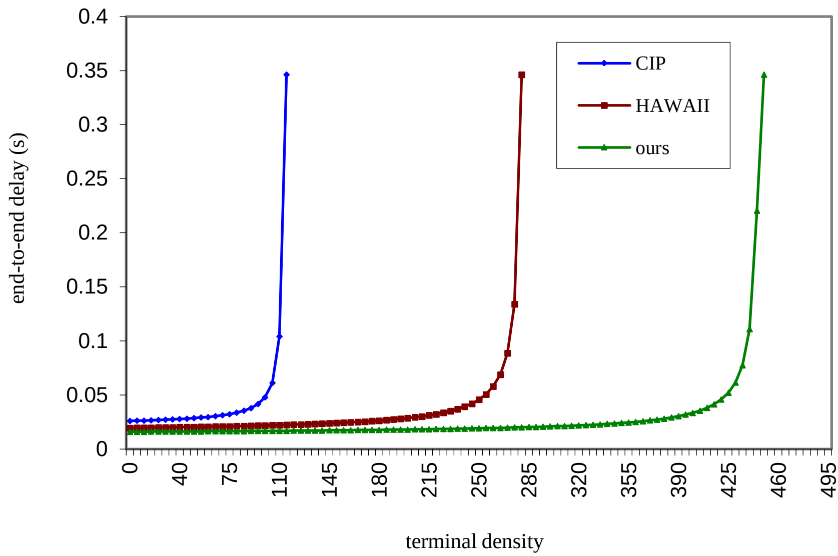

Fig.23: End-to-end delay for 3-level hierarchy
(l=0.5Km, r=20, v=5.6Km/hr)

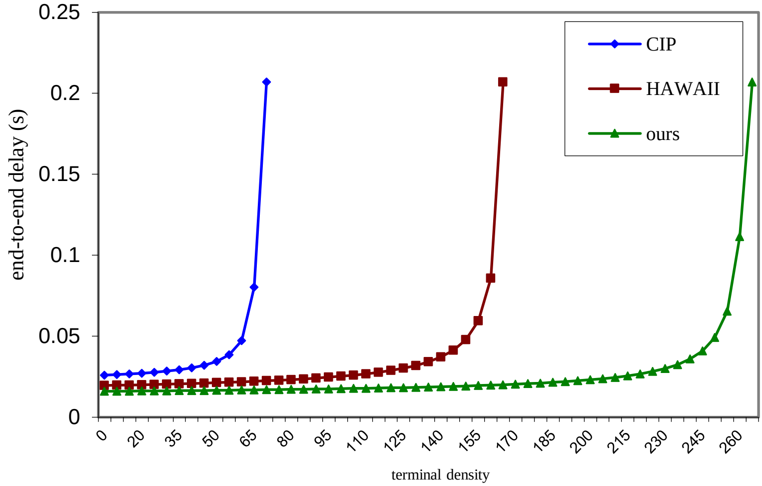

Fig.24: End-to-end delay for 3-level hierarchy
(l=0.8Km, r=20, v=5.6Km/hr)

5.2 Paging Design

A paging design for mobile cellular internet enhanced by locality in user-behavior [12] was also considered. Recall that the network must know the location of a mobile node (MN) in order to send messages to it. For this reason, MNs register their location areas (LAs) with the network and also perform location update within given time intervals. However, location area gives the network a general, but not an exact location of the MN. This is because, to minimize MN power consumption, LAs are designed to be larger than cell coverage areas, to reduce the number of registration signals it has to transmit. For the same reason, MNs are designed to be in a dormant mode when they are not actively communicating, which means a low power mode. So, when a message comes for a given MN, the network determines its exact location by paging. Paging means to search for the MN by polling the cells in the LA with search signal containing the MN identity. The needed MN, on receiving the poll signal will acknowledge it, thereby revealing its exact location.

The problem lies in the design of the paging system for optimal performance. The performance metrics here are delay, bandwidth consumption, and MN power preservation. There are three major approaches: blanket polling where the entire LA is polled, this gives fastest time to locate a MN but consumes a lot of bandwidth resource. The second uses fixed paging areas, which requires the network to sequentially poll small areas within the LA until the MN is located. This method saves cost if a high probability of hit is achieved (which means a high probability of locating the MN in the first or second poll). The third is dynamic paging, in which a paging area is designed for each MN based on its mobility rate, message transaction rate, and mobility pattern. This will save paging cost but its complexity will consume network computational and memory resources.

Considering the limitations of the existing paging system, the author designed a hybrid paging algorithm based on the IP micro mobility architecture shown in Fig19, using the idea of locality in mobile user behavior. Research has shown that there is 70% probability that a mobile user moves around in his home domain, and that most people do not live very far from their place of work [43]. Leveraging this idea the author designed a paging algorithm based on a hybrid of fixed and dynamic paging. The result obtained is cost effective with reduced complexity, see Fig.25.

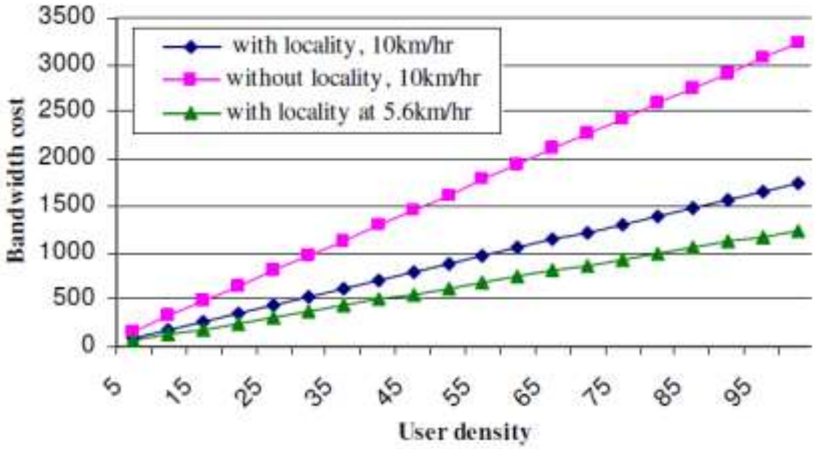

Fig.25: Overall cost of paging and update, with and without locality probability, at 10 km/h and 5.6 km/h (cell radius 500 m)

5.3 Route Optimization in Mobile Network

Working with students, the mobile IP work was extended to consider route optimization [44, 45]. Recall that there is a problem of packet routing optimality in the IP macro mobility protocol. Researchers were proposing various solutions to this problem. We considered that designing intelligence into the network nodes that control the mobile node's movement when away from home network will go a long way to alleviate this problem. The design was simulated on OPNET and yielded appreciable results.

5.4 Conservation of Mobile Terminal Battery

Further work with my students considered an algorithm for conservation of mobile terminal battery using dynamic power control [46]. Recall that the mobile terminal (MT) is a node on the mobile part of the mobile communication network. The user accesses the network and its resources using the MT, which is battery powered. If the battery power of the MT is not properly managed, it will drain very often, hindering the user from benefiting from ample network resources. Certain network conditions negatively impact MT battery power, for example, poor signal strength drains the MT battery faster than good network conditions. For this reason, setting the MT to transmit at a constant power level will result to inefficient use of its battery power. Therefore, in this work, an algorithm was designed to dynamically adjust the transmit power of the MT based on measured network statistics such as received signal strength (RSS) and bit error rate (BER). This means that in a good signal strength condition, the MT can tune down its transmit power level. The algorithm was simulate on OPNET platform and it showed an appreciative performance in conserving MT battery. For the details the reader is referred to the main work [46].

5.5 Network Integration

The reader must have observed that there are different types of wireless networks around us, such as the wireless LAN (WLAN) which is data oriented, the GSM network which is voice oriented, the 3G network – defined under the universal mobile telecommunication (UMTS) guidelines, etc. These networks support different user devices for access, with different radio access technologies, they also serve complementary user needs, and are sometimes collocated. It is not convenient for users to carry multiple user devices in order to optimally benefit from the available wireless networks. For this reason research in network integration is done to find ways a single user terminal can be capable of accessing multiple wireless networks based on the need of the user. In the networking research community, the slogan "Always Best Connected (ABC)" is used to drive these efforts. This is to say that the user should always be connected to the best network anywhere, any time and with any device.

One of the research efforts towards achieving ABC is vertical handoff (VHO), which means that a user device can automatically switch from one type of wireless network to another, either based on prevailing network conditions or based on user preferences. For good performance, the conditions that guide the decision for an MT to perform vertical handoff must be carefully selected and designed into the system. One such condition is that a user who is on GSM voice network but decided to do a file download operation, once the download is initiates the MT will check the network status and decide if the operation can conveniently be completed on the current network, otherwise the terminal should automatically connect to a WLAN if available, due to the fact that WLAN has a wider bandwidth and will therefore perform a faster download. This gives a lot of lift to user experience.

There are a number of conditions that the MT will weigh before deciding to do a vertical handoff, some of them include received signal strength, available bandwidth/data rate, and battery level of the MT etc. Working with my student, we added to the plethora of existing user preferences that could trigger a vertical handoff. This is reported in [17]. Bearing in mind the power problem in our environment, we considered the panic a user will have if he is in the middle of downloading a file on one network while his terminal battery is about to deplete. To solve this problem, we considered that one of the essential conditions that will make the MT decide to switch to another network is comparing the length of time remaining for the download to complete and the time remaining for the MT's battery to deplete. If the available battery cannot last for the download operation to complete in the current network, the MT should switch to a higher bandwidth network to ensure faster and complete download of the user file. Vertical handoff, if poorly designed, could result to an unstable condition described as "ping pong", which means a mobile terminal switching back and forth between two networks. This is usually encountered when vertical handoff (VHO) decisions were poorly set, it will make an MT to behave like a greedy dog, thereby perform poorly. In this work, our decision policies were set to avoid this. Stability performance of the VHO tested appreciably well, for details please see [47].

5.6 Spectrum Management – Cognitive radio

Currently we are looking at spectrum management. The avid reader must have realized that frequency spectrum availability is key to mobile communications and its offerings, and that spectrum is a natural resource that must be wisely managed in order to accommodate all the existing and yet to emerge wireless networks and applications. The research community is currently focusing attention on this daunting problem, and it has been realized that the traditional method by which regulatory bodies such as federal communications commission (FCC) in the US, and Nigerian communication commission (NCC) in Nigeria, assign frequency to wireless network operators is not efficient. This method is describe as fixed assignment, where a portion of the frequency spectrum is assigned to a given wireless service, say television broadcasting on permanent basis. TV transmitters may not always use this spectrum, and whenever it is not being used, no one else may use it, so that it lies idle. To solve this problem, researchers are suggesting dynamic instead of static spectrum assignment method. One of the ways to achieve this dynamism in spectrum assignment is by using cognitive radio technology. Cognitive radio (CR) is an intelligent radio device that is aware of its spectral environment such that it could take advantage of any idle frequency channel when the assigned owner of such channel is not using it. But it must be watchful to know when the owner returns in order to vacate the channel, i.e., it must not cause interference to the owner of the occupied frequency channel. This means that the dynamic assignment will be overlaid on the static assignment method.

The research problems that are being considered for achieving this are: how the CR will know an idle or occupied channel (spectrum sensing), how it will know that the owner of the channel has returned so that it can vacate it (spectrum handoff), how it will move from a channel whose owner has returned to another idle one to continue its transmissions (spectrum mobility), and how to accommodate other CRs, which are also wanting to occupy the same idle channel (spectrum sharing). There is also the problem of rogue CR that will disguise as the owner of the channel for the purpose of denying other CRs access to an available channel. My students and I are working hard to contribute solutions to some of these problems. Some of our work in this area could be found in [48-50].

5.7 Big Data Analytics and Applications

This is a buzz phrase in the contemporary research society. Big Data is defined as an aggregate of datasets that are large and complex, thus overwhelming the traditional data mining tools. Big Data Analytics is a term encompassing the new methods, tools and technologies for collecting, managing and analyzing, in real-time, the vast increase in both structured and unstructured data for insightful and effective decision making [51]. As people and devices are increasingly connected online, society is generating digital data traces at an extraordinary rate, unprecedented in human history. As the mobile communication network is connecting and empowering users so is it generating huge amounts of human behavioral data, stored in the network nodes. Telecommunication industry is said to be one of the industries that have deluge of human behavioral data. This data could be put to use for understanding societal needs and then planning and helping it. Big Data Analytics research is multidisciplinary. Various research communities are focusing on how to use data to understand and make society better.

My students and I are working on using the tool of complex network analysis to track criminals from telecom data. It should be noted that everybody who uses the telecom network leaves digital foot print on it by way of data generated by the network while rendering service. Since criminals also use the network, their foot prints will be on that data. We are aiming to find techniques for gathering crime intelligence from this data, which will aid the crime investigators to easily handle criminals without harming innocent citizens. Besides crime intelligence, this huge telecom data could be used to study user behavior with respect to the network and then plan and adjust the network to better serve them. Our feeble efforts have yielded some results that are ready for the press. These are in the areas of community detection and identification of influential persons in a given community.

Note that people, consciously or otherwise, form groups, clusters or communities as they socialize or relate with one another based on some commonalities (birds of a feather flock together). These days of mobile connectivity, people socialize or interact more conveniently through the mobile communication network. In so doing, there groups or clusters, often called communities, are reflected on the communication network data. Such groups could be detected using certain techniques, and in every such groups, there are usually persons of high influence, who can be considered a leader of some sort. These influential persons can also be identified with appropriate techniques. Detecting communities from data and identifying important persons in such communities has a lot of applications in solving societal problems. We have been able to develop two techniques, one for community detection and another for detection of influential nodes. These were tested with a telecom dataset, and the results were promising [52, 53].

6. Conclusion

Vice-Chancellor Sir, ladies and gentlemen, I have just presented a lecture on how mobile cellular communications is connecting the world and empowering the people (I hope I did not bore you too much). It was established that communication is a natural need for humanity, and that mankind had always sought ways to communicate better with each other and with their environment. We further traced the various efforts man has made to create systems that will enable him achieve this need up to the present time. We could see a systematic progress in the development of these systems, especially the mobile communication systems. Today mobile voice network has made a good progress, and research is looking into mobile broadband data network, that is, mobile internet or IP mobility. Today an average individual is inseparable with his/her mobile device, such that we wonder how we were able to live without it before now. We also discussed how much of the world is connected, and most importantly how much of Nigeria is connected. It was shown that our dear country, giant of Africa, is still poorly connected due to high cost of connectivity, which, in turn, is attributed to many national problems such as poor electricity supply, multiple taxation, average individual poverty level, etc. We also said that mobile connectivity empowers the individual, society and the nation at large. It increases income level by lowering the cost of doing business, upgrades education, brings social inclusion, and improves longevity by empowering health workers and their patients.

With all these benefits from mobile connectivity, it is but a duty onto humanity to continue to do research in mobile communication, to drive cost low so it could be made available to all. It is for this reason alone, and not because we know anything, that we joined the research community to contribute our little quota, no matter how small, in driving technology forward and making the world a better place for all. We also discussed briefly, a few works that Heaven has guided us to do in this respect. However, in doing this, we encounter some challenges.

6.1 Challenges to Research in Our Local Environment

(i) ***Language of Instruction:*** we take it for granted that we must learn a foreign language, then communicate science and technology with it. Our students have two levels of difficulty. Because they do not study in their native tongues, they have to first master the language of instruction before mastering the subject matter. Germans study in German language, Japanese study in Japanese, Chinese study in Chinese, but Nigerians? Or Africans? We study in a borrowed languages, this is a problem.

(ii) ***Enabling Environment:*** Working environment is as poor as it could be. Gross insufficiency in electric power and the ills that come with it is no longer news even to the newly born, except that it gets worse by day. Added to this is insufficient study materials, poor facilities and inadequate spaces. All of this makes the life of a local researcher miserable, to say the least.

(iii) Poverty Level: the general poverty level in the environment is simply depressing.

Vice-Chancellor Sir, unfortunately, these problems are beyond you and your Management. They are not also solvable by research until they are put in context. They hinge on political will. Despite all these, the local researcher has to compete with his/her counterparts on the greener side of life. In writing this short lecture, I know how much I spent on fuel for running generator, and because I had to run out of the office in order to find time to write it, I had to spend money on data bundle because there is no internet to the home, data bundle is also not cheap. Am I asking for too much?

6.2 Recommendations

Water is life, we all know this, but these days some things are competing with water in providing life. Mobile connectivity is one such competitor. Majority of Nigerians who are connected to broadband, are wirelessly connected, even this number is low in comparison to our population all because of high cost of connectivity. Considering the empowerment that connectivity brings to individuals, government should take steps to lower the average cost of connectivity. Some ways to do this is include:

1. Laying communication infrastructure such as fiber optic backbone cable, all around the country so that mobile operators could tap into it to provide services at affordable price. This type of infrastructure, like roads and pipe borne water, should be centrally provided by the federal government.

2. Many businesses, including mobile operators, cry under the burden of multiple taxation. This business expense bounces back to poor consumers. Government should take a serious look at multiple taxation in order to encourage investment and also lighten the burden of poor consumers.

3. Some mobile phone manufacturers that Nigeria patronize should be encouraged to set up a factory in Nigeria. This will bring cost down and create jobs.

4. The cost of electricity in running businesses, including mobile communication business, is also borne by poor consumers. It is estimated that about USD13 billion is spent each year on diesel. Well, on this electricity issue, the government and people of Nigeria should simply declare an indefinite fasting and prayer.

Acknowledgement
I do not have enough words with which to express my gratitude to God the Almighty Who led me all the way to this podium and is still leading me, yea, the Omniscient One, He always answers me whenever I call. What can a mere mortal do in appreciation to the infinite mercies of God? I can only say THANK YOU LORD!

I sincerely appreciate my parents, late Mr. Anthony Onwuka and late Madam Victoria Onwuka. I am raising two children, and I have known it is not easy to raise a child. You raised six of us with your peasant farming occupation. It couldn't have been easy. Thank you is not enough, but God the Almighty will make up for you two where we failed. Papa was ever so cool and Mama complemented with her fire, I love to think that I have 50 of Papa and 50 of Mama in me. If one must talk about 'Super Mum', Mama was a Super Mum! Wherever your souls are residing now, may the light of the Lord illuminate your paths.

I grew up in different homes, and I am grateful to these families for shaping my feet as I grew. I especially appreciate Mrs. Helen Uba and her husband Mr. Felix Uba, and their entire family. I always remember fondly late Mr. Mathew Ezekwe, with whose family I lived from age 9. He was a fatherly friend.

I am very grateful to my siblings, we are a great bunch, put together in one family out of the wise designs of God. I am luckily placed in the middle of the bunch. That is probably why I got to this level of education. You supported Papa and Mama in getting me to this point (*Professor from a Peasant home! It is the Lords own making, and I really thank Him*). Every single one of you played a role, especially my big brothers, Mr. Bartholomew and Mr. Michael Onwuka, you have always been my heroes since childhood. I measured every other man with my brothers, and my brothers were always better. Unfortunately, I haven't made money, but who knows, maybe it is on the way.

There are several other positive influencers that contributed to my being here today, who never suspected they influenced me this much. One is my aunty Mrs. Beatrice Okafor (Papa's younger sister) her school cupboard that I saw as a small girl, with the books neatly packed in them, told me that this is where I belong. My senior cousin Sir Emma Onwuka, never knew how much he positively influenced me. The entire members of the Onwuka Big Family, I salute you all!

My teachers – my second set of parents, I thank you all. You are too numerous to name. But I must remember my primary one teacher who solved a problem for me in counting, without even knowing she did. Wherever she is, may God bless her. Teachers have a special place in life, they give so much without even knowing how much they give. I charge them to always stand aright because they influence so many people, unfortunately, bad influence is equally rewarded, so teachers must be careful. I am so lucky standing here today amidst my Lectures and my students. Sometimes when teaching, I tried to remember how some of my Lecturers delivered, the elucidation of Prof. Oyedum; the calm and clear explanations of Prof. Daniyan; the precision of Prof. S. Sadiku (of civil eng); the discipline of Prof Adediran (now at uni Ilorin) etc.

My theses supervisors: Mr Godwin Ugwu for my first Degree, Prof Ajose for my Master Degree, Prof Niu Zhisheng (Tsinghua Uni Beijing) for my Doctoral, I thank you for your guidance. I have a special place in my mind for Prof M.G Yisa one of my mentors, Prof Adeboye (Maths dept.) and Prof Li (of Tsinghua University) to mention a few. May God bless you all.

My students, those who have graduated and those who are still around, undergraduate and postgraduate, I thank you deeply. I will like all of you to understand that "the better part of love is severe". You are as important to me as my teachers, you have contributed a lot for me to reach this level today and, you will all reach your desired levels in life.

FUT Minna nurtured me and gave me job. When I work for FUT Minna I do not look back, because I am working for my own. I am almost a Nigerlite. Prof J.O. Ndagi was the VC who admitted me as student and gave me job as staff, he is a father to too many children that he cannot remember them all. A special salute for him! All our VCs and their Management teams have always been good to me. I am lucky to have closely worked with two of them, Prof M.S. Audu and Prof M. A. Akanji. Coincidentally, they were born the same year with my mother's first son, who is now head of our family. Somehow, this makes me always look upon them like big brothers, and they have actually treated me like younger sister. They were patient with me, believed in me and guided me as I worked with them. And I believe in them, yea, the VC said it and it is so!

Prof. Akanji, I must thank you specially, for your gentle and silent corrections and your urge for me to give this lecture. After each inaugural lecture, as we follow the VC out of the theater, he will ask me "is your own coming up next month?" I really thank you Sir, for your interest in my progress.

I have two big sisters here, Prof. (Mrs) V. I. Ezenwa and Mrs. V. N. Kolo. I only need to look at their face to know if getting it right or wrong, and I will quickly correct myself. I thank you.

I tried to make this acknowledgement page short, but it is almost impossible, because I must thank my department, the young Telecommunication Engineering Department, which I am opportune to pioneer as Head of Department. All our success today is attributable to the singular set of staff that I was blessed with. You did all the work and I took all the glory, but never mind, your reward will never pass you by, for God knows it all.

The Heads of Department of the new School of ICT (SICT) and staff, I thank you for making my job of acting Dean easy, special thanks go to my deputy Dean, Dr. Jude T. Kur for patients and understanding. Pioneers never had it easy, all of you are paying the price of pioneering a new School, and history will not forget you. People wondered why we don't fight at the SICT, it is all because of your maturity, understanding and patience you have for me all these years. Heaven will not forget your individual and collective portions.

The School of Engineering and engineering Technology (SEET) and Electrical Engineering Dept., never has it been said that a child forgot his/her parents, it will not start with me. The training you gave me, the long hours of study as a student, the long hours of work as a staff under your supervision and friendship is indeed paying off. I hope I have not disappointed you. Thank you, all.

The entire staff of ITS, for two and half years you bore my burden as Head of unit. You were patient with me, my insistence on collective participation, on putting in extra hours, on taking government work as our own, you agreed with me, worked with me as we tried to achieve internet connectivity on campus with meagre resources. I will always defend your case wherever I meet it, because I know how hard you work in that unit. Yes, because I was involved. You actually did the work and I took the glory. Your portions will not miss you.

I have special crop of friends among the cleaners, the gardeners, the security men etc. I do not know most of their names but I admire them, especially those that pay attention to the duties. I wonder what we could do without their services. I don't think the first in Heaven will be a Professor, I should think it is the one who performed his duty as at when due, irrespective of the position on earth. My good friends, I thank and respect you.

Last but not least, I thank my two kids, James and Lilian. James, I foster for my late younger sister, who died in my arms, about 24 hrs after birth, and Lilian came forth from me. James was my Master Degree and Lilian my PhD. We went through it together, and it was not easy. You have been very good kids and that helped a lot. You endured my long hours in the office, I urged hard work, no mistakes, and no failures. Of course sometimes you did not understand, but I insist that mother knows best. You endured with me, today James is in the University and Lilian in senior secondary. To God be the glory. Please continue to endure with me, for not even a mad mother will deceive her own children.

James and Lilian have given me the confidence to urge women that they can go through school and work with kids, and without hanging them like necklace, bringing them to the classrooms and offices. God has given us women that singular ability of resilience, and patients, all we need add is a little management, a little self-denial here and there, and we will make it. I normally say "If it is hard to be a man, try being a woman for one week!"

I thank you my audience who considered me worthy of being listened to. I am not taking your respect for granted.

Vice-Chancellor Sir, thank you again for this singular opportunity.

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A Brief Profile of the Inaugural Lecturer

Elizabeth Nonye Onwuka was born on 30th of January 1965 at Azigbo in Nnewi-south Local Government Area of Anambra State, Nigeria.

Her early education started at the local nursery school (*ota akara*, which means bean-cake eater) in her home town, Azigbo. Between 1973 and 1980, she went through a circuit of four primary schools in for different towns, starting from Igbo-ukwu, Enugu, Aba, and finally did her primary six at Azigbo Community Primary School. As second best in the common entrance exam she proceeded to Ozubulu Girls' Secondary School, where she sat the GCE O'level at form four in 1984, and scored six credits out of six subjects registered. She then sat for WEAC in her form five in 1985 and scored seven A's out of nine registered subjects. While in secondary school, she was selected into the school quiz team from form four up to form five. Then only one school (DMGS Onitsha) defeated her school team in the finals at the zone. She was the school regulator (bell ringer) in form four and was appointed the Senior Prefect (Head Girl) in form five. She wrote JAMB to study medicine at the University of Jos, but fell short of the cut-off score for medicine and was offered Chemistry. However, Jos cold and the childish ambition to study a professional course drove her out of Jos to FUT Minna to enroll in the one-year pre degree class. After the Pre degree class she enrolled into the department of Electrical and Computer Engineering (ECE), and graduated with Second Class Upper as the 3rd best in her class in 1992.

Her working career started in 1993 at FUT Minna when, after the mandatory youth service at Kaduna, she was absorbed in the dept. of ECE as an Assistant Lecturer. She enrolled in the Master of engineering class, part-time, in 1995 and graduated in 1998 in telecoms option. In 1999, she obtained the Chinese government scholarship through the Nigerian federal scholarship board, and proceeded to Beijing for doctoral studies. She came back to her job in FUT Minna in 2004 with a PhD in information and communication systems engineering. Since then, she has done nothing but serve the University.

It was very difficult to hire and keep staff in electrical engineering dept, due to attractions of the industry. After her return from studies, together with then Dr. Adediran (now Prof at Uni illorin) resuscitated the Master of engineering programme in telecommunications. At the split of the ECE dept, Telecom Dept inherited the Master programme and added a PhD programme in telecoms. The programme has produced many master graduates (almost all our staff were trained here) and a PhD.

Over the years, Prof. Onwuka has been permitted to serve the University through various engagements, such as membership of various committees, level adviser, examination officer, Head of ITS, Head of Telecom Dept., acting Dean of SICT, member of the editorial board of the university journal, and the board of the academic publishing unit.

Prof. Onwuka is a registered Engineer by COREN, and a member of professional associations such as: IEEE, IEEE women in engineering (WIE), APWEN, and Third World Organization for Women in Science (TWOWS)

She has also received some modest recognitions such as: over all best student at form four in secondary school, three years in Dean's list at under graduate, foreign student price for good performance at Tsinghua University, one of selected best paper at IEEE conference in 2003.

Prof Onwuka holds a chieftaincy title in her home town (Chief *Anya Luo Uno*), she won the university Servicom award in 2008, and Patriot Award in her home town in 2015.

From the rank of Assistant lecturer in 1993, she rose gradually but steadily to the rank of Professor of telecommunications engineering in October, 1, 2013.