WIRELESS LOCAL LOOP IN DEVELOPING COUNTRIES: IS IT TOO SOON FOR DATA? ***<u>The case of Kenya</u>***

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ABSTRACT

The demand for data communications in Kenya is growing at a steady rate. Information technologies have become ubiquitous all over the world, including in developing countries like Kenya. Already, educational, health and trade networks connecting remote regions to the rest of the world are taking advantage of the Internet phenomenon. Banks, insurance and financial services firms, and other corporations need data communications for real time information gathering, automated remote services, intra-corporate voice and data communications, etc. However, like in many developing countries, communications infrastructure in Kenya is woefully underdeveloped and ill prepared to satisfy the increasing demand for data communications.

Universal access to communications services for its low income, mostly rural population is a major objective of the Kenyan government. Wireless communications, particularly cellular networks are a promising solution to the infrastructure problem in the country. Wireless networks are faster and relatively cheaper to deploy than conventional wire based communications infrastructure. Unfortunately, most of the wireless networks deployed in Kenya - as in other developing countries are voice-centric. Moreover, the existing government regulation bars the private provision of all fixed wireless access service. Even the on-going reform explicitly guarantees a public monopoly followed by a private monopoly of fixed wireless services.

This thesis describes a cost model that contrasts GSM and CDMA networks, investigating current technologies as well as the projected evolution towards more advanced technologies that are capable of handling broadband data communications. The model determines that CDMA deployments instill flexibility and better evolutionary properties to the network without the burden of extra costs for the operator.

The thesis concludes by recommending CDMA deployment, and that the Kenyan government de-link wireless local loop regulation from the regulation of wire based local access. The government is urged to allow the immediate private provision of fixed wireless local loop services.

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to Laila, My parents Joseph and Jane Kibati, and my siblings Karura and Kinyanjui

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Chapter One

Introduction

1.1 Brief summary

This thesis describes a cost modeling exercise in which different wireless options are tested for their suitability in satisfying both the voice and data communications needs (current as well as future) in the local loop[1] in a developing country context. Cost efficiency and bandwidth[2] capabilities are the key tests applied. This thesis contends that data communications should be just as pressing a concern as voice communications and should inform the legal, regulatory, market and spectrum policies of developing countries.

Forced to grapple with increasingly ubiquitous and powerful information technologies, policymakers and leaders in developing countries have over the past few years been frantically seeking ways and means to shore up the very sparse infrastructure base in those countries. Wireless networks are often cited as the most economically feasible solution to the severe dearth of infrastructure in these countries. For the foreseeable future, the deployment of wireless networks is indeed the optimal solution to the information infrastructure gap in developing countries. Many developing nations have embarked on this road and a loose formula of employing fixed cellular networks for local loops (in the form of wireless local loop) and satellite transmission for long distance and international communications has emerged.

[1] The local loop refers to the communications segment in between the customer (business or residential) premises and the first level local exchange - which in the US is referred to as the Central Office.
[2] Bandwidth refers to the amount of data that can be transmitted in a fixed amount of time. For digital devices, the bandwidth is usually expressed in bit-rates or bits per second (bps) or bytes per second. In this thesis, bps is used to refer to bits per second. A kilobit is equivalent to 2 raised to the power of 10 or 1024 bits, while a megabit is equivalent to 2 raised to the power of 20 or 1024 kilobits. For analog devices, the bandwidth is expressed in cycles per second, or Hertz (Hz).

Yet with remarkable consistency, many countries have focused solely on the installation of voice-centric networks, seemingly oblivious to the growing pervasiveness of the Internet and other data communications. Predictably, most of these countries are poor and have economies in which Internet penetration is low and other forms of high quality data communications underdeveloped. Consequently, the overwhelming and most pressing concern is often voice communications.

Kenya - a typical African country - will serve as a case study. Wireless services in the country focus on mobile services and only cater to a few major cities. Only recently have trials of fixed cellular service been started and even then, not in rural parts of the country where a majority of the population lives. The attainment of universal service access, therefore, remains an overriding objective in Kenya. The main question addressed by this study was:- what is the optimal path for "wireless local loop" infrastructure deployment in developing countries? Rather than blindly follow the model of developed nations which at first built voice networks and then built data-grade networks, can Kenya leapfrog straight from "Greenfield sites" to integrated voice/data networks?

1.2 Kenya: Infrastructure cannot meet data needs

In chapter two, Kenya is described as a poor, largely rural country whose socio-economic characteristics are typical of sub-Saharan African nations and many other developing countries. Communications infrastructure is extremely underdeveloped and universal service is a primary and long running objective of the Kenyan government, which has recently started initiatives to liberalize the telecommunications sector. Also in chapter two, the growing need for data is discussed, with wireless solutions suggested as the means to overcome the inadequate infrastructure. Demand for data is growing and is likely to outstrip the very low level of available communications infrastructure in the country. Wireless communications present themselves as the most viable answer, particularly in the local loop segment of communications because they are:

- Relatively cheap to deploy;

- Relatively easy and quick to deploy; and
- Increasingly growing towards wireline levels in terms of quality of services provided.

The problem is that many of the networks in operation today or those about to be deployed fail to adequately address possible future data requirements or to anticipate necessary future upgrades. Wireless networks deployed in developing countries have been decidedly voice-centric, with no provisions for the growing data and Internet communications having explicitly been made during the deployment of new networks.

1.3. Technological uncertainties

While many around the world are cognizant of the above-mentioned opportunities of wireless networks, many obstacles come in the way of operators and policymakers making the right decisions. This is the subject of chapters three and four.

To begin with, the range of wireless technologies from which to choose is wide and confounding, especially as each is touted as providing unique advantages. The technologies include cellular, cordless, proprietary, microwave and satellite based wireless networks. In chapter three, the reasons for having chosen cellular technologies over these others -wide deployment, low expense, good coverage area and capacity capabilities - are outlined and explained. In that chapter, a brief mention is made of alternative wireless technologies that may - under specific circumstances - provide wireless local loop solutions.

Secondly, even among the modeled set of wireless options - cellular, there are numerous technologies and standards as well as numerous unanswered questions. Chapter four describes the various cellular technologies and attempts to untangle the web of complexity surrounding them. Each of the architectural elements of a cellular network is presented and their functionality then described.

Digital cellular networks are in the process of eclipsing analog networks as are Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) schemes displacing Frequency Division Multiple Access (FDMA)[3] schemes. But the TDMA versus CDMA contest persists. Next generation wireless standards compound the debate even further, with different CDMA standards competing for dominance. That debate appears to have been quashed by a recent agreement between Qualcomm and Ericsson. But the details are still to be hashed out and the implications are uncertain. Will they agree on one standard or agree to develop both Wideband-CDMA (WCDMA) and CDMA2000 as the next generation of wireless standards? Whatever standard is agreed upon, will both Global System for Mobile Communications (GSM) and CDMAONE (The current generation of CDMA networks) be equally able to migrate or will one still be at an advantage over the other? These are mobile standards, what are the implications for operators interested in fixed deployments with no roaming requirements? What about transitional generation technologies such as General Packet Radio Services (GPRS), Enhanced Data Rates for GSM Evolution (EDGE), High Data Rate (HDR)? Might they be able to provide adequate bandwidth capabilities for developing countries like Kenya?

1.4 The model

In chapter five, the model itself is described. A technical reference architecture of the modeled elements is presented.

Two scenarios were modeled:

- Discontinuous scenario - GSM with planned replacement with WCDMA.

- Incremental data scenario - CDMAONE with planned migration to CDMA2000.

The central question under investigation by the model was "which technology best meets the operators requirements in terms of current and future services for the lowest possible cost per subscriber?"

[3] These and all other acronyms of access schemes and technologies in this chapter are described in greater detail in chapters three and four.

Accurate cost figures proved very difficult to obtain, owing to the high level of competitiveness and uncertainty surrounding the wireless industry. Furthermore, most initial network installation costs are unique and dependent on the specific circumstances of the particular project - location, size, vendors, etc. Reasonably accurate costs were eventually obtained from different sources. The baseline or reference parametric values are described in this chapter as well.

1.5 The results

Chapter six provides detailed results for both the discontinuous and incremental scenarios, first employing the baseline parameters and then the results of a series of sensitivity analyses. The sensitivity analyses were conducted to control for any areas of uncertainty there might have been, including component costs, subscriber capacity calculations and penetration level assumptions. The central result is that CDMA networks are more cost efficient than GSM networks in the long run.

1.6 Conclusions

The Kenyan priority for wireless technologies, unlike the developed world, is not mobility, but universal access. This further strengthens the case for CDMA whose most often cited and only disadvantage is that it is not as widely deployed as GSM. For mobility purposes, extensive deployment around the world is a definite advantage since the same mobile subscriber station can roam the world over without having to face compatibility problems. For Kenya, however, where the focus is on fixed wireless access, advantages or disadvantages pertaining to mobility can be discounted. Instead, emphasis can be laid on other more relevant features like capacity and data functionality, in which CDMA has an advantage over GSM. In any case, it is almost certain that the next generation of mobile subscriber stations will be multimodal and thus no particular technology will necessarily have a roaming advantage.

In chapter seven, focusing on their operational advantages and suitability to the Kenyan communications needs and economic capabilities, the recommendation is made to deploy fixed CDMA networks. Policy recommendations, for the government of Kenya, are also made that would further the attainment of the universal access goal through the deployment of wireless networks. Included are recommendations on how to adjust the ongoing reform process which is far from satisfactory both in substance (liberalization provisions laid out) as well as in implementation.

Chapter Two

The Kenyan Situation

2.1 Introduction

This chapter describes the Kenyan telecommunications situation, including the availability of services, policy as well as evolving markets. For Kenya, the overriding telecommunications policy objective remains universal access to all Kenyans. 80% of the Kenyan population of approximately 30 million lives in rural areas. The definition of universal access varies according to the geographic, demographic and economic profile of the different parts of the country. Broadly, the Kenya government has set teledensity targets of 20 lines per 100 people and 1 line per 100 people for urban and rural areas respectively by the year 2015. This would be up from the current teledensity rates of 4 and 0.16 lines per 100 people respectively for urban and rural areas[4]. To jumpstart the process, the Kenyan government has embarked on a liberalization process, with the parliament having recently passed a bill that breaks up the public postal and telecommunications company.

A brief discussion on the possible future demand for data is made, citing the particular educational, health and trade problems of a country like Kenya and the unique ways in which a phenomenon such as the Internet can help alleviate some of these problems. Being a largely rural country there is a dire need for numerous essential services. Remote regions which hither-to have been unable to afford adequate educational and health facilities or to attract competent teachers, doctors, agricultural extension officers, and other professionals now have an alternative medium by which they can benefit from the services of such professionals - interactive multimedia. However, standing in the way of all these possibilities is a real dearth of communications infrastructure, particularly in the very rural areas that would most benefit from virtual access to worldwide resources that they would physically never be able to obtain. At the end of this chapter, wireless infrastructure is offered as a plausible solution to the problem of meeting rising demands for data communications.

2.2 Why worry about data infrastructure?

Kenya is a largely agrarian developing country of approximately 30 million people, on the East Coast of Africa. While there are a number of moderately developed large urban cities in the country, 80 percent of the Kenyan population lives in underdeveloped rural areas. This huge demographic tilt towards a rural based population is a phenomenon that has to be factored into any major government policy. It is therefore not surprising that the achievement of universal access to communications remains a cornerstone of the Kenya government's telecommunications policy.

2.2.1 The need for data

Perhaps the most immediately obvious justification for the deployment of data communications infrastructure in developing nations is the Internet. While Internet growth in developing countries has not been nearly as tremendous as it has in developed ones, it has nevertheless been impressive. In Africa, the number of Internet hosts grew from almost nothing in the early 1990s to some 140,000 Internet hosts in 1997 (Figure 1). During 1998 the last remaining "unconnected" countries established a link to the Internet, thereby joining the global transformation into a true information-based society.[5]

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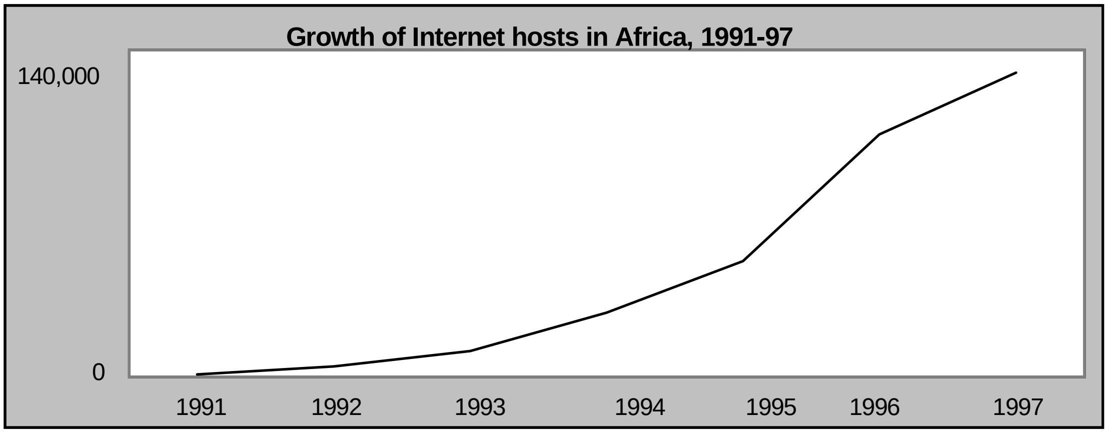
[4] [Postal and Telecommunications Sector Policy Statement, Ministry of Transport and Telecommunications, Kenya, January 1997].

Figure 2.1. Internet diffusion in Africa



Source: World Telecommunication Development Report, 1997, International Telecommunication Union

The challenge arises from the incontrovertible fact that an information-based globe means that a constantly increasing proportion of international communications will be conducted over the Internet and in real time. Business people worldwide - including those in Africa, Asia and Latin America - will have to be extra quick if they are to have any hope of clinching deals in the computer age.

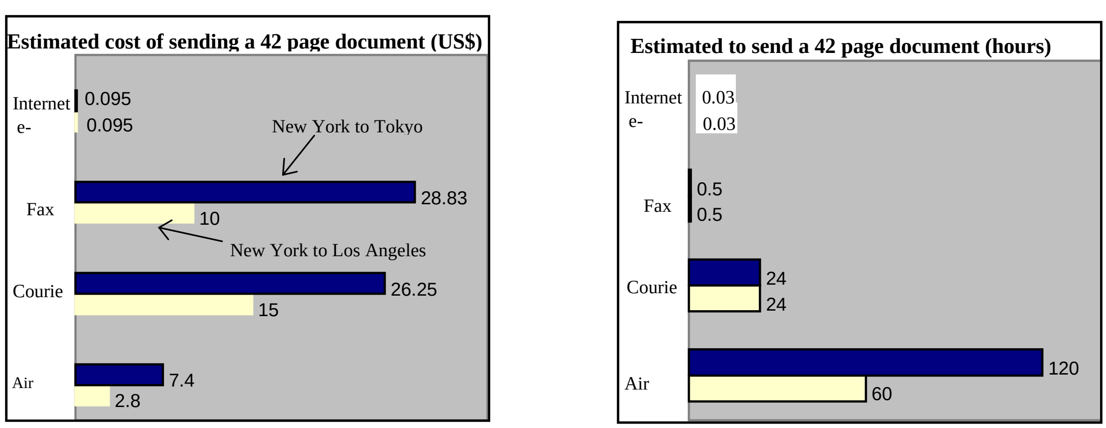
With the ever-increasing number of multi-nationals and large local companies operating mission critical systems for day to day processes, there will be a growing demand for broadband capacity in Kenya. Banking institutions already require computerized teller operations, automated teller machine transactions, local area networks interconnection, wide area networks interconnection and electronic mail. Petroleum and gas companies will require service station point-of-sale verification, field voice and data communications and intra-corporate communications. Insurance and financial service companies will require real time market quotations, claims processing, electronic mail, etc. Most of these industries have already (and all eventually will) set up systems that will require combined voice, data and video networks as communication needs grow.

[5] For more detailed account, see [Challenges to the Network: Internet for Development, International Telecommunication Union, 1999].

Furthermore, consumers will have the opportunity to make more studied choices over the Internet, will be more discriminating and will demand to be better appraised of whatever goods or services that will be peddled to them. Almost certainly, this will mean that any provider of goods or services who hopes to ably compete on an international scale will have to get onto the web.

These challenges, however, carry with them a silver lining for business people from poorer countries. Certainly, even before the knowledge age set in, there was hardly any equity between business people from the South and those from the North. A variety of factors, including lack of resources, skills, and economies of scale, rendered developing world business extremely disadvantaged. With the Internet, however, small-scale farmers, traders, etc., have been afforded such media as web sites through which to quite cheaply advertise their goods and wares. Already, Kenyan farmers are selling "chilli" peppers to a supermarket chain in Britain[6]. Moreover, with every passing day, middlemen who deduct huge commissions edge closer and closer towards extinction, all because of the Internet. Figure 2, below, illustrates the some of the cost reductions occasioned through the use of the Internet.

Figure 2.2 Document mailing cost comparisons



Source: Challenges to the Network, 1997, International Telecommunications Union

[6] Ibid., 5.

It must noted, however, that certain infrastructural aspects - e.g. a computer and telephone line - must be in place before the very low Internet e-mail costs can be realized. Nevertheless, when these capital costs are amortized over the life of the computer, the cost savings are still significant.

Yet over and above the many conveniences that have made the Internet popular in western nations, it presents a unique opportunity for poorer regions. The opportunity derives from the new applications to which the Internet can be put which would be more highly valued in developing countries than they would in developed ones. The Internet, due to its peculiar technological and economic features - efficient digital technologies that can deliver in interactive and asynchronous[7] fashion data, text, images, and video at a low cost - brings new hope to developing nations. Schools that are unable to regularly purchase new editions of textbooks and update their curriculum to keep pace with an ever more dynamic world (and sadly, in many parts of Africa and Asia, this is a common phenomenon) can now exploit the huge databases available on the worldwide web.

The networking of health resources, educational facilities, and trade in low income communities is a more timely and cost-effective solution in the short term, than attempting to build hospitals, health clinics, schools, and physical trade centers in every rural center or urban city. Internet based multimedia networks would allow for more economically feasible provision of numerous vital services to remote underdeveloped locations. Telemedicine would allow doctors to "visit" patients and even perform remote surgical operations, interactive distance education with high quality teachers providing instruction from their institutional bases would become a reality, and small scale traders would have access to markets all around the world. Through information and communication technologies rural populations can obtain access to specialists - who are normally concentrated in tertiary care and educational institutions in major urban centers.

[7] In data communications, asynchronous simply refers to the intermittent transmission of data without enforcing regular or predetermined transmission intervals.

Multimedia drastically transforms the distance education experience by providing real-time interaction between the teacher and students as well as between students, eliminating feedback delays and enhancing learner support.

To be sure, the Internet is no panacea for developed country problems. The question often arises: can remote regions that cannot afford textbooks and health facilities provide sufficient electrical power, maintenance, printers, paper, entire class curriculums, trained teachers and adequate numbers of computer terminals? At a minimum the challenge is enormous. Yet such innovative programs as Healthnet Professional Networks[8] and Volunteers in Technical Assistance (VITA)[9] have managed to develop very viable and robust communications networks in some of the poorest developing countries. Moreover, governments that have always felt obligated to extend their meager by providing the full suite of services in remote districts now only need to provide the basic utilities such as electricity, reduced numbers of teachers, etc.

Ultimately, however, the goal of this thesis is not to make a spirited defense of the case for data services in Kenya or anywhere else. Such a task would in itself have to be so exhaustive and thorough as to merit a separate study and report. Suffice to say that it is a reasonable proposition that a substantial proportion of future communications - even in developing countries - will consist of data. Thus, on the basis of that premise, the task of this thesis is simply to demonstrate the economic and functional efficiency of incorporating data capabilities in the contemporary construction of voice networks.

2.2.2 The Kenyan situation - inadequate infrastructure

2.2.2.1 The current situation

The Kenyan telecommunications system consists of a hierarchical network (both automatic and manual exchanges) with a teledensity of 0.16 and 4 lines per 100 people in rural and urban areas respectively - averaging 1 line per 100 people nationally. The

[8] See http://www.healthnetpro.com/ for more detailed description of the program.
[9] See http://www.vita.org/about.htm.

network is mostly circuit switched[10], 50 percent analogue and 50 percent digital. As Kenya is a poor country, investments in telecommunications infrastructure have been low and consequently national coverage is inadequate - particularly in the local loop. Supply does not meet demand and the waiting list of prospective subscribers as of December 1997 was over 75,000[11]. The waiting period depends on the location of the prospective subscriber and the capacity of the closest exchange. Often, the distance between a potential subscriber and the closest exchange is great, and connection cost very large.

Metering (billing methods) used to be based on distance, but this has since changed, with anything within 60 kilometers now treated as a local call. All intra-national calls beyond 60 kilometers are treated as subscriber trunk dialing (STD). Charging starts when there is an answer on the other end and all calls, local or not are charged on per unit of time basis. Calls to the east and central parts of Africa rate from US$1.50 to US$2 for every 3 minutes and part there-of, while calls to the rest of the world carry a minimum rate of US$ 2.50 for every 3 minutes and part-thereof. Like in many other countries, rates differ according to calling period, with the standard rate being charged between 7.00 a.m. and 9.00 p.m., the lower rate (economy) between 9.00 p.m. and 2.00 a.m., and the lowest rate (discount) between 2.00 a.m. and 7.00 a.m.[12]

In terms of service quality, Kenyan telecommunications are below world standards. Typically, less than 60 percent of all attempted calls to an exchange are successful - which is far below the international average of 80 percent.[13] An inadequate number of telephone lines results in heavy congestion. Additionally, when a telephone lines goes out of order, it takes an unduly long time to have it repaired, and even then, only after the pockets of some telephone technician (and on occasion - some senior telephone company executive) have been "lined". The failure rate of Kenyan telephone lines while mostly due to poor maintenance on the part of the public owned telephone monopoly - the Kenya

[10] Circuit switching refers to the establishment of a dedicated communication path (or circuit) between communicating end-points for the duration of a transmission. An alternative communications scheme is packet switching in which messages are divided into packets and transmitted individually over any free path.
[11] [World Development Report, 1997].
[12] [Ministry of Transport and Telecommunications, Nairobi, Kenya].

Posts and Telecommunications Corporation (KPTC) - is exacerbated by widespread and wanton vandalism of telephone cable wire.

2.2.2.2 Changes in government policy

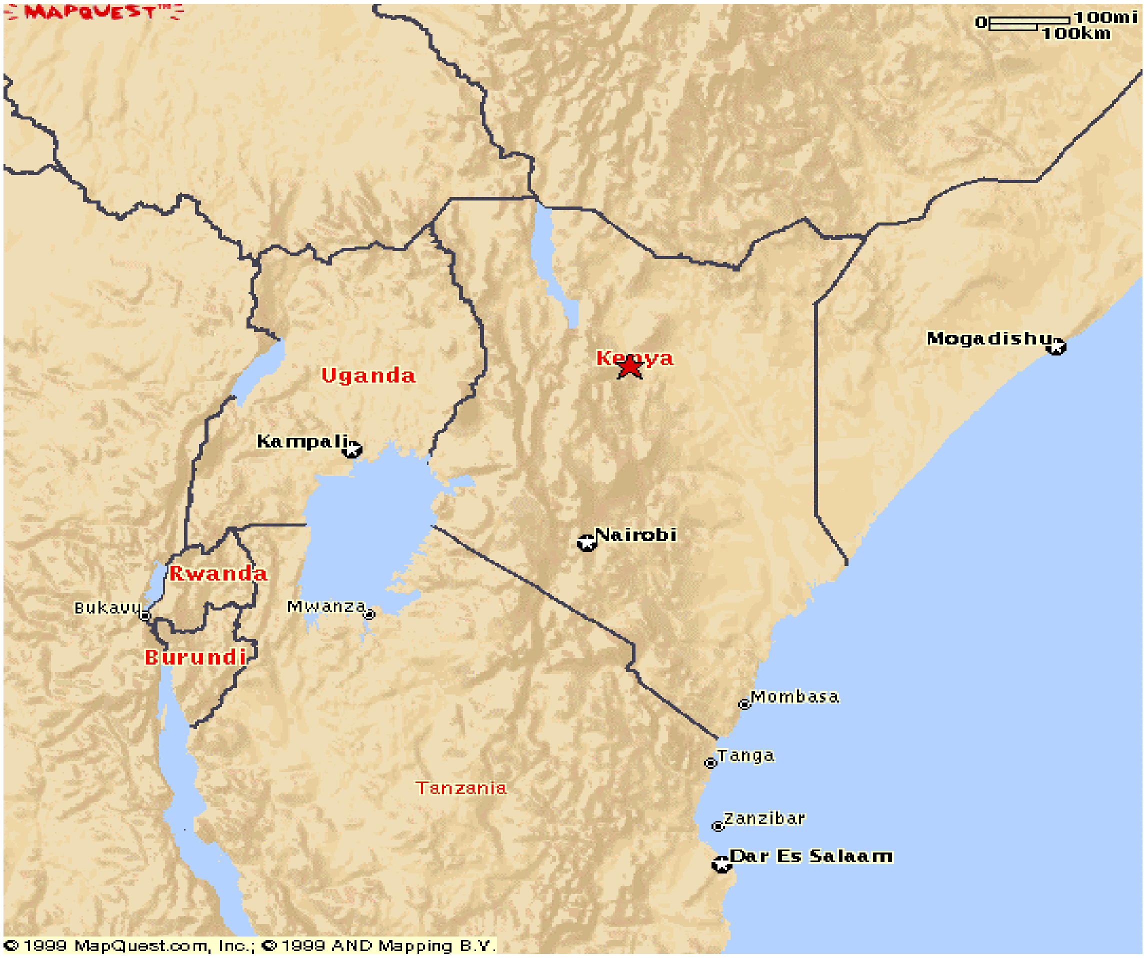
Over the past few years, there has been a significant shift in the government's policy with regard to the provision of telecommunications services. Much like governments the world over, the Kenyan government was caught flat-footed by the advent of such phenomena as the Internet, direct broadcast satellite, and the various such other technological developments as have been "spewed forth" by the very dynamic world of telecommunications. After a brief period characterized by knee-jerk reactions to all these developments, the government finally embarked on comprehensive courses of action, apparently resolved to take advantage of the newly arising circumstances to energize its universal access goals.

For instance, the KPTC undertook to build a nationwide Internet backbone to serve Internet service providers (ISPs) in the country who are currently served through international servers, which are usually based in the US and Europe. The overall effect will be to facilitate and reduce the Internet service costs. Phase I of a project to ensure digital cross-border connectivity is complete and was launched on March 12, 1997. Phase II of the same project is in progress and is aimed at connecting Kenya, Uganda and Tanzania. An optical fiber cable running through the Kenyan cities of Mombasa and Nairobi to the Ugandan city of Kampala is envisaged in order to provide broadband services and multi-media capabilities (see map, figure 2.3). Its expected completion date is in the year 2000.

Also, “high capacity” digital radios for communication with Arusha and Dar-es-Salaam in Tanzania are to be installed. The Kenyan government has also set a target to install 300,000 lines in rural areas and 2.4 million in urban areas by 2015 in order to achieve teledensities of 1 and 20 lines per 100 people in rural and urban areas respectively.

[13] Ibid., 12.

Figure 2.3 Map of Kenya, Uganda and Tanzania



On the policy front, the Kenya government undertook to restructure the KPTC, introducing and passing a parliamentary bill providing for the creation of separate postal and telecommunications companies as well as instituting an independent regulatory body (The Communications Commission of Kenya - CCK). The CCK will regulate licensing, interconnection[14], "public service obligations", fair competition and operators' obligations. The stated objective is to slowly privatize the telecommunications company (Telkom Kenya) and to gradually allow private business to provide more and more of the telecommunications services that were traditionally reserved for KPTC. A graduated trend towards privatization and then liberalization is planned. Indeed, the provision of customer premise equipment (CPE) is already privatized and liberalized. Pledges have been made on paper, with the government stipulating that initially, any private operator be at least 70% owned by Kenyans - this policy is to be reviewed “periodically”. Wired telecommunications infrastructure will continue to be monopolized by Telkom Kenya for the foreseeable future, until the provisions for local, long distance, international gateway service and mobile radio services are fulfilled as outlined in the new bill. Some Parastatals – the Kenya Pipeline Company, Kenya Railways, etc. which already have telecommunications facilities to support critical operations will be allowed to lease excess capacity immediately, but only to Telkom Kenya.

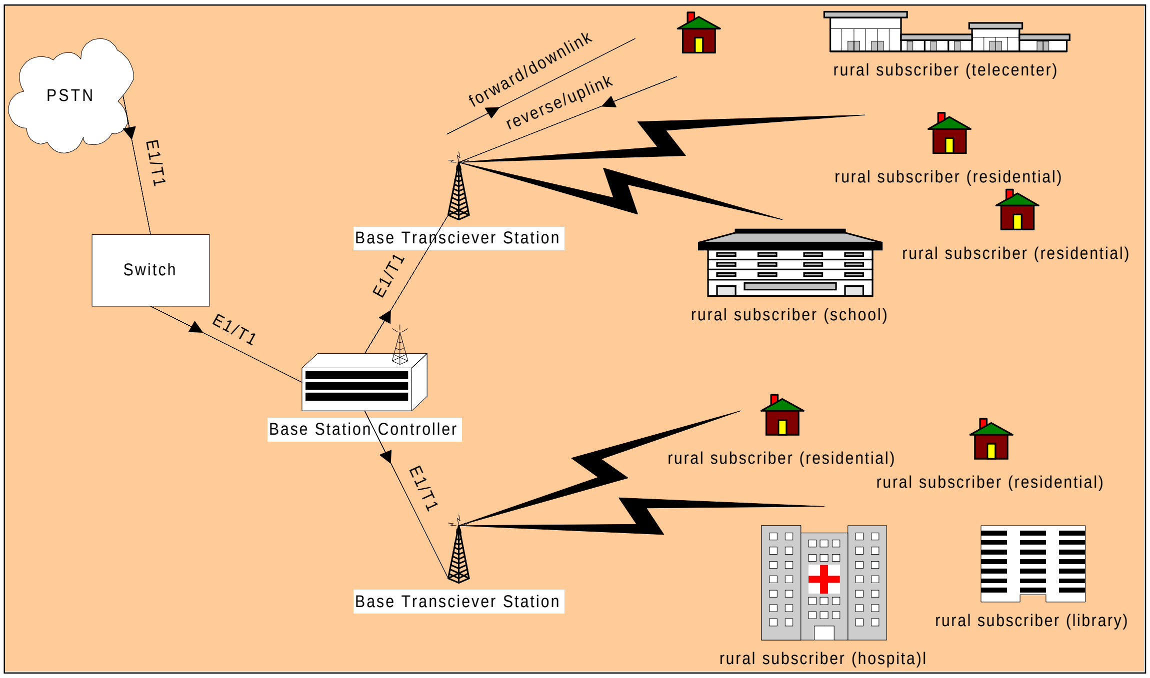
2.2.3 The wireless solution - Wireless Local Loop (WLL)

Thus, as a careful study of the last two sections would reveal, Kenya faces an interesting question. How to overcome a dire lack of infrastructure and satisfy the gradual rise in demand for both voice and data communications, but particularly the latter. Universal access remains a big problem in Kenya and it is unlikely that anyone will come along soon to lay copper cables to satisfy the local access communications demand. . The estimated capital cost of laying the 2.7 million lines planned by the Kenya government by 2015 is US$2000 per line, resulting in a total cost of US$5.4 billion (an astronomical amount by Kenya standards) over the 20 year period. And even then, consider the following:

The government hopes to achieve this through privatization and it is unlikely that any private operator could expect to recover US$5.4 billion (plus operating costs and profits) from the low income Kenyan population in any economically reasonable amount of time. Even after the 2.7 million lines have been deployed, national teledensity in Kenya will still be only 21 lines per 100 inhabitants, with most of the lines still concentrated in urban centers, while rural areas are served at a mere 1 line per 100 inhabitants.

[14] Interconnection refers to the provision of access to telecommunications infrastructure to competing service providers.

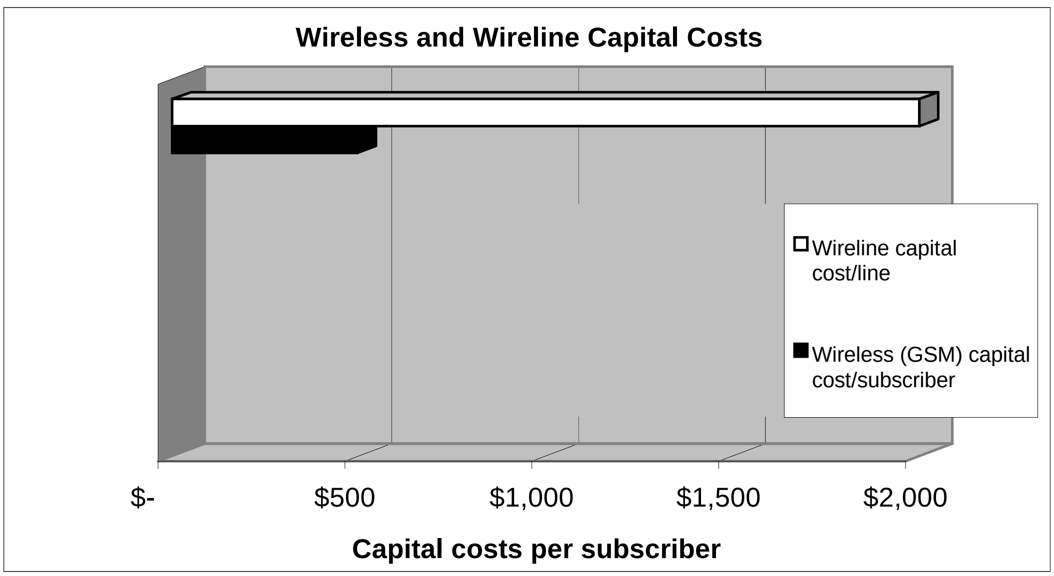
Figure 2.4 Wireless communications in a rural setting



It is with the foregoing in mind that this report argues that wireless solutions be given serious consideration. Wireless infrastructure lends itself as very apt and relatively easily deployable when contrasted to conventional plant (wire based) infrastructure. The absence of cable results in huge savings in cost and time. Expenses normally incurred by the material, labor and time spent to bury cable underground are avoided, as is the costly maintenance occasioned by inevitable wear and tear of the equipment. With wireless infrastructure, one need only concern oneself with nodal equipment at the subscriber and network stations. Deployment time shrinks and maintenance turnaround also rises sharply with wireless networks. In countries such as Kenya where zoning disputes are unheard of, it is simply a matter of putting up a transmitter tower and providing customers with subscriber stations. Maintenance problems are easy to monitor and to trouble shoot as all the equipment is physically and logically very easy to trace.

Even the KPTC has acknowledged that fixed wireless access is a better alternative because it is cheaper and faster to deploy. Moreover, maintenance is also easier and the vandalism problem would diminish if there were no wires to steal. Already KPTC is undertaking trials of cordless and cellular based fixed wireless local loop technologies in several urban centers as follows:- Digital European Cordless Telephone (DECT) in Bamburi area (Mombasa) and Jamhuri area (Nairobi); Digital Advanced Mobile Phone Service (DAMPS) in Embakasi and Industrial area (Nairobi); Personal Handy-phone System (PHS) in Malindi; and Cordless Telephony System - 2 (CT-2) in Nyali area (Mombasa)[15]. Figure 2.3 illustrates the capital cost differences between wire based and wireless installations.

Figure 2.5 A contrast between wireline and wireless costs in Kenya



(Source: Postal and Telecommunications Sector Policy Statement, Ministry of Transport and Telecommunications, Nairobi, Kenya, January 1997, Model)

Wireless communications in Kenya would not be a new phenomenon. Two mobile cellular networks already exist:

- Analog - ETACS [Enhanced Total Access Communication System] (Countrywide) – Provided by KPTC since 1993 with 2000 lines (now 3000 - and used up to capacity), covering all major towns and plans to extend capacity to 10,000; and

[15] See chapters three and four respectively for a description of the various cordless and cellular technologies described here.

- Digital - GSM [Global System for Mobile Communications] (Nairobi, expected to be expanded countrywide in 3 years) – 6,000 lines capacity launched in 1997 (about 4600 subscribers as of November 1998) – to be expanded to 20,000 lines.

Below are some of the costs incurred by end users (subscriber) to mobile services:

- Analog (ETACS) - US$1,000 refundable deposit, US$10 connection charge, US$10 monthly access fee, and a US$0.50 per minute consumption charge[16];

- Digital (GSM) - US$800 connection charge including identity module card, US $500 initial prepayment fee, and a US$0.30 -0.40 per minute consumption charge;

- A GSM and ETACS Internet modem[17] costs US$165 (one time fee) in addition to Internet service costs

- Range of prices for mobile stations in Kenya: US$165 - 750, with the median at US$400

- Suppliers:- Ericsson, Phillips, Nokia, Siemens, Motorola, Panasonic, NEC, Sony, Hagenut, Alcatel, Spark, Sagem

Vendors have to be licensed by KPTC and pay US$ 165 as a license fee. A similar amount as a "type approval fee" is also paid. Of the 5000 or so GSM subscribers in Kenya, 60% use Ericsson sets, about 15% and 10% use Nokia and Motorola sets. There are also about 3000 ETACS customers using Ericsson, Nokia, Motorola and NEC.

The government has also (as part of the privatization process) recently announced a tender for a second cellular company. It will be owned 50% by the soon to be incorporated Telkom Kenya and 50% by private operators. This process has been far from satisfactory with the usual shroud of mystery that characterizes government tenders

[16] Note must be taken of the fact that GDP per capita in Kenya in 1996 was only US$291 compared to, say, the US GDP per capita which was US$28,766 [Ibid., 5]. Thus the purchasing power in Kenya is much lower than it is in the US, especially for manufactures such as computers, which while produced in the US, have to be imported into Kenya.

in other sectors. The process appears to be a step in the right direction, but by no means a giant one.

2.2.4 The policy problem

In general, Kenya has had a very checkered experience with the privatization and liberalization process. For many years, many different players developed entrenched interests in the affairs of key government companies, of which the KPTC was a star prize. So much so that even as the virtues of market driven service provision were becoming plainly evident worldwide and the KPTC was wallowing in financial and operational decline, it took the World Bank and International Monetary Fund wielding a heavy stick before liberalization of the monolithic KPTC was even considered.

Since then, the parliamentary bills that have been passed breaking up KPTC and a tender has been announced for a second mobile cellular company which will be 50 percent privately owned. But while the erstwhile entrenched interested parties have been forced to accept a market based regime, they are still an influential force lurking in the background. The principal actors in the liberalization and privatization saga are:- the KPTC itself, the Ministry of Transport and Communications (MOTC), the parliament, potential private investors, and "politically connected" potential private investors. The whole process is a constant tug of war between these various actors, with politically connected players attempting to leverage their influence so as to win government issued licenses and contracts. To the credit of many government officials, blatant attempts at corruptly winning tenders have been thwarted, but in a political environment like Kenya's, there is only so much that any government functionary can do.

The big question therefore is, even assuming that Kenya was to determine that a particular wireless technology was best suited to fulfil her data infrastructure requirements, what changes in government policy and attitudes would be necessary to encourage the deployment of the specific wireless technology?

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[17] Modem is the acronym for modulator-demodulator. A modem is a device or program that enables the transmission of digital data signals over analog voice lines.

2.3 Conclusion

Demand for data communications in Kenya is steadily rising. While the level to which this demand will grow cannot be determined with absolute certainty, it is clear that the level of infrastructure in the country is inadequate to meet the growing voice and data communications demand. The optimal solution to this problem of a dearth of infrastructure is the deployment of wireless networks, which are inexpensive and quickly deployable. Furthermore, reforms in the policies of the Kenyan government accompanied by changes in the attitudes of the key players are a major prerequisite to the deployment of these wireless networks.

Chapter Three

Alternative Wireless Local Loop Solutions

3.1 Introduction

In a most general sense, wireless local loop (WLL) can be segmented into four major categories:

- Technologies based on cellular mobile radio standards
- Technologies based on cordless mobile radio standards;
- Proprietary WLL technologies;
- Microwave technologies.

Only the cellular based WLL technologies were modeled as it is the position advocated in this thesis, that they are best suited for the specific environment and socio-economic circumstances surrounding a country like Kenya and many others like it.

In this chapter, the alternative technologies are briefly discussed, highlighting their advantages as well as their shortcomings. An attempt is made to suggest cases or scenarios where these other alternative technologies might provide better solutions to WLL than cellular based technologies. However, it is beyond the scope of this thesis to provide quantitative details of the circumstances under which alternative technologies, particularly microwave and proprietary technologies, may be better suited than cellular based ones even in a poor developing country. Perhaps this can form the basis for future research efforts.

Despite the fact that instances of satellite technologies being used for direct telephone communications are rising, they are not discussed in this chapter. Satellite technologies are better suited for backhaul (long-distance) communications. Although Global Mobile Personal Communications Services (GMPCS) subscriber stations that can directly receive signals from satellites have been developed (Iridium, soon - GlobalStar, Teledesic, etc), at $3000 per set, they are beyond the reach of the typical Kenyan consumer as well as, one suspects, the typical developed world consumer. GMPCS communications can also not really be categorized as wireless local loop, because in actuality, they bypass the local loop (and often, the national backbone).

Before reviewing the technologies, it is perhaps instructive to briefly recap the specific situation facing a country like Kenya and enumerate some of the operational qualities an operator would be looking for in selecting a WLL technology which to deploy.

Thus, Kenya:

- Is a low income country;
- Is 80 percent rural;
- Has a very high (long waiting list) demand for voice communications and a steadily growing demand for data communications;
- Has a very low level of communications infrastructure, particularly in the local loop;
- Already has commercially deployed mobile cellular communications in the major cities and trials of cordless standards based wireless technologies; and
- Has no deployments (commercial or otherwise) of either proprietary or microwave technologies.

Given the characteristics listed above, a WLL operator would be seeking to deploy a technology that at the minimum:

- Is inexpensive;
- Is easily and quickly deployable;
- Has moderately good voice quality and at least has room for future improvements in data communications
- Has a long coverage range and moderate capacity capabilities.

The various technologies will now be reviewed, with the exception of cellular based technologies which will be reviewed in depth in chapter four.

3.2 Cordless Technologies

Cordless technologies were designed to replace wired phones to provide limited mobility. Due to the low ranges originally required between the portable subscriber station and the cordless home base station (typically around 200m), low power designs were used. Further, to keep the base station inexpensive, the phone designs were kept simple, avoiding complicated speech coders, channel equalizers, etc. Frequency planning was also not possible as users owned the base station as well as the mobile, so the phones needed to seek a low-interference channel whenever they were used. Today, WLL technologies that developed from these cordless technologies retain much of the original characteristics. Specifically, cordless technologies are low range and high capacity. The main cordless technologies include DECT, PHS, and CT-2.

3.2.1 DECT

Digital European Cordless Telephone (1.88 - 1.9 GHz) was standardized by the European Telecommunications Standards Institute (ETSI) in the early 1990's, initially for use as wireless office PABX (private access branch exchange). DECT transmits using TDMA techniques. Each radio channel is 1.728 MHz wide into which a DECT carrier with data rate of 1.152 Mbps is inserted. Radio channels are spaced at 2 MHz apart. Because the data rate is significantly lower than the bandwidth, DECT allows adjacent channels to be used in the same cells (unlike most other radio standards). But it also means that bandwidth is used inefficiently. Each 1.152 Mbps is divided into 24 time slots. Nominally, 12 time slots the downlink (base station to subscriber) and 12 for the uplink. This channel allocation can be varied dynamically. Because there is transmission in both directions on the same frequency, DECT is time division duplex (TDD), meaning that the transmission time is divided between the different directions in a half-duplex[18] mode. The TDD technique leads to simpler radio frequency (RF) design. Within each of the 24 slots, a 32 kilobits per second (Kbps) bearer capability is provided. Thus, the slots can be concatenated to provide up to 552 Kbps per user (18 slots) as long as most other users are kept from accessing the base station at the same time. Like most other cordless based technologies, DECT has too short a range and may require too many base stations if the subscriber base is sparsely populated.

3.2.2 PHS

Personal Handy-phone System is a Japanese standard used in the 1815 to 1918 MHz frequency band. Like DECT, it is also based on the TDMA-TDD approach. It uses a carrier spacing of 300 KHz, providing four channels (one typically used for control information). It uses 32 Kbps adaptive differential pulse code modulation (ADPCM) coding and like DECT, also uses dynamic channel allocation (DCA) methods to optimally select the best frequency.

3.2.3 CT-2

Developed in the UK, Cordless Telephony System 2 (CT-2) operates in the 864.1 to 868.1 MHz band, using FDMA with channel bandwidths of 100 KHz. Within the FDMA channel, TDD and DCA are used. Each channel can carry 32 Kbps in both directions, providing ADPCM voice coding. CT-2 cannot concatenate time slots and thus lacks the bandwidth flexibility of DECT.

In general therefore, cordless technologies are particularly well suited to areas of very high density - they have been deployed with great success in high density cities in Eastern Europe. However, in low to moderately populated areas, their low range limitations

[18] Half duplex refers to the transmission of data in just one direction at a time.

render their high capacity capabilities useless. They are particularly ill suited to rural areas, as their low range abilities would necessitate the construction of an excessive number of cell sites and base stations.[19]

3.3 Proprietary Technologies

Proprietary technologies employ both TDMA and CDMA techniques and were designed specifically for fixed implementations. In many ways therefore, they have better WLL communications qualities than either cordless or cellular technologies. For instance, they offer a wide range of services, including high bit-rates, data in moderately sized coverage areas, and provide excellent voice quality. Proprietary based cell sites can serve ranges (radii) of up to 15 kilometers in flat, open spaced, rural areas. Among the main proprietary technologies are Nortel Proximity I, Tadiran Multigain, DSC Airspan, and Lucent Airloop.

3.3.1 Nortel Proximity I

Nortel Proximity I is TDMA based and offers a wide range of services, including 64 Kbps voice and data links. It operates in the 3.4 to 3.6 GHz range using frequency division duplex (FDD), which means that the transmission occurs simultaneously on different frequency channels between the different duplex directions. Each of the TDMA channels can support ten 32 Kbps channels but since DCA is not provided, no more than 32 Kbps per line is attainable. Since each subscriber is provided two lines, 64 (32x2) Kbps is available per subscriber. It has a range of up to 15 kilometers in rural areas.

3.3.2 DSC Airspan

DSC Airspan is CDMA based and can provide data speeds of up to 128 Kbps. It operates in 2 GHz range, and each radio channel is 3.5 MHz wide. It has a range of up to 5 kilometers.

[19] For further reading on cordless technologies, see [Goodman, 1997].

Proprietary systems have excellent voice quality and data capabilities. Their main draw back, however is that they are substantially more expensive than their cellular counterparts. This cost premium was justifiable for as long as cellular technologies had no data capabilities and only very poor voice communication qualities. However, much has changed in the recent past and even much more is set to change in the coming months and years. Many of the advantages previously boasted by proprietary technologies - particularly capacity, data and good voice quality will now be provided by cellular technologies at much lower cost. When combined with the specific advantages of cellular telephony - very long range (large coverage area), wide deployment and lower line of sight requirement - the high costs of proprietary technologies become difficult to justify.[20]

3.4 Microwave Technologies

Microwave technologies were originally designed to provide multi-channel broadband broadcasting of video signals, hence the euphemistic and oxymoronic reference to them as "wireless cable". Initially designed as one way signals, they have recently developed full duplex asymmetric functionality. This means that they are now able to transmit signals both downstream as well as upstream, but that the bandwidths in both directions are different. The main microwave technologies are the US-centric MMDS and LMDS and the European MVDS.

3.4.1 MMDS

Multichannel Multipoint Distribution Service (MMDS) is a microwave system that provides 33 analog channels or from five to 10 times as many digital channels. Operating in the 2.5 GHz range, it requires line of sight between the transmitter and receiving antenna. Digital signals let MMDS support more channels and also deal better with the topography. Signals can be beamed to a high building, which can serve as one or more cell sites transmitting in various directions. Microwave technology companies such as Spike Technologies have deployed MMDS networks in developing countries like Ghana.

[20] For further reading on proprietary technologies see [Webb, 1998].

The networks boast base stations with a coverage radius of up to 30 miles and speeds of up to 10 Mbps. Yet the cost to subscribers is extremely high, with subscriber stations alone costing US$1200 and base station deployment costs far exceeding those of cellular networks. Thus, in Ghana only large business clients with the sort of financial wherewithal and data speed requirements that would justify the cost have been targeted.

3.4.2 LMDS

Local Multipoint Distribution Service (LMDS) is also a microwave system that provides two-way transmission in the 28GHz range. Due to the very high frequency range in which it operates, it has very severe line of sight requirements and needs a transmitter every couple of miles. LMDS provides greater upstream bandwidth than MMDS and other wireless services. It is expected to be used for wireless data services and Internet access. LMDS has a range of up to only 5 kilometers and is only really suitable for urban settings. Even more than MMDS, its network and terminal equipment is very costly

3.4.3 MVDS

Microwave Video Distribution Systems (MVDS) are very similar to LMDS, with the main differences being that they operate at an even higher frequency - 40 GHz and that MVDS is a European standard. Like LMDS and MMDS, MVDS systems are acutely asymmetric - 50 Mbps downstream (to the home) and only 20 Kbps upstream (to the network). They have very low range capabilities - only 1-kilometer radius and only offer voice services of a reasonable but not sufficiently high quality.

Because of the very high frequency ranges in which they operate and at which penetration of electromagnetic waves is very low, microwave technology equipment is necessarily complex and consequently very expensive. Microwave technologies while they provide large bandwidth and data speeds, are not economically viable in a developing country context. With regard to developing countries, all microwave technologies suffer the same handicaps - low range, low penetration, very expensive, and poor voice quality. Even in developed countries, they are an immature technology. While microwave technology continues to evolve and prices are expected to eventually drop as more deployments allow economies of scale to be exploited, cellular networks remain the more economically prudent avenue for developing countries, even for data communications.

3.5 Summary

Table 3.1 summarizes the key characteristics of the different technologies including cellular.

Table 3.1 Comparison of the various technologies

Services				
	Cellular	*Proprietary*	*Cordless*	*Microwave*
Telephony	Good	Good	Good	Optimized for data
Data	14 - 384 Kbps (2G) 2 Mbps (3G)	144 Kbps	500 Kbps	10 Mbps
Frequency Band	800/900 MHz	1.5 - 4 GHz	1.7 - 2 GHz	2.5/28/40 GHz
Line of Sight	Not critical	Moderately critical	Moderately critical	Very critical
Supplementary Services	Good	Good	Limited	Very Limited
Capacity	High	High	Very High	Very High for data
Range (radius)	High (>>35 Km)	Low (6 - 15 Km)	Very low (5 Km)	High (30 Km)
Deployment	Very wide	Limited	Limited (but growing)	Very limited (especially in developing countries
Deployment Cost	Moderate	Expensive	Moderately inexpensive	Very expensive

Source: Webb, William, Introduction to Wireless Local Loop, 1998, Artech House Publishers.

Evidently, each technology has its strong points as well as its weaknesses. Nevertheless, an overall and careful review of all the technologies' characteristics together with a conscientious rationalization of these with the immediate and future communication needs and economic wherewithal of a developing country such as Kenya determines that cellular technologies are the WLL solution of choice. Only they, have the unique ability to provide easily deployable, high quality voice and data communications with large coverage areas quickly and inexpensively.

Chapter Four

Wireless Cellular: The optimal solution

4.1 Introduction

Of all wireless communications applications, cellular telephony is the fastest growing. With an estimated over 280 million subscribers[21] around the world, it represents a continuously increasing percentage of all new telephone subscriptions. Its basic architectural premise is the bi-directional transmission of communications signals between several subscriber stations or phones (mobile or fixed) and a central base transceiver station within a technically limited and specified range. This configuration is referred to as a cell - hence the term cellular telephony.

Although several wireless technologies exist that may find application in the local loop, cellular technologies among them promise to be the most viable solution to the local loop problem in Kenya and many other developing nations. As a very widely deployed wireless technology, they render themselves as the most likely to be able to take advantage of huge economies of scale and provide universal local access in the most economically efficient means. More than any other wireless form of communication, cellular technologies are very widely deployed and have been in existence for a considerable amount of time. Consequently, when applied to fixed wireless local loop configurations, they have very good coverage, very high scale economies, and advanced telephony features. In addition, cellular technologies provide immediate availability,

[21] [ARC Group, 1998]

inexpensive subscriber equipment and proven systems (including excellent immunity to channel errors[22]).

Various other technologies do provide certain specific advantages over cellular based configurations. All, however, have drawbacks which leave cellular technologies as - on the balance - the best WLL solution in low income countries like Kenya which require wireless communications infrastructure of a reasonable quality and coverage range as cheaply and as quickly as possible. Alternative to cellular networks include:

- Cordless based technologies, which only transmit within a very low range.
- Proprietary technologies, which are expensive and sparsely deployed.
- Microwave technologies, which are expensive and whose range of transmission is severely limited by line of sight restrictions.

Quantitative modeling of these alternative technologies is outside the scope of this thesis, but they are discussed qualitatively in chapter three.

This chapter describes the various cellular technologies deployed around the world. First, the architecture of a cellular network is described, highlighting the major elements and their functionality in both mobile and fixed configurations. Second, the various multiple access schemes - Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) are described, followed by specific technologies utilizing these schemes. The technologies are categorized as analog and digital as well as first, second, transitional and third generation.

First generation technologies were all analog and included Advanced Mobile Phone Service (AMPS) and Nordic Mobile Telephone (NMT) among others. Second generation technologies, while including advanced analog technologies like Narrowband AMPS (NAMPS), were soon predominantly composed of digital cellular networks, including TDMA (IS-136), Global System for Mobile Communications (GSM) and CDMA (IS-95).

[22] Channel errors refer to transmission faults that may occur in the communications path between the base

All of the currently deployed cellular schemes are either first or second generation (2G). Multiple standards represent each generation of technologies and although no single second generation standard exists, efforts are under way to try and institute a single standard for the next or third generation (3G) of cellular technologies. These technologies will be able to deliver broadband speeds of up to 2 megabits per second (Mbps). Among the technologies vying for dominance in the 3G world, are the GSM based Wideband CDMA (WCDMA) and the IS-95 based CDMA2000. As the shift from 2G to 3G technologies engenders debate, conflict and confusion, a transitional generation of technologies is emerging offering moderately high speeds - ranging from 56 kbps to 384 kbps, including GPRS, EDGE on the GSM end, and IS-95B, HDR on the CDMA end.

4.2 A Brief History of Wireless Communications

Although wireless communications can trace their origins to such figures as James Maxwell in the 19th century and Guglielmo Marconi in the early 20th century, it was not until a breakthrough at AT&T in 1947 that wireless communications expanded to include conventional telephony services. In that year, AT&T began operating a "highway service" between New York and Boston in the 35 to 44 MHz band. Yet although the technology held promise, these early systems were hampered both by a lack of technological sophistication as well as policy constraints. Transmitters had to use great amounts of power to achieve the desired operating ranges, giving rise to extremely high interference levels and consequently, very limited channel reuse[23] possibilities.[24]

Then in 1978, cellular telephony took a giant leap when AT&T rolled out analog based cellular service in a beta trial in Chicago, Illinois, USA. The system - Advanced Mobile Phone Service (AMPS) - comprised ten cells covering 21,000 square miles and operated in the 800 MHz band newly allocated by the Federal Communications Commission

and subscriber stations.

[23] A communication channel - a band of frequencies - can be used simultaneously by several subscribers if these subscribers are spaced physically far enough apart that their communications do not interfere with each other. The minimum distance at which there is no interference is called the channel reuse constraint. For further reading on this, see [Ahlén, Lindskog,Sternad and Tidestav, 1996].

(FCC) - the US regulatory body responsible for the allocation and management of frequency spectrum. Although the impending breakup of the Bell system coupled with a new FCC competition requirement delayed its commercial take off in the US, a two cell system was deployed in Bahrain in May 1978 and an 88 cell system in Tokyo in December 1979. It was not until 1983 that AMPS was launched commercially in the US in the original beta trial city of Chicago.[25]

Meanwhile, Europe had leaped ahead of the US, introducing the Nordic Mobile Telephone System (NMT) in 1981. NMT operated in the 450 MHz range and began in Denmark, Sweden, Finland and Norway. In 1985, the Total Access Communications System (TACS) - yet another analog mobile technology was launched in Great Britain operating in the 900 MHz range. The advent of the West German C-Netz, the French Radiocom 2000 and the Italian RTMI/RTMS[26] gave rise to the regime of incompatible analog radio telephone systems which was the impetus for the eventual development of a pan- European digital standard - Global System for Mobile Communications or GSM. It was devised as a single European open, non-proprietary digital cellular standard, with the goal of seamless roaming in all countries. New spectrum at the 900 MHz band was set aside for cellular service. By 1991, commercial GSM networks were operational in Europe at 900MHz in the continent and 1.8 GHz (Digital Cellular System - DCS1800) in the United Kingdom.

In the US, the AMPS dominated cellular market blossomed - reaching 1.6 million subscribers[27] in 1988, resulting in an entrenchment of the analog standard and a marked disinterest in developing a digital system. But the North Americans soon caught on, quickly introducing TDMA IS-54 or Digital AMPS (DAMPS) and developing dual mode phones which could access both analog and digital AMPS systems. Following the allocation of spectrum in the 1900 MHz band by the FCC in 1994, GSM specifications in that band were developed in the US and commercially deployed in 1996. These were

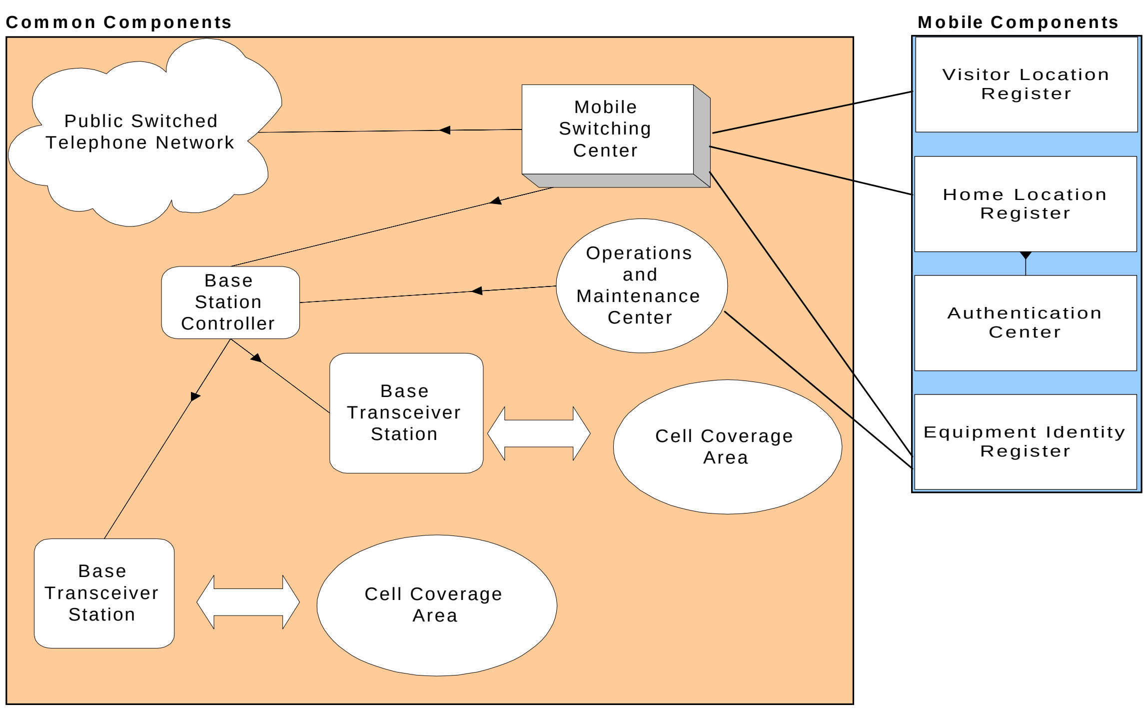
[24] See ["Wireless history: AT&T cuts the cord"] and [Farley, 1999].
[25] Ibid., 24.
[26] RTMI stands for "Radio Telefono Mobile Integrato", while RTMS stands for "Radio Telefono Mobile di Seconda generazione".

known as the Personal Communications System (PCS 1900). Meanwhile, while AMPS had become the most widely deployed analog standard in the world, GSM dominated the international digital cellular market outside the US. So much so that when Qualcomm (a US based cellular firm) proposed a new technology that allowed increased capacity - CDMA, even its supposed technical superiority was insufficient in convincing operators to abandon the increasingly ubiquitous GSM. Which brings us to contemporary wireless technological situation.

4.3 Cellular Architecture

Both GSM and CDMA networks follow similar design principles (CDMA operators elected to adopt GSM designs when they came into being). The network elements of the two systems are therefore almost identical. Figure 4.1 illustrates the architecture of a mobile cellular network. A fixed network would not include the mobile components shown and, in addition, would have a less complex switching interface to the PSTN.

Figure 4.1. A cellular network architecture



[27] Ibid., 24.

4.3.1 The Public Switched Telephone Network (PSTN)

The Public Switched Telephone Network (PSTN) refers to the world's collection of interconnected voice-oriented public telephone networks, both commercial and government-owned. Sometimes referred to as the Plain Old Telephone Service (POTS), the PSTN is composed of the local loop (the section of the network between the subscriber and the local exchange or central office) and the backhaul (the section that connects the central office to the rest of the world). Although wireless backhaul technologies exist such as satellite and microwave transmitters, the bulk of wireless communications both mobile and fixed - including cellular - operate in the local loop. Throughout this thesis, they are collectively referred to as wireless local loop systems (WLL).[28]

4.3.2 The Central Office (CO)

The Central Office (CO) is the interface between the local loop and the backhaul network of the public switched telephone network (PSTN). It is the place where wire based phone companies store their switches and other network equipment. In the case of a wireless network, the wireless system's switching center (mobile or fixed) would most likely be collocated with the central office via which the switching center would switch communications from (and to) the wireless local loop to (and from) the backhaul PSTN network.

4.3.3 The Common Components[29]

4.3.3.2 The Switching Center

The switching center performs the telephony switching functions of the system. It provides the connection to the public fixed networks and controls calls to and from other telephone and data systems. It switches calls in progress from different Base Station Controllers (BSCs) or to other switching centers. It records all billing information for

[28] Many people constrain WLL to refer only to fixed wireless systems. In this thesis, however, WLL refers to both fixed as well as mobile implementations of wireless infrastructure at the local loop.

[29] For further reading on the cellular network components described in sections 4.3.2 and 4.3.3, see [Compaq, "GSM: Overview and Principles"] and [IEC, (GSM) Tutorial].

calls made in its area and sends the data to the Operations and Maintenance Center (OMC). It also performs such functions as routing, call set-up, and common channel signaling, among others. Thus the switching center provides the interface between the wireless local loop and the PSTN, integrated services digital network (ISDN), etc. In a mobile configuration, it is referred to as the mobile services switching center (MSC) and additionally provides all the functionality needed to handle a mobile subscriber, including registration, authentication, location updating, inter-MSC handovers, and call routing to a roaming subscriber.

4.3.3.3 The Operations and Maintenance Center

The Operations and Maintenance Center (OMC) is responsible for the administration, maintenance, data integrity, network updating, software download and data base download operations of the base station systems, switching centers, and all the various components of the wireless local loop network. It is connected to all equipment in the switching center and to the BSC. The implementation of the OMC is called the operation and support system (OSS). The OSS is the functional entity from which the network operator monitors and controls the wireless system. Important functions of the OSS include the provision of cost-effective support for centralized, regional, local operational and maintenance activities.

4.3.3.4 Base Station Subsystem

All radio transmission related functions are performed in the base station subsystem (BSS). The BSS consists of the base station controllers (BSCs) and the base transceiver stations (BTSs).

4.3.3.5 Base Station Controller

The Base Station Controller (BSC) manages several BTSs and provides all the control functions and physical links among the different BTSs and between the switching center (SC) and the BTSs. It is a high-capacity switch that provides functions such as cell configuration data, and control of radio frequency power levels in BTSs. A number of BSCs are served by one switching center.

BSCs are typically limited in capacity by the number of transmission ports they have. Decentralized architectures such as those provided by Motorola and Nokia may allow a maximum of 120 transmitters on the BTSs they serve regardless of the number of cell sites. Centralized architectures such as Ericsson's, on the other hand, offer larger BSC designs which allow up to 512 transmitters for their BTSs. Nevertheless, in any practical deployment, BSCs are rarely loaded beyond 80 percent of their transmitter capacity in order to avoid overloading the BSCs processors.[30]

4.3.3.6 Base Transceiver Station

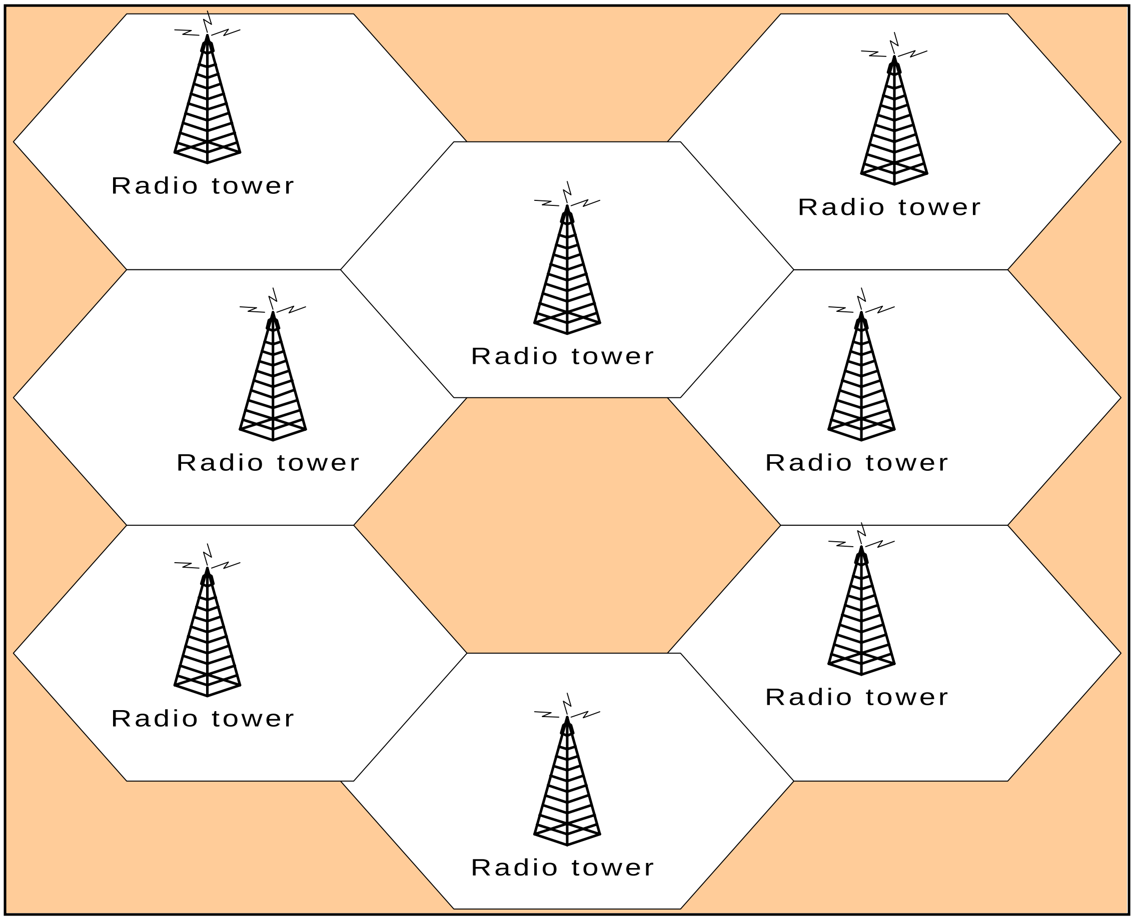
The Base Transceiver Station (BTS) provides the physical and radio interface between subscriber station and the BSC. Radio transmission coverage is logically divided in areas known as "cells". The BTS comprises the radio equipment (transceivers and antennas) that is required to service each cell in the network. Indeed, each cell in a network is controlled by a BTS, and in turn, a group of BTSs is controlled by one BSC.

4.3.3.7 Cell Coverage Area

The basic geographic unit of a cellular system is a cell. The term "cellular" is derived from the word cell and refers to the honeycomb shape of the areas into which one cell's coverage region is divided (See figure 4.2). Each cell is a base transceiver station transmitting signals to (as well as receiving signals from) numerous subscriber stations within the hexagonal geographic area that is within the range of the transceiver station. The size and shape of each cell varies according to landscape and the constraints imposed by natural terrain (e.g. mountainous areas) as well as man-made structures (e.g. buildings).

Figure 4.2 A cellular network

[30] Conversations with Randall J. Oster, Senior Manager - Wireless Systems, MediaOne Labs.



4.3.4 The Mobility Components

4.3.4.1 Home Location Register

The Home Location Register (HLR) contains all the administrative information of each subscriber registered in the corresponding GSM network, along with the current location of the subscriber. The HLR stores permanent data on subscribers, including a subscriber's service profile, location information, and activity status. It assists in routing incoming calls to the mobile subscriber station, and is typically the Signaling System 7 (SS7)[31] address of the visited MSC. There is logically one HLR per GSM network, although it may be implemented as a distributed database. When a potential subscriber buys a

[31] Signaling System 7 (SS7) is the means by which elements of the telephone network in the US exchange signaling information. For further reading, see [(SS7) Tutorial, 1998].

subscription from a GSM network operator, he or she is registered in the HLR of that operator.

4.3.4.2 Visitor Location Register

The Visitor Location Register (VLR) is a database that contains temporary information about subscribers that is needed by the MSC in order to service visiting subscribers. Although the VLR can be implemented as an independent unit, it is typically integrated with the MSC so that the areas controlled by both the MSC and VLR can coincide exactly. When a mobile station roams into a new MSC area, the VLR connected to that MSC will request data about the mobile station from the HLR. Later, if the mobile station makes a call, the VLR will have the information needed for call setup without having to interrogate the HLR each time.

4.3.4.3 Authentication Center

The Authentication Center (AUC) shields network operators from fraud and is a protected database that stores a copy of the secret key stored in each subscriber station's subscriber identity module (SIM) card. It provides authentication and encryption to effect the verification of the user's identity and ensures the confidentiality of each call.

4.3.4.4 Equipment Identity Register

The Equipment Identity Register (EIR) is a database that contains a list of all valid mobile subscriber stations on the network, where each mobile equipment is identified by its International Mobile Equipment Identity (IMEI). It prevents calls from stolen, unauthorized, or defective subscriber stations.

4. 4 Fixed Versus Mobile Cellular Implementations

Due to the extra functionality imposed by the need to support mobility, fixed cellular systems realize an immeasurable savings in bandwidth. The mobility components illustrated in figure 4.1 and described in section 4.3.3 are not necessary in a fixed implementation of a cellular network. Thus the a less complex switch replaces the MSC and the HLR, VLR, EIR and AUC are eliminated from a fixed network since the coordination of handoffs[32], location updates, and other mobility-related functions is no longer necessary.

Furthermore, in fixed networks, the network and cell planning no longer needs to provide for the inter-cellular overlap that is necessary for handoffs to occur smoothly. In a mobile deployment, cell coverage areas must provide sufficient areas of overlap with neighboring cells in order to allow for continuous communications during handoffs (smooth handoffs).

Additionally, in a fixed terminal installation with a directional[33] antenna installed external to the subscriber structure (residential or business premises), better range and reduced interference between signals from separate but proximate communication channels (interference rejection) are possible if the antenna orientation is optimal. Compared to mobile systems, fixed terminal deployments achieve a gain in range of up to 20 dB (ten times) through the use of directional antennas mounted at roof-top level. A further 20 dB is gained since building penetration loss required to provide in-building mobility is not a factor in fixed subscriber set configurations. The fixed unit is connected to the roof-top antenna by wire. Thus a cell size of 400m radius with mobility could easily increase to 5km without mobility.[34]

4.5 Multiple Access Schemes

Multiple access schemes define the manner in which the frequency spectrum is shared out to provide the different users with communication channels. Cellular technologies differ in the multiple access schemes that they use. Analog technologies all use Frequency

[32] A handoff is the process of transferring the handling and management of a mobile subscriber station's communications from one Base Transceiver Station (BTS) or cell site to another, as the first BTS' transmission range limit is approached.
[33] Unlike omnidirectional antennas which scatter signals in all directions and disperse signal energy in an unfocused manner, directional antennas are focused on a restricted sector, reducing signal energy dispersal and resulting in increased transmission radius.
[34] For more detailed description of technical capabilities and limitations of fixed cellular systems, see [Webb, 1998].

Division Multiple Access (FDMA), while digital technologies use Time Division Multiple Access (TDMA) or Code Division Multiple Access (CDMA).

4.5.1 Analog

4.5.1.1 Frequency Division Multiple Access (FDMA)

In FDMA schemes, the entire available frequency is divided into slots or bands or channels, each of which is assigned to a station. FDMA is characterized by continuous access to a given frequency band for the duration of the call. No coordination or synchronization is required among stations (both base and subscriber) and each subscriber station is able to use its own frequency band free of interference from other on going communications. Simplicity is FDMA's strong suit. This scheme, however, is particularly wasteful, especially when the load is momentarily uneven. When a subscriber station is idle, its share of the bandwidth cannot be used by other stations. FDMA is also inflexible, as adding a new station requires modification of the equipment.

4.5.2 Digital

4.5.2.1 Time Division Multiple Access (TDMA)

In TDMA schemes, time is divided into slots. Each time slot is pre-assigned to a station. During the assigned slot, each station is allowed to transmit freely, and the entire system resources are devoted to the station. The slot assignments are periodic, and each period is called a cycle or a frame. A station could be assigned to one or more time slots during a cycle. The stations must be synchronized so that each station knows exactly when to transmit. The major disadvantage of TDMA is the requirement that each station must have a fixed allocation of channel time whether or not it has data to transmit. In most data applications transmission requirements are bursty. This means that data transfer occurs in an irregular fashion, with brief periods of high rates of data transmission interspersed with long periods of no transmission at all.

Thus, briefly, the advantages of TDMA when compared to the FDMA scheme include:

- At any instant, a single station occupies all of the channel bandwidth, albeit for a brief period of time. This ensures that a high transmission throughput is available for a large number of stations;
- The reduced need to control the transmitting power of the stations;
- The utilization of digital processing leads to operational simplicity;
- Simplified tuning since all stations transmit and receive on the same frequency.

The disadvantages, again compared to FDMA include:

- The need for synchronization;
- The need to dimension the station for transmission at high throughput;
- The need for costly equipment - this cost, however, may be compensated by better channel utilization which leads to better throughput.

For TDMA, a fixed allocation of channel time to each station is still wasteful of resources.

4.5.2.2 Code Division Multiple Access (CDMA)

In CDMA schemes, the information contained in a particular signal is spread over a much greater bandwidth than the original signal, through a technique known as spread spectrum technology. Spreading means that digital codes are applied to the data bits associated with users in a cell. These data bits are transmitted along with the signals of all the other users in that cell. When the signal is received, the codes are removed from the desired signal, separating the users and returning the call to its original transmission point bit rate. Spread spectrum signals have traditionally been used by the military because the wide band nature of the signals makes it difficult to identify, interfere with or jam them. Commercial CDMA based networks retain these characteristics and are inherently more private than networks based on other access schemes.

CDMA works by adding a special "pseudo-random code" to the signal that repeats itself after a finite amount of time. Base stations in the system distinguish themselves from each other by transmitting different portions of the code at a given time - time offset versions of the same pseudo-random code. In order to assure that the time offsets used remain unique from each other, CDMA stations must remain synchronized to a common time reference using the Global Positioning System (GPS)[35] which provides this precise common time reference.

4.6 The Technologies

4.6.1 First Generation Cellular Technologies

The first generation of cellular networks comprised exclusively of analog technologies, employing the FDMA access scheme.

4.6.1.1 AMPS Analog

Advanced Mobile Phone Service (AMPS) was the first automatic cellular system. Based on FDMA and sometimes referred to as analog cellular service, AMPS operates in the 800 MHz to 900 MHz frequency band with 30 KHz bandwidth reserved for each channel[36]. Originally launched in the US, AMPS based cellular telephones are the most widely deployed in the world. Since 1988, the AMPS standard has been maintained and developed by the Telecommunications Industry Association (TIA).[37]

4.6.1.2 Other Analog standards

While North and South American analog cellular systems conform to the AMPS standard, in the rest of the world, several types of analog cellular standards developed. In Europe and Asia, these included Total Access Communications System (TACS), Nordic

[35] GPS is a satellite based, radio navigation system capable of providing a practical and affordable means of determining continuous position, velocity, and time to an unlimited number of users.
[36] [Wireless Local Loop Technology Standard Overview, 1998] and [IEC, North American Analog Cellular Systems].
[37] The TIA is a national US trade organization with a membership of about 900 suppliers of communications and information technology products whom it represents on public policy, standards and market-development issues.

Mobile Telephone (NMT), Cnet and MATS-E. Soon however, a new second generation of technologies offering better quality and more advanced services began to appear[38]. While networks based on these analog technologies still exist, digital networks are slowly eclipsing them.

4.6.2 Second Generation Cellular Technologies

Despite widespread popularity, AMPS had several limitations including:- low capacity; limited spectrum; little room for spectrum growth; poor sound quality; poor data communications; minimal privacy and inadequate fraud protection. Furthermore, demand for low cost higher capacity wireless systems was booming. When consumer demand saturates the capacity of a cellular system, there are three ways to expand: move into new spectrum bands, split existing cells into smaller cells, or introduce new technology to make more efficient use of existing bandwidth. Since no new radio spectrum would be available, and splitting cells requires very expensive additional network infrastructure especially in congested areas, new technology seemed to be the best route.

To stimulate technology creation in the US, the FCC declared in 1987 that cellular licensees may employ alternative cellular technologies in the 800 MHz band, provided that interference to other cellular systems was not created. This encouraged the cellular industry to search for new transmission techniques that would increase the efficiency of radio spectrum use compared to existing AMPS systems.

4.6.2.1 Analog

4.6.2.1.1 NAMPS

Narrowband Analog Mobile Phone Service (NAMPS) was developed in response to the low capacity problem of first generation AMPS. Although it was introduced only as an interim solution, it has since spread to at least 35 US and international markets[39]. Despite being an analog standard that utilizes analog voice processing techniques, NAMPS employs digital signaling methods, tripling the capacity of AMPS systems. NAMPS uses

[38] For a more detailed account, see [Berck, 1998].

frequency division to carve out three channels in the AMPS 30 KHz single channel bandwidth. Three users are served in an AMPS channel by dividing the 30 KHz AMPS bandwidth into three 10-kHz channels. This increases the possibility of interference because channel bandwidth is reduced.

All NAMPS did, however, was to squeeze out a few extra communication channels from AMPS networks. Indeed in the process of increasing number of channels, it reduced bandwidth available to each channel from 30 KHz to 10 KHz. Thus it did not improve sound or data quality, and only succeeded in increasing capacity at the expense of reduced bandwidth per channel.[40]

4.6.2.2 Digital

Only after fully digital technologies began to emerge did sound quality and data handling capabilities really begin to improve. Moreover, significant capacity enhancements were now possible while retaining the bandwidth available to each communications channel. All digital cellular technologies use the TDMA or CDMA access techniques.

4.6.2.2.1 TDMA - IS-54/IS-136

As the names suggest, TDMA IS-54 (IS-54) and TDMA IS-136 (IS-136) are cellular standards that are based on the TDMA multiple access scheme in which each communicating pair (base to subscriber station) is assigned different time slots within the same frequency. Of the two, IS-54 was the earlier standard and is still the more widely deployed. It is based on the US centered IS-54 specification which - like IS-136 - is an Electronics Industries Association/Telecommunication Industries Association (EIA/TIA) standard. Consequently, IS-54 and IS-36 are found mostly in the US, where they are indeed the most widely deployed digital cellular standard.

The development of IS-136 was driven by specific subscriber requirements for evolving existing analog cellular capabilities to include: advanced digital features; complete in-building digital coverage; increased subscriber growth and demand; expanded mobility;

[39] [IEC, NAMPS].

lower costs (e.g., terminals, user rates); and personalized devices. Alternatively referred to as D-AMPS or Digital AMPS, IS-136 is an improved revision of IS-54 and is specified as a PCS technology for both the cellular (850 MHz) and PCS (1.9 GHz) spectrum in the United States.[41]

4.6.2.2.2 GSM

Global System for Mobile Communications (GSM) was developed in Europe. Like TDMA IS-136, GSM is based on TDMA technology. Although GSM technology has a lot of similarities to TDMA IS-136, it developed along a very different path. Unlike the United States, where the industry moved, without stewardship or coordination, from a single analog standard - AMPS - to a new generation of multiple competing digital standards, in Europe the exact opposite was true. Careful and deliberate efforts to achieve a single standard were orchestrated in Europe, resulting in GSM - an open standard whose equipment could be easily multi-sourced by different operators (see section 4.2 of this chapter). In the United States, commercial GSM 1900 cellular systems have been operating since 1996 in the 1900 MHz band. GSM is currently the only technology that permits automatic roaming between North American, European and Asian countries. It is the most widely deployed digital cellular technology in the world.

GSM divides up spectrum into 200 KHz TDMA channels, each modulated using Gaussian minimum shift keying (GMSK) [42]. Each channel is nominally divided into 8 full rate voice channels, but in reality, this turns out to be effectively about 7.5 voice channels because some of the bandwidth is used up for control purposes.

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[40] For further reading on NAMPS, see [Goodman, 1997]
[41] For further reading on TDMA - IS-54/IS-36, see [Harte, Smith and Jacobs, 1998].
[42] Modulation refers to the communications practice of using a constant carrier signal to transmit variable data signals. At the receiving side, a device demodulates the signals by separating the data signals from the carrier signal. Gaussian minimum shift keying (GMSK) is a frequency modulation (FM) technique in which the frequency of the carrier signal varies directly proportionally to the data signal amplitude (message). At the receiving end, the signals are easily demodulated by comparing the modulated carrier/data signals to the unmodulated carrier signal.

Although GSM is a circuit switched service, it offers both voice and limited data services. It was designed to be interoperable with integrated services digital network (ISDN)[43], and the services provided by GSM are a subset of the standard ISDN services. In addition to voice, various data services are supported at specified rates of 14.4 Kbps, a speed that in practice is rarely ever attained. Specially equipped GSM terminals can connect with PSTN, ISDN, packet and circuit switched public data networks, through several possible methods. Also supported, are fax and limited cell broadcast (e.g. traffic reports) communications. A service unique to GSM, the Short Message Service (SMS), allows users to send and receive point-to-point alphanumeric messages up to a few tens of bytes. It is similar to paging services, but much more comprehensive, allowing bi-directional messages, store-and-forward delivery, and acknowledgement of successful delivery. Further supplementary services include:- call forwarding and call barring; multiparty calls; advice of charge; and call waiting.[44]

4.6.2.2.3 IS-95 CDMA (CDMAONE)

IS-95 CDMA refers to an international standard now named cdmaOne. The earliest proposals on how to apply spread spectrum technology to cellular systems were in the late 1970's. In the late 1980's and early 1990's, the Qualcomm corporation proposed and developed a CDMA based system. In 1993, the Qualcomm system was modified and adopted by the Telecommunications Industry Association as the Interim Standard 95 (IS-95). Several network operators adopted this standard with plans to adopt CDMA for dual-mode operation with analog at both the 800 and 1900 MHz frequency bands. In 1996, commercial systems began operation. CDMAONE boasts many advantages over other technologies, including:-

- Increased capacity which lowers the operators' investment cost per subscriber

[43] Integrated Services Digital Network (ISDN) is an international communications standard for sending voice, video, and data over digital telephone lines. A single line supports data transfer rates of up to 64 Kbps and where two lines (B channels) are provided, the data rates can go up to 128 Kbps. While ISDN did not take off in the US, it is relatively widely deployed in Europe.

[44] For further reading on GSM networks see [Harte, Levine, Livingston, 1999] and [Ibid., 29].

- Fewer dropped calls in mobile mode due to a technique known as soft-handoff[45]
- Security and privacy due mainly to the spread spectrum technique
- Low power consumption allowing for smaller batteries and hence (hopefully) increased portability
- Packet data services in newer versions of IS-95

CDMA uses single cell clusters, in which all subscriber stations transmit their data signals on the same carrier signal[46], whose bandwidth is 1.228 MHz. Speech is first encoded using a variable rate coder/decoder (codec). Each communication channel is then encoded to generate a transmitted bit rate of 19.2 Kbps, which is spread by a 64-chip Walsh code[47] sequence to generate the 1.228 (19.2x64) Mbps transmitted waveform.[48]

Despite the much touted advantages of IS-95 over other technologies, its adoption has been slow owing principally to the ubiquitous nature of GSM and the resultant difficulties with compatibility, especially with roaming services for mobile configurations. Additionally, many operators were initially skeptical of the robustness of untested CDMA networks. However, some markets such as South Korea have taken the giant leap of faith and adopted IS-95 CDMA as their main cellular technology of choice with appreciable success.

4.6.2.2.3.1 CDMA in South Korea[49]

The case of commercial deployment of CDMA in South Korea is unique and merits special mention. Until 1990, national security concerns in the country sustained stringent

[45] [Ibid., 32] for the description of a handoff. Soft handoffs allow the mobile subscriber station to shift from one BTS or cell site to another without interrupting the communication. This is possible because for a brief period of time during handoff, both BTSs simultaneously manage the mobile subscriber station, with the relinquishing BTS only shutting down communications after it has been ascertained that the new BTS is handling the subscriber's communications.

[46] Ibid., 42.

[47] For further details on Walsh codes, see [Jhong and Miller, 1998] and [da Silva, 1998].

[48] For further reading on CDMA, see [Prasad and Ojanperä, 1998]. See also [Jhong and Miller, 1998]

[49] For more detailed account of CDMA development in South Korea, see [Report: ATIP98.03]. Also see [SK Telecom, March 27 1997].

government restrictions on wireless communications. In that year, however, the government relaxed the tough regulations and charged its own Electronics and Telecommunications Research Institute (ETRI) with the task of helping develop wireless technology. In the early 1990s, ETRI decided to base its wireless systems on CDMA because of its "perceived technical advantages and possibilities". It was a bold step, given the heightened level of skepticism about the new (CDMA) technology at the time. In addition to the fact that there was no other commercial CDMA system anywhere in the world, ETRI had no prior experience in deploying wireless networks.

Nevertheless, in January 1996, ETRI launched the first commercial CDMA service in the world through the vehicle of the Korea Mobile Telecom Company (later renamed Sungkyong Telecom or SK Telecom). By October 1997, the success of the Korean government's brazen initiative was plain for all to see. There were now a total of five CDMA operators, three of whom were PCS. SK Telecom had services in all 78 South Korean cities and reached 80% of the population, providing subscribers with digital cellular service, enhanced voice and call quality, greater security, wireless fax and data transmission. Today, SK Telecom boasts over 2.9 million[50] subscribers in its CDMA network in Korea and many other parts of the world have also deployed CDMA networks.

4.6.2.2.4 PCS

Personal Communications Service (PCS) refers to the North American implementation of the digital technologies already described -IS-95 CDMA, IS-136 TDMA and GSM in the 1900 MHz band. In 1994, the FCC announced it was allocating spectrum specifically for PCS technologies at the 1900 MHz band, and began a series of auctions for US frequency spectrum. In the years following, network operators deployed cellular service in each of the three technologies at the 1900 MHz frequency band. The PCS frequency allocation in the US is three 30MHz allocations and three 10 MHz allocations. The idea was to develop systems which would be simpler and less costly to deploy, to incorporate such

[50] [SK Telecom, December 15 1997].

features as an all encompassing wireless phone with paging, messaging, data service and a greatly improved battery-standby time.[51]

4.6.3 Transitional Generation Cellular Technologies

Most of the second generation digital cellular standards were - very much like the first generation analog standards - optimized for voice communications. With the exception of CdmaOne, none of the second generation cellular networks can handle packet switched data directly.

Ostensibly, as part of the evolution to a third generation of technologies that will be able to intrinsically handle packet switched data at very high speeds, a set of transitional technologies has been developed both by the GSM as well as CDMA groups. Set for commercial release between the end of 1999 and the beginning of 2000, these transitional technologies will provide data speeds of up to 384 Kbps.

4.6.3.1 GSM-Based

The GSM-based transitional technologies so far under development include: High Speed Circuit Switched Data (HSCSD); General Packet Radio Services (GPRS); and Enhanced Data Rates for GSM Evolution (EDGE). These technologies are separate and independent of each other and operators have to make careful choices as to which particular one they would like to adopt.

4.6.3.1.1 HSCSD

High Speed Circuit Switched Data (HSCSD) is a new standard that gives GSM users the mobile equivalent of an ISDN line. Up to six times faster than standard GSM, HSCSD provides an uncompressed bit-rate of up to 57.6 kbps by multiplexing (combining) four 14.4 Kbps communication channels into a single time slot. With further developments of end to end compression, speeds up to 200 kbps could be achieved. Companies such as *Nokia* in Finland and *Ericsson* in Sweden have already conducted successful trials and

[51] [Goodman, 1997] and [IEC, Personal Communications Services Tutorial].

Nokia, for instance, has initiated commercial deployments for *Hong Kong Telecom* and for *Telenor Mobil* in Norway [52]

4.6.3.1.2 GPRS

General Packet Radio Services (GPRS) is an enhancement of existing GSM networks planned for release on a trial basis late 1999, with full commercial availability expected early 2000. GPRS introduces packet switching capabilities to GSM networks for the first time and is nominally expected to offer data speeds in excess of 100 Kbps. Four transmission channel coding schemes are defined for GPRS, allowing between 9.05 Kbps and 21.4 Kbps per GSM timeslot in use. As there are a maximum of 8 timeslots, the maximum data rate for GPRS is 171.2 (=8x21.4) Kbps.

However, subscriber terminal functionality coupled with the desire by operators to partition bandwidth between data and voice capacity will likely limit available data speeds. The technical specifications will set the maximum limits, but commercial reality will dictate lower speeds. For instance, a GPRS subscriber station will be limited to transmitting on 4 consecutive timeslots in order to keep the terminal complexity reasonable, even though it could be possible to build a terminal that used all 8 timeslots[53].

4.6.3.1.3 EDGE

Enhanced Data Rates for GSM Evolution (EDGE) is a further enhancement of GSM networks which will enable delivery of speeds of up to 384 Kbps on the existing GSM spectrum allocations of 900, 1800 or 1900 MHz. A higher modulation scheme enables EDGE-enabled radio channels to support bit-rates of 62.5 Kbps per time slot, allowing overall data throughput capability of up to 500 (8x62.5) Kbps. No major new investments in network elements would be required for EDGE functionality whose availability is estimated to be in 2001.[54]

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[52] For further details on HSCSD, see [Hagros, Kaj]. See also, [Emmerson, 1998].
[53] For further reading on GPRS, see [Holley and Costello, 1998].
[54] For further reading on EDGE, see [Welcome to the Future, Ericsson, 1998] and [Ericsson takes a further step into wireless multimedia, October 15 1998].

4.6.3.2 CDMA-Based

The CDMA-based transitional technologies include: IS-95C and High Data Rate (HDR)[55].

4.6.3.2.1 IS-95C

Much like GPRS is a GSM enhancement, IS-95C is an enhancement to existing IS-95A or CDMAONE networks. However, CDMAONE networks already have packet switching capability and IS-95C merely increases bit-rates to 144 Kbps by allocating a further 1.25 MHz of spectrum (i.e. doubling available bandwidth per signal transmission). Like GPRS, IS-95C is expected to be available between late 1999 and early 2000, and like GPRS, data speeds may also be limited by subscriber terminal functionality and the partitioning of bandwidth between voice and data.

4.6.3.2.2 HDR

High Data Rate (HDR) technology is slated to increase cdmaOne data speeds to rates greater than 1.5 Mbps by allocating a further 1.25 MHz of spectrum for data capacity (i.e. tripling available bandwidth per signal transmission). According to Qualcomm, for a low, incremental cost, existing cdmaOne networks can support HDR capabilities using existing infrastructure equipment and network plans. HDR is ideal for data applications like home Internet use and is expected to be commercially available in 2000.

4.6.4 Third Generation Cellular Technologies

The next generation of wireless systems is geared towards achieving broadband[56] speeds for data transmission applications. Commonly known as third generation technologies, they are expected to be able attain speeds of up to 2 Mbps. In an effort to avoid the problems brought about by the multiplicity of second generation standards around the world, the International Telecommunication Union (ITU) launched an initiative known as the International Mobile Telecommunications 2000 (IMT-2000). The mandate of IMT-

[55] Interviews with industry experts from Qualcomm, MediaOne, Sprint PCS.

2000 is to help bring about the adoption of common worldwide standards (convergence) for third generation wireless systems[57].

Several proposals of radio transmission technologies (RTTs) - both TDMA and CDMA based- were submitted by various vendors (assorted on a regional basis) for consideration by the IMT-2000 committee. Of the TDMA based proposals, the UWC-136 RTT[58] presented by the US based Universal Communications Consortium (UWCC) that comprises mainly of vendors of the second generation technology - TDMA IS-136/IS-54 will likely be the TDMA standard. Most of the attention, however, has been focused on the principal CDMA based proposals - Wideband CDMA (WCDMA) and CDMA2000. The WCDMA proposal[59] was presented by the Japanese Association of Radio Industries and Businesses (ARIB) in conjunction with the European Telecommunications Standards Institute (ETSI), both of which comprise of GSM vendors, while the CDMA proposal[60] was presented by US based Telecommunications Industry Association (TIA) on behalf of CDMAONE vendors.

A recent agreement[61] between Ericsson - the main WCDMA proponent- and Qualcomm - the main CDMA2000 proponent, "finally" brought to an end a contentious debate between the two companies and the standards they propose for adoption by IMT-2000. So bitter had the dispute become, that at a certain point Qualcomm threatened not to license its CDMA technology to the WCDMA vendors unless its version of CDMA technology was adopted by IMT-2000, promptly invoking the committee's wrath.

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[56] Broadband refers to the transmission of several data channels through a single communications medium. In contrast, baseband transmission allows only one signal at a time. Cable TV is an example of an application that uses broadband transmission.

[57] For further details on the IMT-2000 initiative, see http://www.itu.int/imt/.

[58] For further details on the UWC-136 RTT, see "UWC-136 RTT update", TIA Technical Sub-Committee, TR-45.3, February 26 1999, http://www.itu.int/imt/2-radio-dev/proposals/usa/tia/uwc136r6a.pdf.

[59] For further details on the WCDMA RTT, see "Japan's proposal for Candidate Radio Transmission Technology on IMT-2000", http://www.itu.int/imt/2-radio-dev/proposals/j/j.pdf

[60] For further details on the CDMA2000 RTT, see "The cdma2000 ITU-R RTT Candidate Submission (0.18), TR45.5.4, 1998, http://www.itu.int/imt/2-radio-dev/proposals/cdma2000(0.18).pdf

[61] [Reuters, March 25 1999].

At issue, were the chip rates[62] to be adopted in the new generation of systems. CDMA2000 proposes a chip rate of 3.6864 Megachips per second (Mcps), which is a direct multiple of the existing CDMAONE chip rate of 1.23 Mcps (this would ease the shift from CDMAONE to CDMA2000). The WCDMA camp on the other hand proposes a chip rate of 3.84 Mcps (recently amended from 4.096 Mcps), a move which caused the CDMA2000 camp to allege that the WCDMA camp was deliberately trying to deny it an obvious competitive advantage for no apparent valid technological reason. The CDMA2000 camp refuses to accept the WCDMA camps claims that the higher chip rate affords a 10 percent improvement in capacity. In February 1999, however, Qualcomm and Ericsson entered an agreement under which they propose that the ITU adopt a "single" CDMA standard with 3 modes, two of which will be WCDMA and CDMA2000.

So "all's well that ends well", or is it? While the agreement settles the question for the vendors, it does nothing to assuage the concerns of other key players. The debate as to which will be the easiest transition - GSM to WCDMA or CDMAONE to CDMA2000 - remains painfully relevant to network operators and continues to rage in other aspects in addition to chip rates. For instance, it appears that while CDMA2000 will be backward compatible with CDMAONE since they share the same air interface, the same will not be true for GSM and WCDMA. It will be necessary to replace all base station equipment when the shift from GSM to WCDMA occurs. The counter argument advanced by the WCDMA camp is that 3G subscriber stations will be multi-mode and that therefore, compatibility will not be an issue. Multi-mode subscriber stations will of necessity be more complex and consequently, more expensive to construct and maintain. While the jury is still out on the issue, the switch to IMT-2000 appears less certain for GSM than for CDMA. In any case, it is instructive that the TDMA based GSM group has chosen to adopt a CDMA standard for its next generation of networks.

[62] In spread spectrum communications such as CDMA, the most elemental component of a signal is a chip; that is, the longest duration signal in which signal parameters are approximately constant. The chip rate is thus the rate at which the information signal bits are transmitted interpreted as a pseudo-random sequence of chips. The chip rate is usually several times the information bit rate.

Chapter Five

The Cellular Cost Model

5.1 Introduction

This chapter describes a cost model developed for the provision of wireless service in Kenya. It provides details of the various scenarios modeled and then presents the model itself. The model results which are presented in the next chapter, are given in terms of costs incurred by the cellular network operator per subscriber.

5.1.1 The model objective

The objective is to investigate the best routes towards the installation of networks that will in future be able to meet both data and voice requirements in developing countries. As indicated earlier, although voice services are the current drivers of technology, the model anticipates a future in which data services such as full Internet access will be a crucial component of communications. The model is based on the premise (which is representative of the actual situation) that 1.) Voice only networks are in place in urban parts of Kenya, and 2.) No networks at all are in place but plans to construct voice-only networks are under way in rural parts of Kenya.

5.1.2 Focus on the local loop (WLL)

The scenarios modeled in this thesis looked specifically at the local loop, the proverbial "last mile", ever mindful of the fact that these would be heavily dependent on the availability of national backbone connections. Wireless local loop (WLL) is that part of a telecommunications network that connects subscribers to the public switched telephone network (PSTN) using airborne electromagnetic signals as a substitute for copper for all or part of the connection between the subscriber and the PSTN. The costs modeled here include all communications from the subscriber to the interface with the PSTN backbone network. In Kenya there is a reasonably good availability of inter-city and inter-district wire based (trunk) connections and the government has recently announced plans to build a high speed data backbone (fiber based) which would at least be able to handle megabit level speeds.

5.2 The modeled scenarios

5.2.1 Discontinuous scenario - GSM with planned replacement with WCDMA

As described in chapter 3, GSM networks are expected to evolve in stages through GPRS and EDGE to WCDMA (the third generation standard for GSM). For many operators, GSM would be a logical choice of technology because it already is the most popular and fastest growing digital cellular technology in Kenya and other parts of Africa and the developing world. It is a technology that has been tried and tested (at least in mobile configurations) and with which operators in that part of the world are relatively familiar. It is also very well supported by manufacturers such as Ericsson and Nokia, particularly the former. Presumably, these GSM operators would gradually deploy GPRS, EDGE and eventually, WCDMA as the technology becomes available. This is the situation and course of events that is represented by this first scenario. Since the technical details (and costs even less so) of EDGE and WCDMA are yet to be finalized and released by the vendors, the model only quantitatively analyzes GSM and GPRS implementations. Indeed, even for GPRS, not all technical details or costs have been clearly ascertained as it is also yet to be commercially deployed.

5.2.2 Incremental data scenario - CDMAONE with planned migration to CDMA2000

Much like GSM networks, IS-95 CDMA networks (also referred to as CDMAONE) are expected to evolve in stages through IS-95C, to HDR, and finally to CDMA2000 (the third generation standard for CDMA). Unlike GSM, CDMA is not very widely deployed in the developing world and is not deployed at all in Kenya. Despite being intrinsically able to handle data (CDMA can handle packet data directly while GSM requires modems to convert circuit switched into packet data) and the fabled capacity capabilities of CDMA, dislodging GSM from its dominant market position has proved to be an uphill battle for CDMA. To many operators outside the United States and South Korea it is a virtually unknown quantity since it has only been much more recently developed and commercially deployed. Moreover, in the mobile cellular world where intercellular roaming is a vital feature (and in the absence of interoperability between CDMA and GSM), operators view CDMA's sparse deployment as a disadvantage since the vast majority of cell sites are GSM.

Yet CDMA networks are growing at a terrific rate, with operators and consumers becoming ever more familiar with them. And as they become more widely deployed, their strengths as well as their weaknesses vis-a-vis GSM networks are becoming better understood. Furthermore, for a country such as Kenya where mobility is not the priority, CDMA is a technology worth investigating. This second scenario represents the situation in which a CDMAONE network is deployed to begin with, and then gradually phased up to IS-95C and ultimately, CDMA2000. Again, as in the GSM case, transitional and third generation technologies like IS-95C and CDMA2000 are yet to be deployed. Consequently their cost structures are yet to be determined and in the instances where this has been done, the data remains highly proprietary. The model therefore only quantitatively models CDMAONE implementations.

5.2.3 Modeling the transitional scenarios - GPRS/EDGE and IS-95C/HDR

As has already been indicated, quantitative modeling of the network components of second generation technologies - GSM and CDMAONE - was comprehensively conducted. Technical details for the third generation technologies - WCDMA and CDMA2000 - are not yet available, and so they were only analyzed and contrasted qualitatively throughout this thesis.

For the transitional technologies, however, the availability of information or lack there-of was not so symmetric. In the case of GSM-based transitional technologies, technical (and some limited cost) data was available for GPRS but not for EDGE. Indeed, even for GPRS, only the technical specifications were readily available. From these, plausible assumptions as to component costs were made, by comparing GPRS components with similar components in existing second generation networks. In the case of CDMA-based technologies, there was insufficient technical and cost data for the implementation of a cost model for either CDMA IS-95C or HDR. Thus a cost model was developed for GPRS, whose results were useful in developing a speculative cost budget for IS-95C (the comparable CDMA technology).

Although transitional CDMA technologies were not modeled, there is no reason to believe IS-95A upgrades to IS-95C would be any more expensive than the incremental cost of GPRS over GSM. In fact, it is likely that the transitions would be slightly less costly since IS-95A already has packet data handling capabilities incorporated.

5.3 The technology reference models

5.3.1 Fixed cellular architecture reference model

As explained in chapter four, both GSM and CDMA networks follow similar design principles. Since the network elements of the two systems are almost identical, it is possible for a simplified general technical reference model representing both architectures to be drawn and modeled.

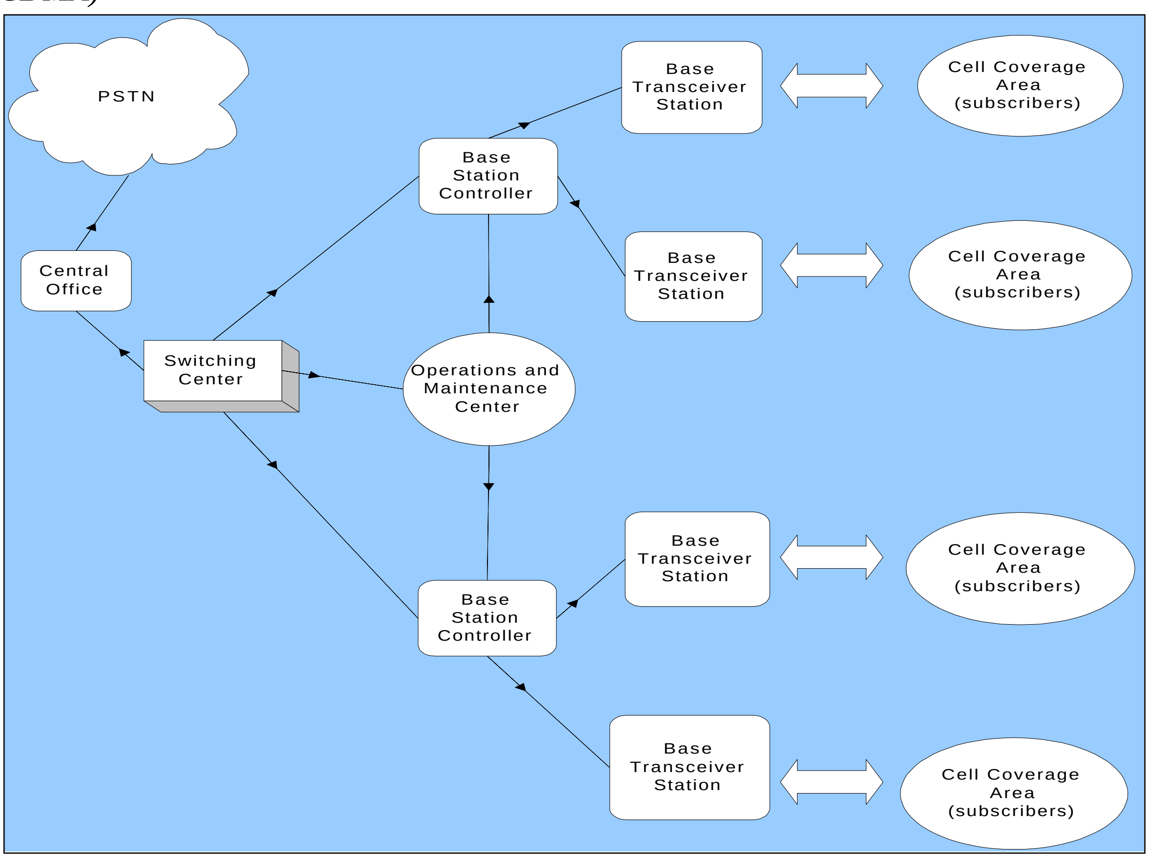
Below is an illustration of the fixed cellular architecture of the modeled network components (Figure 5.1). The main components[63] are:

- The Cell Coverage Area: The subscriber coverage area within which a base transceiver station (BTS) is able to transmit (and receive) signals to (and from) subscriber stations.

[63] These components are described in greater detail in section 4.3 of chapter four.

- The Base Transceiver Station (BTS): Provides the physical and transmission interface between the subscriber stations and the base station controllers (BSC).
- The Base Station Controllers (BSC): Provides control and switching functions for several BTSs, and switches them to the switching center.
- The Switching Center: Performs the telephony switching functions, from the base station controllers (BSCs) - via the Central Office - to the backhaul networks, in between different BSCs, as well as to other switching centers.
- The Operations and Maintenance Center: Performs the administration and maintenance tasks of the wireless network.
- The Central Office: The point of interface between the WLL network and the rest of the public switched telephone network (PSTN).

Figure 5.1. The general architecture of the modeled fixed network components (GSM and CDMA)

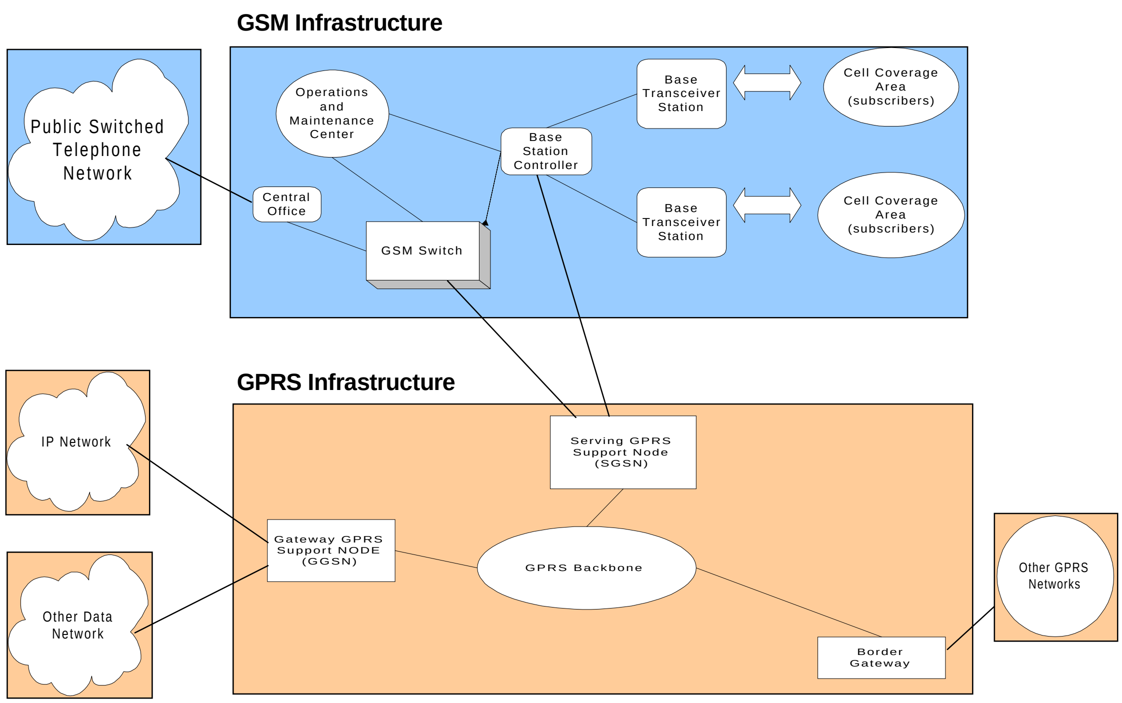


5.3.2 Transitional technology reference model: Adding GPRS to GSM

As observed in section 5.2.3, of the transitional technologies, only the enhancement of GSM by GPRS was quantitatively modeled, as sufficient cost data for the other technologies was not available.

As illustrated in figure 5.2, GPRS introduces two new nodes into the GSM network - Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). The SGSN provides the interface between the GPRS and GSM systems, routing packets from the GSM switch to the GPRS backbone and onto the GGSN. The GGSN then converts the GSM packets into other packet protocols (IP or X.25 for example) and sends them out onto other external networks. Border gateways provide the interface between different GPRS backbones.

Figure 5.2. The general architecture of the modeled network components for a GSM/GPRS network



The subscriber logs on to the network separately for GPRS and establishes a Packet Data Protocol (PDP) which is a logical connection between the subscriber and the GGSN via the SGSN. In this manner, a GSM subscriber is able to directly access data networks such as the Internet without the necessity of a modem.

5.4 The demographic parameters

In undertaking the modeling, account is taken of the fact that the market is heterogeneous - urban as well as rural, as is explained in chapter two. Consequently, the resultant differences in demographic, geographic and economic characteristics affect the performance of the various technologies differently and have a significant bearing on the choice of wireless network that an operator would want to deploy. For this reason, urban and rural regions were modeled separately.

- Urban - *Mombasa*, a coastal Kenyan city which is also the second largest city in Kenya was modeled to represent urban Kenya.

- Rural - *Kirinyaga* a central Kenyan district was modeled to represent rural Kenya.

As a moderately large urban city, Mombasa is much more densely populated than rural Kirinyaga. In addition, owing to the cultural and socio-economic norms and conditions prevailing in Kenya, several assumptions could be (and were) made.

Rural dwellings are typically much larger than urban ones. Thus the model assumed an average urban household of 5 people and an average rural household of 10 people. The number of households in a given area was used to represent the number of potential subscribers in the said area (see table 5.1).

Table 5.1 Fixed parameters based on demographic statistics and assumptions

	Total population	*Geographical area (square kilometres)*	*Population density*	*People per Household (hholds)*	*Number of hholds*
Mombasa - urban	601000	210	2862	5	572
Kirinyaga - rural	450000	1130	398	10	40

Source: Population and geographic size figures were obtained from the Central Bureau of Statistics, Kenya

Demand for communications services as well as the ability to pay for them is higher in urban areas than it is in rural ones. For the reference case therefore, the deployed network was assumed to grow to a target saturation penetration ratio of 40% of potential subscribers in the urban case, and 10% in the rural case (see table 5.2). Sensitivity analyses were conducted for various target penetration ratios.

Table 5.2 Variable parameters based on demographic statistics and assumptions

	Target saturation	*Subscribers per*	*Total*
	Penetration	*square kilometer*	*subscribers*
Mombasa - urban	0.40	229	48080
Kirinyaga - rural	0.10	4	4500

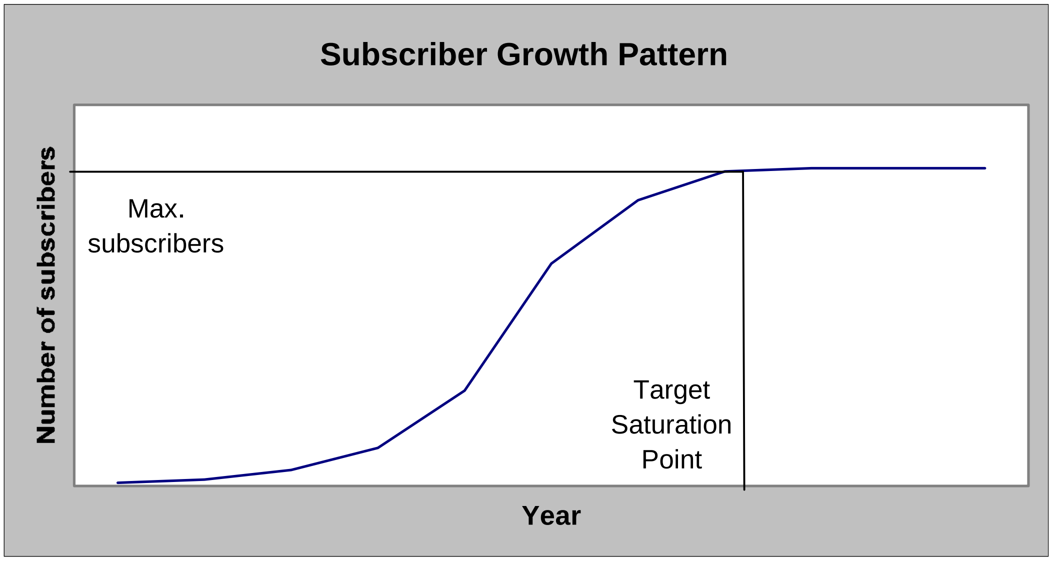
5.5 Basic model assumptions

5.5.1 Market assumptions

The main market assumptions involved electronic equipment prices that were assumed to drop at 10% annually[64], and subscriber growth. The subscriber growth trend was assumed to be an S curve (see figure 5.3) in which a few subscribers take up the service in the beginning, with a period of rapid (exponential) growth until the saturation points of 40% in urban areas and 10% in rural areas are attained. It is this saturation points that were varied in the sensitivity analyses that was carried out, while retaining the same growth pattern.

Figure 5.3 the modeled subscriber growth pattern

[64] Assumption based on interviews of industry experts.



5.5.2 Technical assumptions

For both GSM and CDMA:

- A typical 3-sector cell[65] was assumed, with a maximum of 6 transmitters in each sector. The number of transmitters per sector depends on the number of subscribers. As the subscriber base grows, additional transmitters are deployed to accommodate them up to a maximum of 6 per sector.

- Many of the capital costs are directly proportional to the number of subscribers. One critical cost - the switch, however, handles numerous cell sites simultaneously and is constrained by a minimum subscriber capacity. For the networks modeled here, the switch has a capacity of 2500 Erlangs[66] and typically operates at a maximum 80% full load capacity.

- The base station controller was assumed to have a total capacity of 512 transmitters.

[65] For further reading on cell sectorization, see [Harte, Levine and Livingston, 1999].
[66] An Erlang is a voice traffic unit defined as one communication channel being used continuously for one hour. Thus four consecutive conversations of 15 minutes each are equivalent to six consecutive

- A capacity of 0.069 Erlangs per subscriber[67] was assumed. Table 5.3 illustrates the calculations for maximum subscriber capacity for both GSM and CDMA.

5.5.2.1 GSM

Each transmitter in a GSM cell site provides an effective number of 7.5 voice channels[68]. At 6 transmitters per sector, this implies (7.5x6=) 45 voice channels per sector. From the Erlang B tables (assuming full availability and a probability of failed communication attempts of 0.01, i.e. 1% blocking) 45 voice channels provide 33.43 Erlangs of capacity. Thus the capacity of the GSM cell site is 33.43 Erlangs per sector or (33.43x3=) 100 Erlangs per cell site. The 2500 Erlang switch can therefore serve (2500/100=) 25 cell sites nominally. As the switch typically operates at a maximum of 80% full load capacity, it can realistically only handle up to a maximum of (80% of 25=) 20 cell sites.

For the urban case, the cell coverage area was assumed to be 18 square kilometers, while for the rural case it was assumed to be 1455 square kilometers[69].

5.5.2.2 CDMA

In the case of a CDMA cell site, each transmitter provides an effective number of 12 voice channels[70]. At 6 transmitters per sector, this implies (12x6=) 72 voice channels per sector. From the Erlang B tables (again assuming full availability and 1% blocking) 72 voice channels provide 58 Erlangs of capacity. Thus the capacity of the CDMA cell site is 58 Erlangs per sector or (58x3=) 174 Erlangs per cell site. The 2500 Erlang switch can therefore serve a maximum of (2500/174=) 14 cell sites nominally and (80% of 14=) 11 cell sites.

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conversations of 10 minutes each and are equal to one Erlang. Erlang Tables can be found in [Freeman, 1985].

[67] The same capacity per subscriber was used as was used in, [Economic Report, PRTM, 1999].

[68] The nominal number of voice channels per transmitter/radio is 8. However, as some bandwidth is used for control purposes, the actual number of channels drops to about 7.5.

[69] Literature review of (1) [Economic Report, PRTM, 1999] and (2) [Webb, 1998].

[70] 12 voice channels per transmitter [Webb, 1998] was the most conservative estimate available. A Qualcomm report [Economic Report, PRTM, 1999] uses a figure of 24 voice channels per transmitter.

For the urban case, the cell coverage area was assumed to be 37 square kilometers, while for the rural case it was assumed to be 2953 square kilometers[71].

5.5.2.3 GSM + GPRS

Most of the assumptions made for the GPRS installation were the same as those for GSM since GPRS systems will be plugged onto existing GSM systems. In addition it was assumed that: one GPRS backbone is needed for the urban location and one for the rural location; two BTS cell sites per BSC; and each GPRS backbone is connected to 10 other backbones.

Table 5.3 Cell capacity calculations

Measurement	***CDMA***	***GSM***
Carrier Bandwidth	1.25 MHz	200 KHz (0.2 MHz)
Maximum Number of Carriers	6	6
Voice Channels/Transmitter	12	7.5
Sectors/Cell	3	3
Voice Channels/Sector	6x12 = 72	6x4.5 = 45
Erlangs/Sector	58	33.4
Erlangs/Cell	58x3 = 174	33.4x3 = 100
Maximum Simultaneous Calls/Cell	72x3 = 216	45x3 = 135
Maximum Subscribers/Cell	174/0.069 = 2522	100/0.069 = 1450

Thus the baseline or reference cell capacity used in the model was 1450 subscribers per cell for GSM and 2522 for CDMA. In the event, the resultant CDMA:GSM capacity ratio of 1.75 was very conservative. Subsequent sensitivity analyses obtained model results using higher capacity ratios.[72]

5.6 Methodology

The principal direct modeling goal was to come up with the annual cost per subscriber for an operator to deploy a wireless local loop network and operate it over a period of ten years.

[71] Ibid., 69.
[72] See appendix 2 for spreadsheet of model.

The model focused on the network components of a wireless network. Subscriber capital costs were not modeled:

- As they are insignificant when contrasted to the rest of the network which bears the overwhelming cost burden of a cellular deployment; and

- Because the model sought to cater for all categories of network operators including those who do not assume responsibility for the subscriber station costs. Moreover, in a fixed wireless deployment, the lack of mobility functionality greatly reduces the complexity of the subscriber station, reducing the cost of the equipment and rendering it even more insignificant.

It was very difficult to obtain accurate cost figures for any of the technological architectures. The high level of competitiveness and uncertainty in the industry has heightened the need for discretion and very secretive handling of such sensitive data as network deployment costs. Furthermore, most initial network installation costs are negotiated and depend on location, negotiation prowess of parties (vendors versus operators), type of relationship between vendor and operator (new, old relationship, etc.). Ultimately, it was possible to obtain reasonably accurate component-based costs for GSM network equipment from various corroborative sources[73]. CDMA network costs proved more difficult to ascertain. However, after a review of various industry sources including the Qualcomm corporation's economic feasibility reports and interviews with neutral third party sources[74], it was possible to come up with CDMA network electronic equipment costs. For generalized operating costs, which would include:- network maintenance; interconnection charges (access to the PSTN), salaries, buildings, insurance, customer service, etc, estimates were obtained from various industry experts and literature sources[75].

[73] Telephone conference calls and e-mail contact with Randall Oster of Media One, Mangal Manish of Sprint PCS and Jim O'Connor of Media One International.
[74] Ibid., 74
[75] Conversations with Randall Oster of Media One, Jim O'Connor of MediaOne International, Ozlem Uzuner, Gwenaelle Jeunhomme, and Mark Lee all of the Massachusetts Institute of Technology.

The costs of the major network components were listed on a spreadsheet. For each area - Mombasa and Kirinyaga, the number of cell sites required per architecture was calculated on the spreadsheet. Given the number of cell sites required, the fixed capital costs for each network as well as the variable fixed costs per cell site were then worked out on the spreadsheet for each technology. The annualized capital costs per subscriber in each of the given areas were then obtained. These (capital costs) were added to the operating costs (discounted at 10 percent - the assumed trend rate for annual drops in prices of electronic equipment) to give the total annual cost per subscriber that an operator would have to incur in deploying and operating a network for ten years. In order to obtain a more thorough analysis, various sensitivity analyses were conducted, the details of which are provided in the next chapter.

Chapter Six

Model Results and Analysis

6.1 Introduction

This chapter presents the modeling results in the form of costs incurred by the infrastructure provider per subscriber in deploying the network. Results from sensitivity analyses varying those parameters of the model, which present the most uncertainty, are also analyzed. The parameters varied include operating costs, target saturation penetration levels, CDMA/GSM capacity ratios, fixed configuration switching costs and GPRS software costs.

6.2 The Baseline Results

Baseline assumptions for the major parameter values are:

- Urban penetration - 40%
- Rural penetration - 10%
- Operating costs - US$ 600 per annum per subscriber (before discounting)
- CDMA:GSM capacity ratio - 1.75 (this factor only affected the CDMA scenario)

The bottom line is that IS-95/CDMAONE (CDMA) is more flexible than GSM in terms of offering more opportunities for future data upgrades. CDMAONE networks are marginally less expensive to set up and share the same fundamental technology - CDMA - with the next (third) generation of cellular networks.

Table 6.1 Estimated annual costs per subscriber for Kenya over a ten-year period (US$)

a). Mombasa (urban)

Second Generation Costs

	GSM Fixed	CDMA Fixed
Annual Capital Costs (US$)	60	41
Annual Operating Costs (US$)	305	305
Software licensing (US$)	3	3
Total Costs (10 years)	**367**	**349**
Number of Cells	42	24
Data speed	>> 14.4 Kbps	>> 14 Kbps
Coverage area - Sq. kilometers	18	37

+

Incremental Transitional Generation Costs

	Modeled Incremental GPRS Costs	Estimated CDMA IS-95C Budget
Annual Capital Costs (US$)	17	
Annual Operating Costs (US$)	51	
Total Costs (10 years)	**68**	**87**
Number of Cells	42	24
Data speed	>>115 Kbps	>>144 Kbps
Coverage area - Sq. kilometers	18	37

=

Total Transitional Generation Deployment Costs

	GSM/GPRS	CDMA IS-95C Budget
Annual Capital Costs (US$)	77	
Annual Operating Costs (US$)	356	
Software licensing (US$)	3	
Grand Total (US$)	**435**	**435**

b). Kirinyaga (rural)

Second Generation Costs

	GSM Fixed	CDMA Fixed
Annual Capital Costs (US$)	250	244
Annual Operating Costs (US$)	305	305
Software licensing (US$)	3	3
Total Costs (10 years)	**557**	**551**
Number of Cells	4	3
Data speed	>> 14.4 Kbps	>> 14 Kbps
Coverage area - Sq. kilometers	1455	2953

+

Incremental Transitional Generation Costs

	Modeled Incremental GPRS Costs	Estimated CDMA IS-95C Budget
Annual Capital Costs (US$)	160	
Annual Operating Costs (US$)	51	
Total Costs (10 years)	**211**	**217**
Number of Cells	4	3
Data speed	>> 14.4 Kbps	>> 144 Kbps
Coverage area - Sq. kilometers	1455	2953

=

Total Transitional Generation Deployment Costs

	GSM/GPRS	CDMA IS-95C Budget
Annual Capital Costs (US$)	410	
Annual Operating Costs (US$)	356	
Software licensing (US$)	3	
Grand Total (US$)	**768**	**768**

Table 6.1 displays the results of the modeling using the baseline parameter values. The primary finding was that there is no significant difference in the second generation costs of implementing any of the modeled scenarios in a given area, i.e. there is not much difference in cost between deploying a GSM or a CDMA network in Mombasa, and similarly in Kirinyaga. In both cases, the cost of deploying a CDMA network proved to be marginally lower than that of deploying a GSM network. Thus, for a given set of demographics, it is possible to base decisions on the suitability of particular second generation cellular technologies (GSM or CDMA) purely on two primary factors:

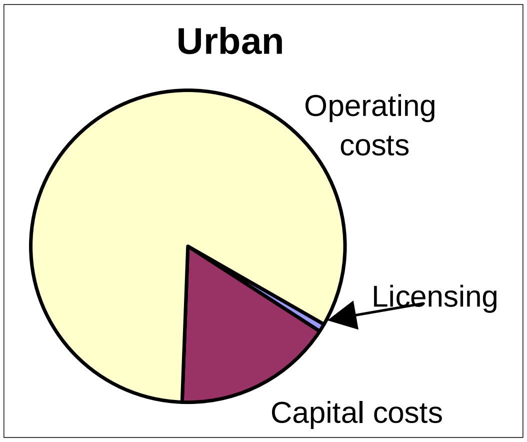
- Their present and future functional capabilities; and
- The projected costs of migrating to transitional and third generation technologies.

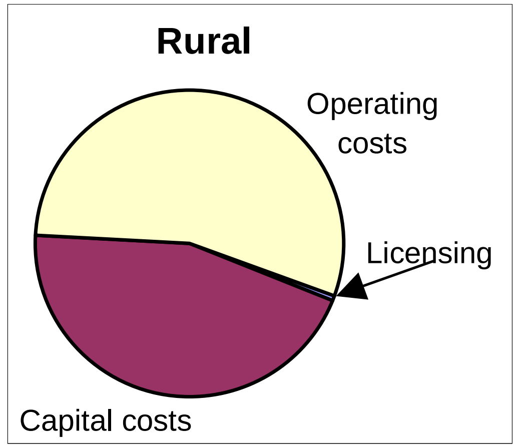
The current costs of deploying these second generation technologies should play only a minor role in determining which should be the technology of choice.

Over the past few years, CDMA electronic components have become nearly cost competitive with GSM components as CDMA begins to benefit from the greater economies of scale arising from its increasing deployment. Despite the slightly higher unit costs of some CDMA electronics, it was not surprising that CDMA deployment costs were actually marginally lower than for GSM. Higher cell capacity allows CDMA based networks to use fewer cells than GSM for the same number of subscribers, resulting in substantial capital cost savings for CDMA operators.

However, this capital cost difference is rendered insignificant since over the long term (ten years in this model), operating costs dominate capital costs (see figure 6.1). This is particularly true in urban areas where the subscriber base is huge and fixed capital costs are distributed over a large number of people. In rural areas, often, major equipment components are heavily underutilized, giving rise to much higher capital costs per subscriber. Even in rural areas, however, the CDMA cost advantage is still insignificant.

Figure 6.1 Annual cost distribution per subscriber - both GSM and CDMA





As figure 6.1 also illustrates, across demographic profiles, the differences in capital costs are significant - with rural capital costs per subscriber being much higher than urban costs. This is principally due to the much lower subscriber base in rural areas. As outlined in chapter five, two factors, all of which were factored onto the model, account for this:

- Rural areas are much more sparsely populated and have larger households. Thus, not only is the population density lower in rural areas, but for a given population density, larger households means fewer households which in turn lowers the potential number of subscribers (see table 5.1 in chapter five).

- Lower income levels and purchasing power in rural areas imply lower target penetration ratios

The addition of GPRS functionality onto GSM increases the annual capital costs per subscriber appreciably but by no means prohibitively, except in the rural area case. In the urban case, total annual cost per subscriber increases by 16%, in the rural case it increases by 27% (figure 6.2).

Figure 6.2 Projected total annual costs per subscriber for transitional generation technologies over a period of ten years

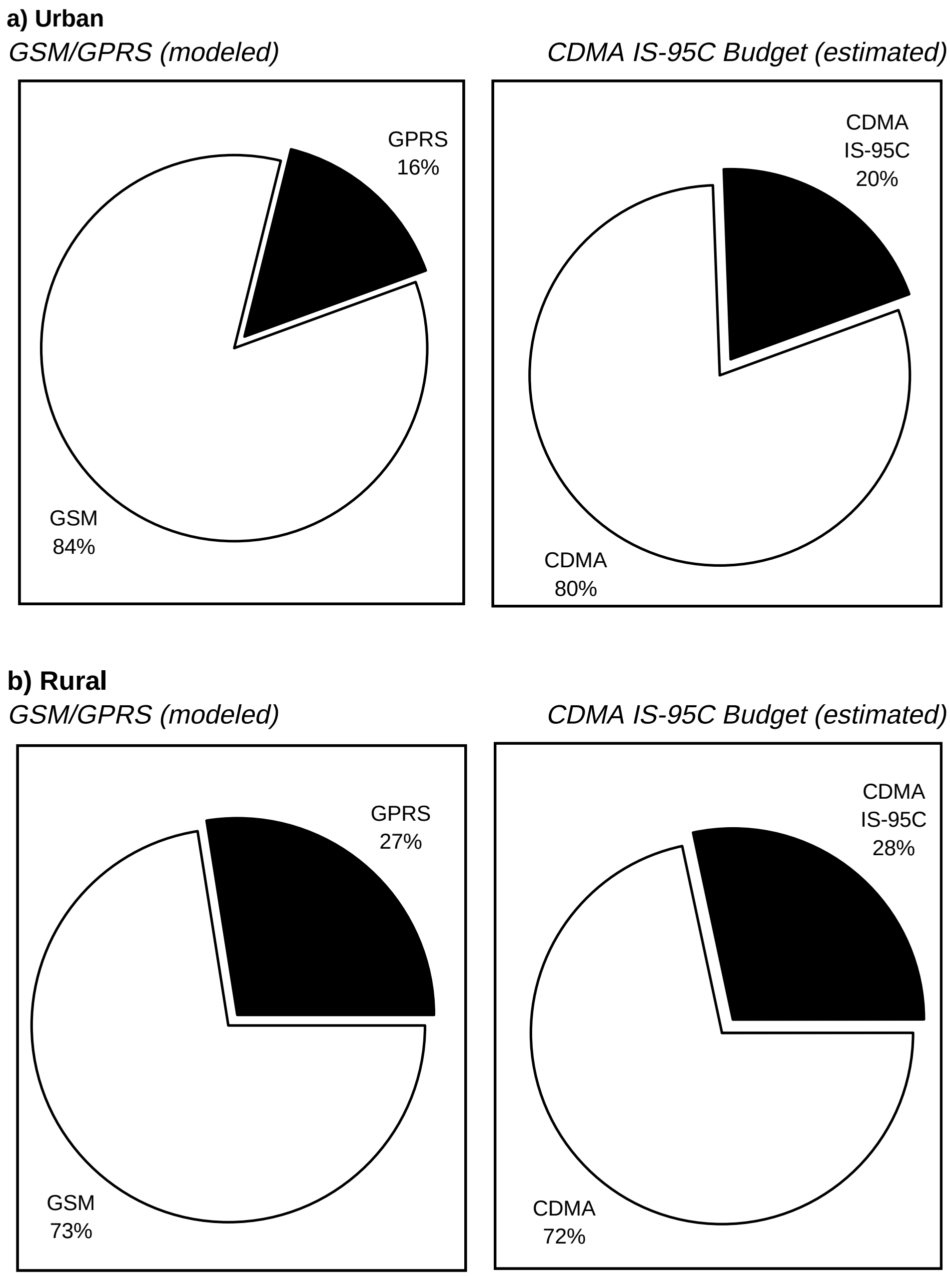


Figure 6.2 also illustrates the budget constraints that would face operators hoping to deploy transitional generation CDMA IS-95C and to compete with GSM/GPRS networks. In the urban location where annual incremental GPRS costs amount to US$68 per subscriber, for instance, the CDMA IS-95C operator could incur annual incremental

costs of up to US$87 per subscriber and still be cost competitive with the GSM/GPRS operator.

6.3 Sensitivity Analyses

6.3.1 CDMA:GSM Capacity ratio

Due to the highly competitive and dynamic nature of the wireless communications industry, as well as the widely different impacts that various topographical and demographic environments have on similar systems, technical performance parameters such as cell site capacity and coverage area are highly variable. One of CDMA's most advertised benefits is its ability to handle much larger capacity cell sites than any of the other existing technologies. Figures given for the capacity advantage of CDMA over GSM range from approximately 1.75 to 5 times the number of subscribers in a GSM cell site in a CDMA one.

For this modeling exercise, the very conservative estimate of 1.75 times GSM capacity for a CDMA cell was used. However, sensitivity analyses were conducted to test the difference in results with higher capacity ratios at different penetration ratios. The unsurprising results, depicted in figure 6.3, show that CDMA's cost advantage increases the larger its capacity advantage is assumed to be, especially in urban areas.

Target saturation penetration ratios on both sides of the baseline case (40% urban and 10% rural) were tested. For all the three penetration levels, the capital costs diverge as expected, since the higher the CDMA capacity the lower the capital costs associated with CDMA deployment would be expected to be. Furthermore, at all the penetration levels, the urban capital costs diverge much more than the rural ones, indicating that the larger subscriber base in the urban area accentuates the CDMA capacity advantage. For the baseline case, the difference in capital costs between the urban and rural areas is in the order of 500 percent.

Also - again as would be expected, the higher the penetration ratio the lower the capital costs and the greater the CDMA capacity-driven cost savings. In fact, at very low saturation penetration levels (2%) in the rural area, capital costs are prohibitively high (in excess of US$1000 annually per subscriber) and there is absolutely no cost distinction between GSM and CDMA. This is because at these rates, subscriber demand is easily and quickly met long before any of the cell site capacity limitations of either GSM or CDMA are attained, denying CDMA its advantage.

Figure 6.3 Effect of CDMA:GSM ratio on both urban and rural annual capital costs per subscriber

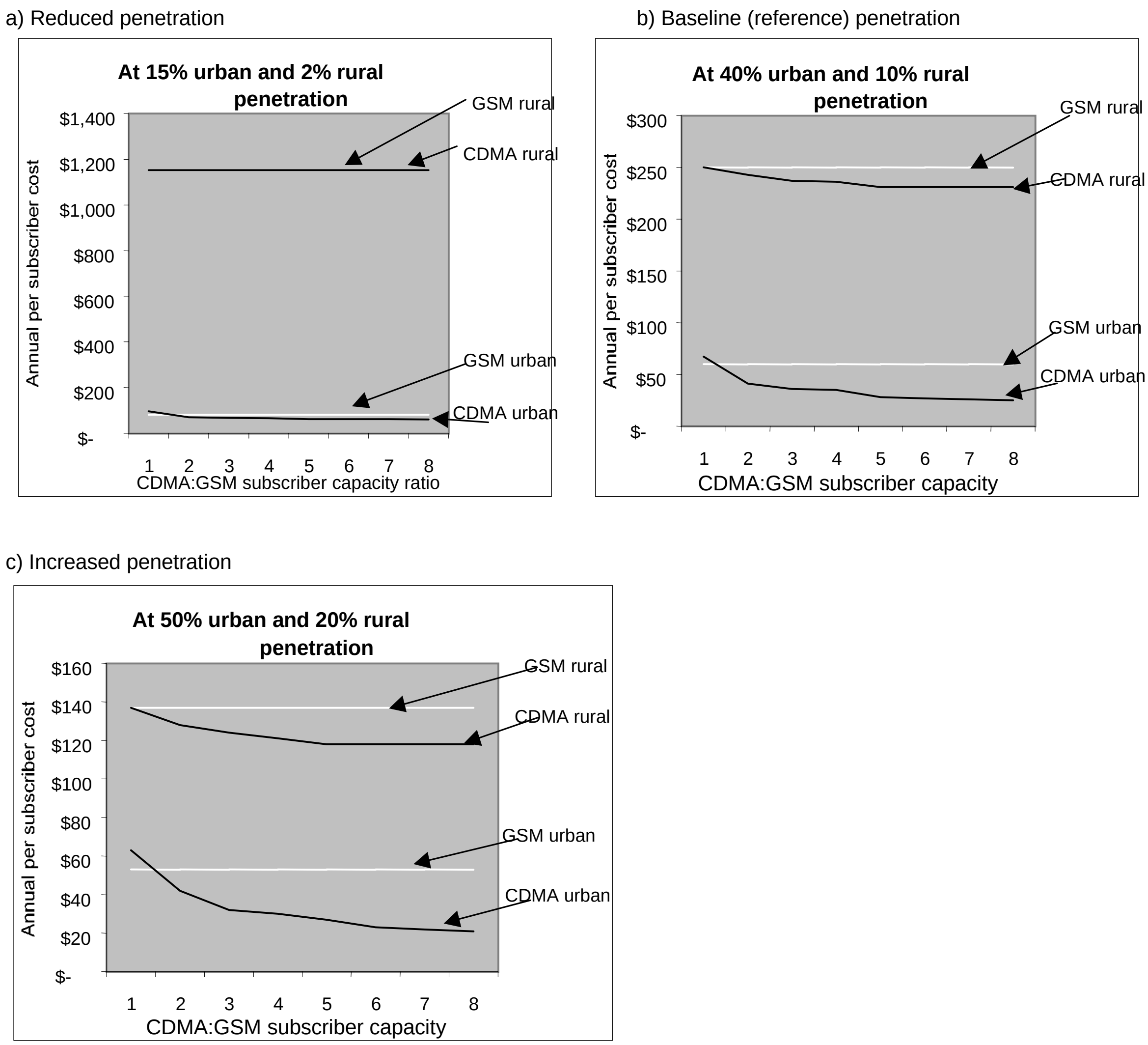


Figure 6.3 also shows that at CDMA: GSM capacity ratios below 1.25 and 1.5 for the rural and urban cases respectively, GSM capital costs are actually lower than those of

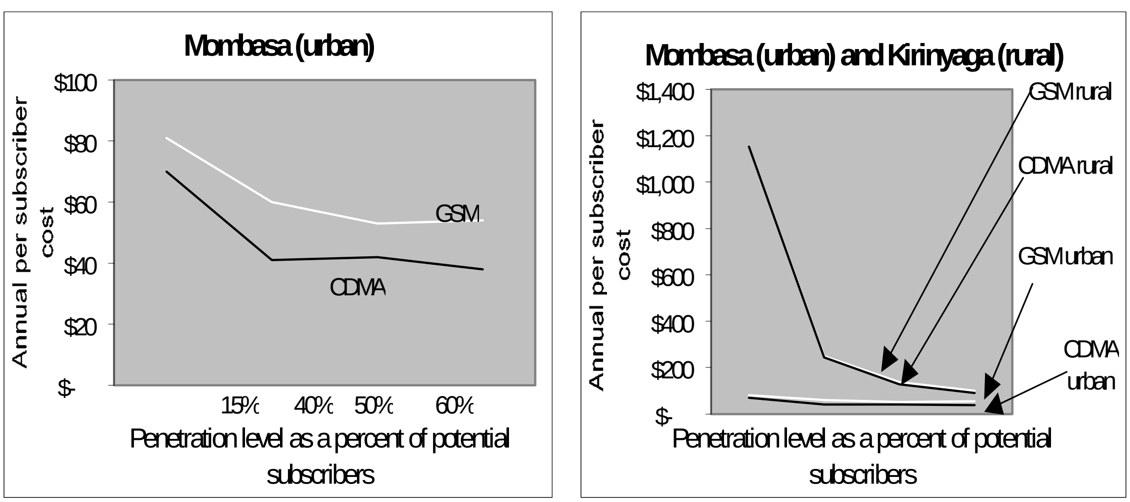
CDMA. These ratios, however are below the most conservative independent industry estimates of 1.75. As the capacity ratio increases, the divergence reduces, converging towards an absolute cost advantage. This however is heavily dependent on the size of the subscriber base in addition to the penetration ratio. These two facts combined suggest that in an area with a very high subscriber density, a high CDMA:GSM ratio would mean substantial savings in capital costs.

Additionally, with a CDMA:GSM capacity ratio of 5, the budget constraints for prospective deployment of the transitional generation technology - CDMA IS-95C - relax. At that capacity ratio, it is possible for CDMA operators to upgrade their urban networks to IS-95C and incur costs of up to US$101 (up from US$87), while remaining cost competitive with GSM/GPRS operators.

6.3.2 Saturation penetration levels

As the capacity sensitivity analysis in the previous section showed, increased penetration ratios lead to a drop in capital costs. Figure 6.4 illustrates that the drop in capital costs is much sharper for rural than it is for urban deployments and slightly sharper for CDMA than it is for GSM.

Figure 6.4 Effect of saturation penetration levels on annual capital costs per subscriber

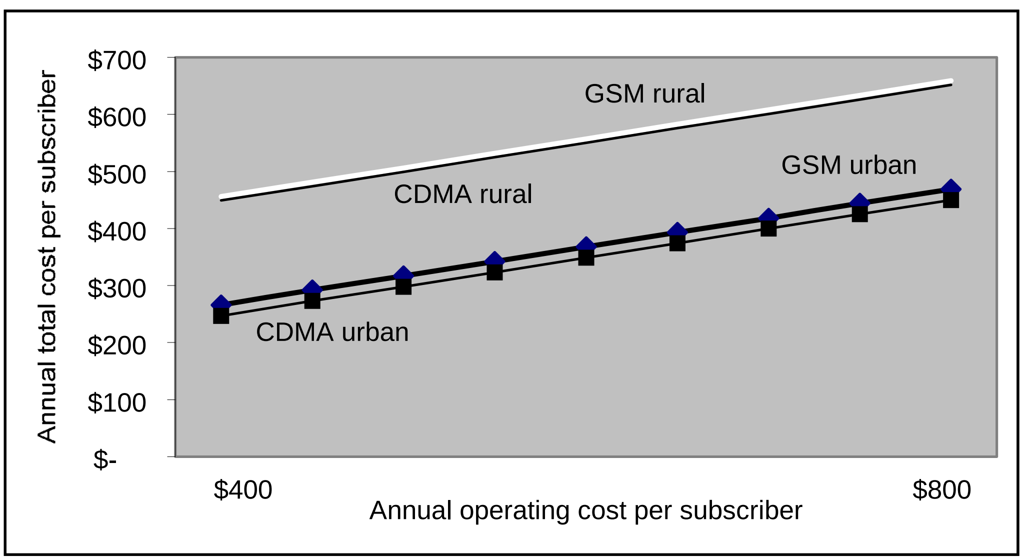


An interesting turn occurs in the urban CDMA curve in between the 40 and 50 percent penetration levels. The capital costs actually rise even as the number of subscribers grows. This rise in capital cost is as a result of the increased subscriber base necessitating purchase of an additional base station controller system (BSC). The cost per subscriber attributable to this new BSC is very high in the beginning because it is highly under-utilized. As the subscriber base and number of cell sites grows, however, economies of scale set in and the BSC's cost is distributed among a greater number of subscribers. As figure 6.4 further illustrates, this results in the capital costs resuming their downward trend after the 50 percent subscriber level, even as the GSM curve begins to inch upwards for the same reason.

6.3.3 Operating costs

The results generally indicate that operating costs dominate capital costs. Figure 6.5, while making a trivial point - that high operating costs result in higher total annual costs per subscriber, nevertheless illustrates the profundity of the impact that operating costs have on per subscriber costs.

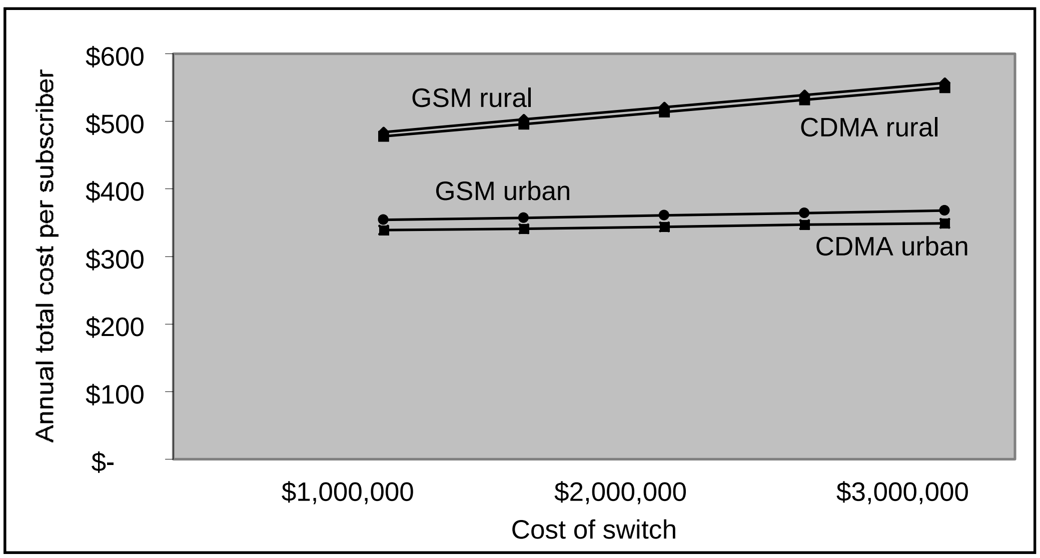
Figure 6.5 Effect of operating costs on total annual costs per subscriber



6.3.4 Switching center costs

The switching center costs applied to the model - US$ 3 million for a 2500 Erlang switch actually represent the cost of a mobile switching center (MSC). In an actual fixed wireless deployment, a switch with reduced mobility functionality would be deployed. Such a switch would not need to monitor mobile subscribers and would be less complex than a mobile switch. Presumably, it would consequently be less expensive. Figure 6.6 below illustrates the effect that lower switching costs would have on the annual total cost per subscriber. For the urban area, the annual cost per subscriber does not change appreciably, while for the rural district it is appreciable but not very significant.

Figure 6.6 Effect of switching costs on annual costs per subscriber

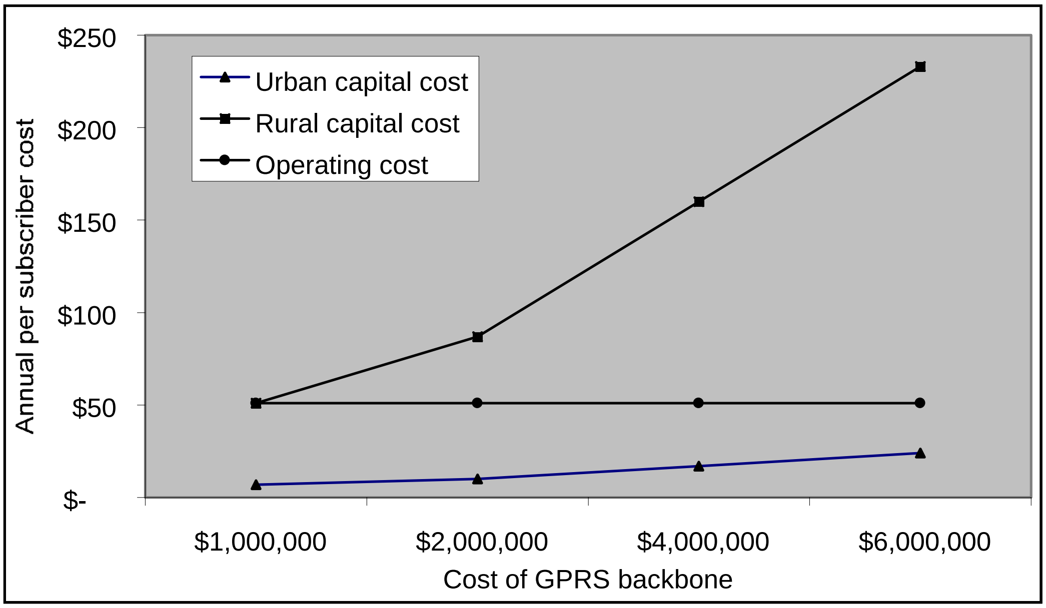


6.3.5 Incremental GPRS costs

GPRS systems are only just about to be launched commercially and it is not clear how GPRS services will be priced. As is to be expected with any new technology, the vendors have been very secretive about their cost structures. Nevertheless, it is clear that the single most significant cost will be the GPRS backbone, for which reason a sensitivity analysis of different backbone costs was conducted.

Figure 6.7 shows the various incremental GPRS per subscriber costs (which would be added to GSM network costs) at different backbone costs. In the urban area, the differences are insignificant, while in the rural area the impact is substantial. This implies that the cost per subscriber cost would barely be affected by varying backbone costs for a network with a huge subscriber base.

Figure 6.7 Effect of GPRS backbone cost on incremental GPRS costs



6.3.6 Best case/worst case scenario

Finally, a sensitivity analysis was conducted to discover and compare the best and worst case scenarios.

For the best case scenario, the parameters as well as the most variable costs were set as follows:

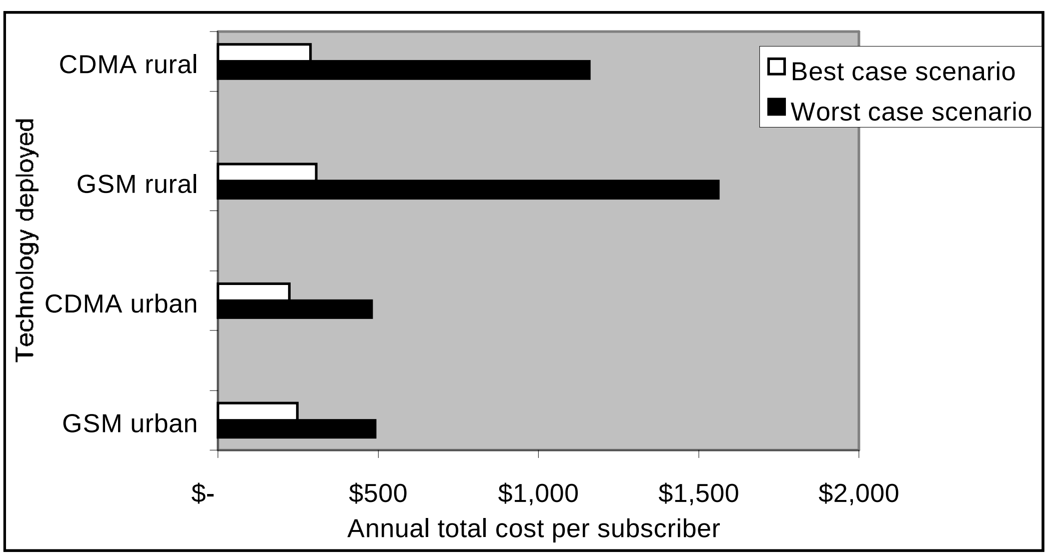
- Urban penetration - 50%
- Rural penetration - 20%

- Switching center costs - US$ 1,000,000
- Operating costs - US$ 400 per annum per subscriber (before discounting)
- CDMA:GSM capacity ratio - 5 (this factor only affected the CDMA scenario)

For the worst case scenario, the parameters and costs were set as follows:

- Urban penetration - 15%
- Rural penetration - 2%
- Switching costs - US$ 3,000,000
- Operating costs - US$ 800 per annum per subscriber (before discounting)
- CDMA:GSM capacity ratio - 1.75 (again, this factor only affected the CDMA scenario)

Figure 6.8 Range of total cost per subscriber at the most optimistic and most pessimistic estimates



The results obtained were as illustrated in figure 6.8 and depicted in table 6.2. For both GSM and CDMA, the greatest variation was to be found in the rural district. In that setting, the variation for GSM was greater than it was for CDMA. In the urban area, the situation was reversed and markedly better (see table 6.2a). However, comparison of the scenarios across technologies reveals that in each case, CDMA operators are at least marginally better off than GSM operators are. Interestingly, the variation across technologies is significantly greater for the worst case scenario in the rural area, while it is significantly greater for the best case scenario in the urban area (see table 6.2b).

Table 6.2 Best and worst case scenario comparisons

a) Variations across best and worst case scenarios within same geographical area

	GSM	*CDMA*
Rural variation (across scenarios)	409% *(Best case over worst case)*	302% *(Best case over worst case)*
Urban variation (across scenarios)	98% *(Best case over worst case)*	116% *(Best case over worst case)*

b) Variations across technologies within same geographical area

			Variation across technologies
	GSM	*CDMA*	
Worst case scenario (rural)	US$1561	US$1158	34% *(GSM more costly than CDMA)*
Best case scenario (rural)	US$307	US$288	7% *(GSM more costly than CDMA)*
Worst case scenario (urban)	US$490	US$479	2% *(GSM more costly than CDMA)*
Best case scenario (urban)	US$248	US$222	12% *(GSM more costly than CDMA)*

Three major conclusions may be drawn from this particular sensitivity analysis:

- In absolute terms, CDMA is always less costly to deploy per subscriber.
- In the serendipitous case where wireless communications are universally adopted by a majority of the population in an urban or similarly densely populated setting (as in the urban best case scenario), the cost advantages of CDMA over GSM are accentuated.
- In the unfortunate circumstance that the uptake of wireless communications is low in an already sparsely populated area such as a rural district (as in the rural worst case scenario), the cost advantages of CDMA over GSM are again heavily accentuated.

6.4 Results Summary

It must be reiterated that the capacity assumptions made for CDMA in this model were only the most conservative of the many estimates available. Thus operators who firmly believe that the capacity ratio should be higher than the reference 1.75 utilized in the model may want to pay close attention to the sensitivity analysis on capacity - particularly figure 5.3b which represents the analysis at the reference penetration levels used throughout the model.

The following is a summary of the primary results:

- For the baseline case, there is no significant difference in costs of implementing second generation component of any of the modeled scenarios, but CDMA is always cheaper to deploy in absolute terms.

    - Although still slightly more expensive than components of the more widely deployed GSM, CDMA component costs have continued to drop with CDMA's increasing deployment;

    - Higher cell capacity allows CDMA based networks to use fewer cells than GSM based networks for the same number of subscribers, resulting in capital cost savings for CDMA operators. CDMA's cost advantages increase the larger its capacity advantage is assumed to be, especially in urban areas, where the larger subscriber base accentuates the CDMA capacity advantage;

    - In the long term, operating costs dominate capital costs, resulting in the CDMA cost advantage over GSM diminishing over the life of the networks deployment;

- Under baseline[76] conditions, prospective deployments of the transitional generation CDMA technology - IS-95C - could incur annual incremental costs of up to US$87 per subscriber (in the urban case) and still be cost competitive with GSM/GPRS networks. When the CDMA:GSM capacity ratio is increased to 5, the CDMA IS-95 budget constraints relax further to US$101, while remaining cost competitive.

Indeed, the wireless cellular industry continues to be a very dynamic industry and many questions remain unanswered. For the current (second) generation of technologies, this

[76] Baseline parameter values are: 40% target penetration and CDMA:GSM capacity ratio of 1.75.

model determines only marginal cost savings for CDMA deployments over GSM. For the upcoming transitional generation technologies, the GPRS US$87-101 cost range should serve as a benchmark for prospective CDMA IS-95C deployment.

For the next generation (3G) of technologies, however the case is not so clear-cut. Almost all key players (including GSM equipment vendors) appear set to move into the CDMA world. The only major group still holding out for a TDMA version of 3G is the American Universal Wireless Communications (UWC) group. And even they are beginning to develop "cold feet" for 3G, recently suggesting that they might decide to implement EDGE - most definitely a transitional technology - as their 3G standard[77]. The Datacomm Research Company predicts that CDMA will overtake GSM in the global market place[78]. Operators of all types of technologies stand to incur large costs in shifting from second to third generation technologies, but GSM operators stand to incur greater costs than CDMA operators, since there is absolutely no compatibility between GSM and WCDMA - the 3G CDMA network to which they hope to upgrade. All base stations and switching systems will have to be replaced. CDMA operators on the other hand will benefit from several areas of compatibility between existing (CDMAONE) and 3G (CDMA2000) networks.

Taking all possible future developments into consideration, particularly 3G, CDMA stands out as the more flexible of the two systems. CDMA operators are likely to incur much lower migration costs than GSM operators.

[77] See [Gohring, 1999].
[78] See ["New Study Predicts CDMA Will Overtake GSM In Global Market Race", 1999].

Chapter Seven

Conclusions and Recommendations

7.1 General conclusions

Data is as much a growing component of communications in developing countries as it is worldwide. Consequently, developing regions will eventually have to upgrade their infrastructure to accommodate data communications. For these poorer regions, wireless networks are a very viable option to conventional wired plant, as they are relatively inexpensive to install and maintain and are quickly deployable. The cost model demonstrates that it would be prudent to incorporate data capabilities in any new installations, and to adopt technology that will be able to easily support the shift to the next (third) generation of wireless networks. The pace at which this is done would depend on the specific circumstances of a particular country. In developing countries, but more so in African countries, of which Kenya is a typical case, the model's findings are two-tier:

- First, cellular technologies afford the best opportunity of all available wireless technologies for communications infrastructure deployment in a country like Kenya; and

- Second, of all cellular technologies, fixed CDMA networks would be the most technically and economically suitable.

7.2 Operational recommendations

Beyond the mere fact that there will surely be an increased demand for data communications even in less developed countries like Kenya, it is not clear how much that demand will be. It is thus not possible to declare with certainty how much bandwidth or what type of infrastructure will eventually be deemed necessary to meet that demand or what "eventually" actually means. Whatever the case, CDMA is the technology with more avenues for compatibility with future upgrades and therefore the most flexible. The results of the modeling show that this flexibility of CDMA does not carries no burden of cost whatsoever.

Even at the most conservative estimates of CDMA's capacity and spectral efficiency, CDMA networks are at least as cost efficient as GSM networks. Furthermore, as CDMA networks continue to gain worldwide acceptance, production economies of scale set in for their components, resulting in CDMA component costs dropping faster than GSM component costs. Similar studies, albeit based in the developed world, corroborate the findings of this report with more emphatic assertions of the fact that CDMA provides the lowest cost per subscriber of all cellular technologies[79].

More important, however, with all the uncertainty surrounding future architectural standards, CDMA promises the least expensive migration to third generation (3G) technologies. For the transitional technologies which offer data speeds of up to 384 Kbps, neither GSM nor CDMA based technologies appear to offer any significant advantages. Thus whether one determines future data requirements for Kenya to be in the hundreds of Kbps magnitude (which speeds would be met by transitional generation technologies) or in the 3G realm of 2Mbps, no advantage whatsoever can be gleaned from picking GSM over CDMA. However, should data requirements ever reach the 3G range, then CDMA would be a much safer bet.

For instance, for data speeds of up to 384 Kbps (certainly up to 115 Kbps), the GSM based transitional generation technologies - GPRS and EDGE - appear to be cost effective solutions. Although some limited amounts of hardware will be necessary, upgrades from GSM to GPRS will be largely software based and the same is likely to be true for GPRS to EDGE upgrades. However, the same is also true for CDMA based transitional generation technologies - IS-95C and HDR. Thus if Kenya were to develop a peak data

[79] Reported in [Mcgarty, 1996].

demand of up to 384 Kbps over the next decade, both GSM and CDMA based systems would be equally likely to provide cost effective solutions in their transitional technologies.

But what if Kenya should find that within the next decade, demand for data speeds of up to 2Mbps (third generation realm) materializes? The upgrades from GSM or even GPRS/EDGE to WCDMA (GSM's version of 3G) will most certainly require replacements of BSC and BTS electronics as well as switching systems. CDMAONE's upgrade to CDMA2000 while also requiring certain electronic upgrades appears to offer greater opportunities for cost savings based on the backward compatibility of CDMA2000 to CDMAONE. In this case, operators of CDMA networks would have a definite advantage.

Any operator seeking to deploy a new network in Kenya would be remiss not to give both data demand scenarios serious consideration. And having done that, the prudent operator would be hard pressed to justify a decision to deploy a GSM based network, which while hardly equally cost effective with CDMA in the first demand scenario would be at a definite cost disadvantage with respect to CDMA in the second demand scenario.

CDMA's most often cited and only disadvantage is that it is not as universally deployed as GSM. The argument advanced by proponents of this line of thought is that CDMA will never really take hold worldwide and therefore mobility will always be a problem for CDMA networks and components will always be expensive. The terrific rate at which the growth of CDMA networks continues to progress belies their dismal prognosis. As stated elsewhere in this chapter, CDMA costs are already dropping faster than GSM costs. Furthermore, in making the most operationally optimum choice of technology, sight must not be lost of the larger goals. The Kenyan priority, unlike that of the developed world is not mobility but universal access. Moreover, it is almost certain that the next generation subscriber stations will be multimodal and thus no particular technology will have a roaming advantage.

Finally, as is the case for most developing countries, most of Kenya can be treated as a Greenfield site and as such the opportunity to take off on the right footing should not be lost. Many countries - including the US - have found themselves trapped with archaic technologies because of the heavy investment they have had in them. One of the reasons why GSM did not catch on in the US was the sunk costs already incurred in the form of extensive investments in an analogue AMPS network. In developing nations like Kenya there are no such sunken investments to consider. Indeed the crux of the Kenyan problem is that the exact opposite is true - too few sunk costs in communications infrastructure. Kenya and other developing countries should borrow a leaf from South Korea, which a few years ago boldly decided to deploy CDMA as the mobile cellular network of choice. The Koreans were successful even though their priority was mobility. Today, Kenya faces a much better set of circumstances. The priority is universal access and not mobility, CDMA is less expensive, better understood and much more widely deployed. True, a certain amount of uncertainty remains on many fronts - technology, standards, future data needs, etc. A careful consideration of all the available facts, however, suggests that a choice could be made out of prudence rather than a pure gamble on the future or simplistic adherence to tested but short-lived technology.

Thus, when decisions on which cellular technology to deploy are based on their present and future functional capabilities and on the projected costs of migrating to transitional and third generation technologies, CDMA is the prudent choice.

7.3 Policy recommendations

In laying out policy for wireless communications, much like in making operational technological choices, local priorities should prevail. Restating them again, these include:

- Universal service provision;
- Quick and inexpensive deployment of communications infrastructure;
- Incorporating data or at least providing for smooth data communications upgrades; and

- Fixed rather than mobile communications.

7.3.1 The reform process

To be sure, the on-going reform process is a positive step in Kenyan telecommunications. The articulated objectives are noble and much of the outlined implementation process sound. However, there remain areas that could benefit from further improvement. The process has not been as transparent as it should have been and announcements that should be released to the public have on several occasions been delayed to the benefit of those on the inside track.

In addition to the information asymmetry, the ministerial policies on the liberalization and privatization (particularly the latter) have been very vague. Three ingredients are lacking which are of vital necessity in the current reform process:

- Transparency;
- Predictability; and
- Reduced discretion on the part of key players.

Transparency is vital if the entire process is to win the confidence of the business community and the public at large, and can only be achieved if the government undertakes to keep the public informed at every stage. Predictability is crucial if investors - particularly foreign ones - are to deign to make any substantial investments. Obvious loopholes are bound to raise suspicions and erode investor confidence and should be eliminated. Predictability can also be achieved through the clear enumeration of powers amongst different telecommunications authorities. For example, rather than the vague dictate that "all carriers in the telecom sector must be 70% Kenyan, a policy that will be revised from time to time", a more specific time frame along with specific benchmarks with regard to this policy would boost investor confidence greatly. Vague policies and time frames leave too much discretion in the hands of the government and political officials who have little credibility with the business sector and the public at large. Without a thorough restructuring of the politics and structure of decision making both in the telecommunications sector as well as the political periphery, the articulated aims and objectives will be achieved only in part.

7.3.2 Inadequate reforms

Even on an apolitical basis, the pace envisaged for the reforms is unsatisfactory. With particular regard to wireless services, there is no lucid reason to allow privatized mobile cellular services, while delaying - for the foreseeable future - any private provision of fixed cellular services. The privatization of wireless local loop services should be de-linked from that of wire-based local loop. Insisting upon a concurrent timetable between the two completely negates the great benefits and savings in time and expense that wireless services bring over wire-based services.

The stipulation that the provision of local access service and local telephone exchanges will remain a monopoly of Telkom Kenya until "at least three years after the initial public offering"[80] of the company should be amended immediately. To begin with, it is unclear when this initial public offering will be, but more importantly, wireless local access should be treated separately from wireline. This should not constitute a huge shift in policy, since the government is already issuing a tender for a second mobile cellular company that is 50% privately owned. This will be a local access provider much like any other WLL service would be, the only difference being that in one case, the subscriber stations will be mobile, while in the other, it will be fixed.

More courageous reform action is also required in several other important areas, including:

- Allowing network operators (including wireless operators) to set up public telephone systems and sell lines to the public;
- Allowing private operation of exchanges;

[80] Ibid., 4.

- Tariff regulation under a competitive regime.

Many provisions in the new bills appear designed to provide Telkom Kenya with an extended period of exclusivity. This is entirely unnecessary and does nothing to further the overriding goal of ensuring universal service provision in the shortest time possible. Even as the complexities of infrastructure based competition are worked out - unbundling, interconnection agreements, collocation, etc - service based competition should be launched at the earliest possible opportunity. In particular, WLL competition should not present any problems and there is absolutely no reason to delay the licensing of private WLL operators. Studies show that competition in and of itself has a positive correlation to teledensity. Contrary to popular belief that competition puts penetration into lower-revenue areas at risk, most available data point to an increase in network penetration and service availability with competition. For instance, competition in cellular services which has been introduced more widely and for longer than competition in wireline services in developing countries clearly has led to much greater network penetration than monopolies in Asia and Latin America.[81]

Tariff regulation is unnecessary in the face of sufficient competition to allow market forces to determine pricing levels. The only exceptions would be:

- To prevent collusion;
- To eliminate any threats or acts of predatory pricing;
- In areas which are still under a monopoly provider; and
- In areas where competition is not sufficient to ensure acceptable levels of affordability.

7.3.3 Regional standardization

Spectrum allocation should be coordinated and standards setting harmonized on a intra-regional rather than a national basis. Specifically, Kenya should coordinate with the other member states of the newly rejuvenating East African Cooperation. Already, other types of governmental infrastructure building coordination are taking place among the regional body member nations. Several benefits would accrue from such a course of action including:

- Operators would have a larger potential subscriber base;
- Regional rather than national standards rationalization would provide better and increased economic opportunities for operators and hence hasten progress towards universal access through a much faster deployment of infrastructure by these private operators.

7.3.4 Related issues and policy

Rule of law and order, protection of property rights. Infrastructure investment (even wireless) is an expensive undertaking and investment protection as well as assurances of a continued enabling environment to allow operation is critical. In a comprehensive comparative study[82] of telecommunications regulation in Jamaica, the Philippines, Chile, Argentina and the United Kingdom, the following was ascertained to be crucial:

- Mechanisms to restrain arbitrary administrative action;
- Mechanisms to provide substantive restraints on the discretionary actions by the regulator;
- Formal or informal restraints on changing the regulatory system; and
- Institutions to enforce the restraints.

7.4 Conclusion

The research outlined in this report determined cellular technologies - specifically CDMA based networks - to be the most suitable wireless local loop solution for the specific

81 See [Petrazzini, 1996]
82 See [Levy and Spiller, 1996]

circumstances facing developing countries like Kenya today. Countries that have large rural populations, low communications infrastructure development, and very low per capita incomes. Many developing countries exhibit a profile similar to Kenya, particularly in sub-Saharan Africa, parts of Asia and parts of Latin America. In many of these regions policy reforms like those taking place in Kenya are under way at various stages. Thus many of the operational as well policy recommendations made with regard to Kenya would be highly applicable to those countries as well.

While the South Korean model in which the government imposed CDMA as the fundamental technology of choice is tempting, Kenya should take a different track. The Koreans have already proven that the technology is commercially very viable. It should be up to the market to see to it that the right technology choice is made for Kenya. Private operators should be able to competitively deploy the most optimum technology for the country, and indeed for the entire East African region. Forward looking operators would be well advised to give very serious consideration to CDMA.

While the Kenyan government should not impose a mandate on which technology option should be deployed, the onus is upon it to encourage the deployment of CDMA. CDMA promises to most efficiently fulfil the universal access goals of the government. Thus any government owned networks should, of necessity be CDMA based.

More fundamentally, however, the Kenya government should get rid of all regulatory obstacles to private (market - driven) deployments of fixed wireless local loop networks immediately. Fixed wireless local loop should be de-linked from wire-based the regulatory regime and instead be privatized and liberalized under the same program as that being applied to mobile wireless local loop. Only if this is done can the twin goals of satisfying the Kenyan government's objective of universal voice access and the growing data demand be met.

Finally, there are several wireless alternatives available, the main ones of which were outlined in chapter 3. It is possible that several of these as they evolve over the next few years might acquire characteristics that would make them suitable for deployment in the local loop of developing nations. Microwave technologies, for instance, with their excellent broadband capabilities would be an interesting point of departure for future research.

Appendix One

List of Acronyms

ADPCM	Adaptive Differential Pulse Code Modulation
AMPS	Advanced Mobile Phone Service
ARIB	Association of Radio Industries and Businesses
AUC	Authentication Center
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transceiver Station
CCK	Communications Commission of Kenya
CDMA	Code Division Multiple Access
CO	Central Office
CPE	Customer Premise Equipment
CT-2	Cordless Telephony System - 2
DAMPS	Digital Advanced Mobile Phone Service
DCA	Dynamic Channel Allocation
DCS	Digital Cellular System
DECT	Digital European Cordless Telephone
EDGE	Enhanced Data Rates for GSM Evolution
EIA	Electronics Industries Association
EIR	Equipment Identity Register
ETACS	Enhanced Total Access Communications System
ETRI	Electronics and Telecommunications Research Institute
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
GGSN	Gateway GPRS Support Node
GMPCS	Global Mobile Personal Communications Services
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Services
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HDR	High Data Rate
HLR	Home Location Register
HSCSD	High Speed Circuit Switched Data
IMEI	International Mobile Equipment Identity

IMT	International Mobile Telecommunications
IP	Internet Protocol
IS-95	Industry Standard 95
ISDN	Integrated services digital network
ISP	Internet Service Provider
ITC	Internet and Telecoms Convergence Consortium
ITU	International Telecommunication Union
KPTC	Kenya Posts and Telecommunications Corporation
LAN	Local Area Network
LMDS	Local Multipoint Distribution Service
MMDS	Multichannel Multipoint Distribution Service
MOTC	Ministry of Transport and Communications
MSC	Mobile Switching Center
MVDS	Microwave Video Distribution Systems
NAMPS	Narrowband Advanced Mobile Phone Service
NMT	Nordic Mobile Telephone
OMC	Operations Maintenance Center
OSS	Operation and Support System
PABX	Private Access Branch Exchange
PCS	Personal Communications Systems
PDP	Packet Data Protocol
PHS	Personal Handy-phone System
POP	Point-of-Presence
POTS	Plain Old Telephone Service
PSTN	Public Switched Telephone Network
RF	Radio Frequency
RPCP	Research Program on Communications Policy
RTMI	Radio Telefono Mobile Integrato
RTMS	Radio Telefono Mobile di Seconda generazione
RTT	Radio Transmission Technologies
SGSN	Serving GPRS Support Node
SIM	Subscriber Identity Module
SMS	Short Message Service
SS7	Signaling System 7
STD	Subscriber Trunk Dialing
TACS	Total Access Communications System
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TIA	Telecommunications Industry Association
VITA	Volunteers in Technical Assistance

VLR	Visitor Location Register
WCDMA	Wideband-CDMA
WLL	Wireless Local Loop

Principal Model Spreadsheets

Second Generation GSM Cost Model

BASIC ASSUMPTIONS

A. Equipment Specifications	
a. 6 Radios per sector @ 200 KHz spectrum per radio (1.2 MHz per sector)	
b. 12 MHz bandwidth in each direction	
c. 3 sectors per cell	
d. ~7.5 voice channels per radio	
e. Switch typically attains 80% full load capacity	
f. Average cell site load capacity when network is fully operational - 80%	0.8
Hence reciprocal of average load capacity is	1.3
B. Market Trends	
a. Equipment costs dropping at a rate of 10% per year	

GSM Network Equipment Costs (US$)	
70 m Lattice Tower	
Materials and Installation	35000
Site Preparation	20000
Single sector - 2 initial transmitters (TRX)	70000
Single sector - Each additional TRX	9000
Antenna installation - urban site	8000
Antenna installation - rural site	40000
Container for cell site with AC wiring, security, etc.	10000
4xE1 microwave for cell interconnection+installation	30000
Base station controller and transcoders (512 TRX) @ US$3000/TRX	1536000
Switch, 2500 Erlangs capacity	3000000
Software licensing - per subscriber	30
Authentication center - 50000 subscribers	500000
Operation management center - 50000 subscribers	500000
Billing and customer management system - 50000 subscribers	500000

Second Generation GSM Cost Model *(Cont.)*

Network Equipment Costs, adjusted to a single 3 sector cell site (US$)

Urban cell site

Cell Site Parameters				
Cell capacity		Coverage area	Max. sq. km/cell	Cells required by coverage area
Subs./Cell	Erls/Sub.	(CA)	(SK/C)	(CR)
1450	0.07	18.00	6.33	11.67

Costs

Average annual operating cost per subscriber
600

Scalable costs	
70 m Lattice Tower Materials and Installation	35000
Site Preparation	20000
Cell site (BTS), 6 TRX, power system, 6 antennas/cables	178000
Antenna installation	8000
Container for cell site with AC wiring, security, etc.	10000
4xE1 microwave for cell interconnection+installation	30000
Total scalable network costs (TSNC)	*281000*

Management costs		Capacity
Authentication center	500000	
Operation management center	500000	
Billing and customer management system	500000	
Total network management costs (TNMC) - 50,000 subscribers	*1500000*	50000 subscribers

BSC and Switch costs		Capacity
Base station controller and transcoders (BSC)	*1536000*	28 cell sites
Switch, 2500 Erlangs capacity	*3000000*	20 cell sites

Year	Subscribers		Number of cell sites	TSNC	Operating Costs	TNMC	BSC	Switch
	Adoption as % of subs.	Number of subscribers		(discounted at 10% per year)	(discounted at 10% per year)	discounted at 10% per annum		
Year of initial deployment - **2000**	1%	481	1	281000	288480	1500000	1536000	3000000
2001	2%	962	1	0	524509	0	0	0
2002	5%	2404	3	464463	1192066	0	0	0
2003	12%	5770	5	422239	2600872	0	0	0
2004	30%	14424	13	1535414	5911072	0	0	0
2005	70%	33656	30	2966141	12538637	0	953735	1693422
2006	90%	43272	38	1268937	14655550	0	0	0
2007	99%	47599	42	576790	14655550	0	0	1399522
2008	100%	48080	42	0	13457805	0	0	0
2009	100%	48080	42	0	12234368	0	0	0
2010	100%	48080	42	0	11122153	0	0	0
Average annual number of subscribers		26619						
Total costs (US$)				7514984	89181060	1500000	2489735	6092944
Total costs per subscriber (US$)				282	3350	56	94	229
Software licensing @ $30 per subscriber (US$)	3							
Average annual capital costs (US$)	60							
Average annual operating cost (US$)	305							
AVERAGE ANNUAL COSTS PER SUBSCRIBER (US$)	**367**							

1. In this case, cell capacity dominates cell coverage area - while cell coverage area suggests that for all subscriber demand to met 11.86 cell sites are required, capacity limitations suggest that 17 cell sites are required.
2. For the TNMC, BSC and Switch, no further costs are incurred until the system has a) 50,000 subscribers (TNMC), b) (25/1.25) or 20 cell sites (Switch) and c) (512/6*3) or 28 cell sites (BSC)

Second Generation GSM Cost Model *(Cont.)*

Rural cell site

Cell Site Parameters

Cell capacity		Coverage area	Max. sq. km/cell	Cells required by coverage area
Subs./Cell	Erls/Sub.	(CA)	(SK/C)	(CR)
1450	0.07	1455.00	364.11	0.78

Costs

Per cell site scalable costs	
70 m Lattice Tower Materials and Installation	35000
Site Preparation	20000
Cell site (BTS), 6 TRX, power system, 6 antennas/cables	178000
Antenna installation	40000
Container for cell site with AC wiring, security, etc.	10000
4xE1 microwave for cell interconnection+installation	30000
Total scalable network costs (TSNC)	*313000*

Management costs		Capacity
Authentication center	500000	
Operation management center	500000	
Billing and customer management system	500000	
Total network management costs (TNMC) - 50,000 subscribers	*1500000*	50000 subscribers

BSC and Switch costs		Capacity
Base station controller and transcoders (BSC)	*1536000*	28 cell sites
Switch, 2500 Erlangs capacity	*3000000*	20 cell sites

Year	Subscribers		Number of cell sites	TSNC (discounted at 10% per year)	Operating Costs (discounted at 10% per year)	TNMC	BSC	Switch
	Adoption as % of subs.	Number of subscribers				discounted at 10% per annum		
Year of initial deployment - **2000**	1%	45	1	281000	27000	1500000	1536000	3000000
2001	2%	90	1	0	49091	0	0	0
2002	5%	225	1	0	111570	0	0	0
2003	12%	540	1	0	243426	0	0	0
2004	30%	1350	2	191927	553241	0	0	0
2005	70%	3150	3	174479	1173541	0	0	0
2006	90%	4050	4	158617	1371672	0	0	0
2007	99%	4455	4	0	1371672	0	0	0
2008	100%	4500	4	0	1259570	0	0	0
2009	100%	4500	4	0	1145064	0	0	0
2010	100%	4500	4	0	1040967	0	0	0
Average annual number of subscribers		2491						
Total costs (US$)				806023	8346813	1500000	1536000	3000000
Total costs per subscriber (US$)				324	3350	602	617	1204
Software licensing @ $30 per subscriber (US$)	3							
Average annual capital costs (US$)	250							
Average annual operating cost (US$)	305							
AVERAGE ANNUAL COSTS PER SUBSCRIBER (US$)	557							

1. In this case, cell capacity dominates cell coverage area - while cell coverage area suggests that for all subscriber demand to met 0.78 cell sites are required, capacity limitations suggest that 4 cell sites are required.
2. Again, for the TNMC, BSC and Switch, no further costs are incurred until the system has a) 50,000 subscribers (TNMC), b) (25/1.25) or 20 cell sites (Switch) and c) (512/6*3) or 28 cell sites (BSC)

GPRS Cost Model

BASIC ASSUMPTIONS

A. Equipment Specifications

a. Switch typically attains 80% full load capacity	
b. Average cell site load capacity when network is fully operational - 80%	0.8
Hence reciprocal of average load capacity is	1.3
c. One GPRS backbone is needed for the urban location and one for the rural location	
d. Two BTS cell sites per Base Station	2
e. Each GPRS backbone is connected to 10 other backbones	10
f. 0.07 Erlangs per subscriber	

B. Market Trends

a. Equipment costs dropping at a rate of 10% per year

GPRS Network Equipment Costs (US$)

Packet Data Protocol	
DNS servers	1000
Software to Packetize data	1000
Router Software	1000
SGSN	
Software to route packets between subscriber and GGSN	1000
Computer to run the software	5000
Line to BSC	3000
Line to GPRS Backbone (T1)	15000
GGSN *(Two per GPRS backbone on average)*	
Software to convert GPRS data into IP format	3000
Software for routing packets between SGSN and IP network	1000
DNS servers	1000
Line to GPRS Backbone (2 T1 lines)	20000
Lines to various data networks (1 T1 lines) *(Leida model)*	20000
Routers *(one main and backup per border gateway)*	
Main router	3000
Backup router	3000
Border gateway *(one for connection to every other GPRS backbone)*	
Routers	1000
Switches	3000
firewalls	2000
Charging gateway *(one per backbone)*	
cost of charging gateway	5000
cost of charging gateways for the entire network	
cost of charging gateways per cell	
Operating System Costs	
Software licensing	4050
Authentication center	1350
Operation management center	3000
Billing and customer management system	3000
GPRS Backbone	
cost of GPRS backbone	4000000

GPRS Cost Model *(Cont.)*

Network Equipment Costs, adjusted to a single 3 sector cell site (US$)

Urban cell site

Cell Site Parameters

Cell capacity		Coverage area	Max. sq. km/cell	Cells required by coverage area
Subs./Cell	Erls/Sub.	(CA)	(SK/C)	(CR)
1450	0.07	17.71	6.33	11.67

Fixed capital costs	
GGSN	45000
Routers	60000
Border Gateway	60000
Charging Gateway	150000
GPRS Backbone	4000000
Total Fixed Costs (TFC)	*4315000*

Average annual operating cost per subscriber
100

Variable costs per cell site	
SGSN	12000
Packet Switched System	3000
Operating System Costs	11400
Total Variable Costs (TVC)	*26400*

Year	Subscribers: Adoption as % of subs.	Subscribers: Number of subscribers	Number of cell sites	TVC (discounted at 10% per year)	Operating Costs (discounted at 10% per year)	TFC
Year of initial deployment - **2000**	1%	481	1	26400	48080	4360000
2001	2%	962	1	0	87418	
2002	5%	2404	3	43636	198678	
2003	12%	5770	5	39669	433479	
2004	30%	14424	13	144252	985179	
2005	70%	33656	30	278669	2089773	
2006	90%	43272	38	119217	2442592	
2007	99%	47599	42	54189	2442592	
2008	100%	48080	42	0	2242967	
2009	100%	48080	42	0	2039061	
2010	100%	48080	42	0	1853692	
Average annual number of subscribers		26619				
Total costs (US$)				706034	14863510	4360000
Total costs per subscriber (US$)				27	558	164
Average annual capital costs (US$)	17					
Average annual operating cost (US$)	51					
AVERAGE ANNUAL COSTS PER SUBSCRIBER (US$)	**68**					

Rural cell site

Cell Site Parameters

Cell capacity		Coverage area	Max. sq. km/cell	Cells required by coverage area
Subs./Cell	Erls/Sub.	(CA)	(SK/C)	(CR)
1450	0.07	1455.00	364.11	0.78

Year	Subscribers: Adoption as % of subs.	Subscribers: Number of subscribers	Number of cell sites	TVC (discounted at 10% per year)	Operating Costs (discounted at 10% per year)	TFC
Year of initial deployment - **2000**	1%	45	1	26400	4500	4315000
2001	2%	90	1	0	8182	
2002	5%	225	1	0	18595	
2003	12%	540	1	0	40571	
2004	30%	1350	2	18032	92207	
2005	70%	3150	3	16392	195590	
2006	90%	4050	4	14902	228612	
2007	99%	4455	4	0	228612	
2008	100%	4500	4	0	209928	
2009	100%	4500	4	0	190844	
2010	100%	4500	4	0	173494	
Average annual number of subscribers		2491				

Second Generation CDMA (IS-95) Cost Model

A. Equipment Specifications

a. 6 Radios per sector, each occupying all 1.25 MHz capacity
b. 12 MHz bandwidth in each direction
c. 3 sectors per cell
d. ~12 voice channels per radio
e. Switch typically attains 80% full load capacity

f. Average cell site load capacity when network is fully operational - 80%	0.8
Hence reciprocal of average load capacity is	1.3

B. Market Trends

a. Equipment costs dropping at a rate of 10% per year

CDMA Network Equipment Costs (US$)

70 m Lattice Tower	
Materials and Installation	35000
Site Preparation	20000
Single sector - 2 initial transmitters (TRX)	70000
Single sector - Each additional TRX	9000
Antenna installation - urban site	8000
Antenna installation - rural site	40000
Container for cell site with AC wiring, security, etc.	10000
4xE1 microwave for cell interconnection+installation	30000
Base station controller and transcoders (512 TRX) @ US$3000/TRX	1536000
Switch, 2500 Erlangs capacity	3000000
Software licensing - per subscriber	30
Authentication center - 50000 subscribers	500000
Operation management center - 50000 subscribers	500000
Billing and customer management system - 50000 subscribers	500000

Second Generation CDMA (IS-95) Cost Model *(Cont.)*

Network Equipment Costs, adjusted to a single 3 sector cell site (US$)

Urban cell site

Cell Site Parameters

Cell capacity		Coverage area	Max. sq. km/cell	Cells required by coverage area
Subs./Cell	Erls/Sub.	(CA)	(SK/C)	(CR)
2522	0.07	37.00	11.02	11.67

Costs

Average annual operating cost per subscriber
600

Scalable costs	
70 m Lattice Tower Materials and Installation	35000
Site Preparation	20000
Cell site (BTS), 6 TRX, power system, 6 antennas/cables	178000
Antenna installation	8000
Container for cell site with AC wiring, security, etc.	10000
4xE1 microwave for cell interconnection+installation	30000
Total scalable network costs (TSNC)	*281000*

Management costs		Capacity
Authentication center	500000	
Operation management center	500000	
Billing and customer management system	500000	
Total network management costs (TNMC) - 50,000 subscribers	*1500000*	50000 subscribers

BSC and Switch costs		Capacity
Base station controller and transcoders (BSC)	*1536000*	28 cell sites
Switch, 2500 Erlangs capacity	*3000000*	12 cell sites

Year	Subscribers: Adoption as % of subs.	Subscribers: Number of subscribers	Number of cell sites	TSNC (discounted at 10% per year)	Operating Costs (discounted at 10% per year)	TNMC	BSC	Switch
						discounted at 10% per annum		
Year of initial deployment - **2000**	1%	481	1	281000	288480	1500000	1536000	3000000
2001	2%	962	1	0	524509	0	0	0
2002	5%	2404	2	232231	1192066	0	0	0
2003	12%	5770	3	211119	2600872	0	0	0
2004	30%	14424	8	959634	5911072	0	0	0
2005	70%	33656	17	1570310	12538637	0	0	1693422
2006	90%	43272	22	793086	14655550	0	0	0
2007	99%	47599	24	288395	14655550	0	0	0
2008	100%	48080	24	0	13457805	0	0	0
2009	100%	48080	24	0	12234368	0	0	0
2010	100%	48080	24	0	11122153	0	0	0
Average annual number of subscribers		26619						
Total costs (US$)				4335776	89181060	1500000	1536000	4693422
Total costs per subscriber (US$)				163	3350	56	58	176
Software licensing @ $30 per subscriber (US$)	3							
Average annual capital costs (US$)	41							
Average annual operating cost (US$)	305							
AVERAGE ANNUAL COSTS PER SUBSCRIBER (US$)	**349**							

Second Generation CDMA (IS-95) Cost Model *(Cont.)*

Rural cell site

Cell Site Parameters

Cell capacity		Coverage area	Max. sq. km/cell	Cells required by coverage area
Subs./Cell	Erls/Sub.	(CA)	(SK/C)	(CR)
2522	0.07	2953.00	633.30	0.78

Costs

Per cell site scalable costs	
70 m Lattice Tower Materials and Installation	35000
Site Preparation	20000
Cell site (BTS), 6 TRX, power system, 6 antennas/cables	178000
Antenna installation	40000
Container for cell site with AC wiring, security, etc.	10000
4xE1 microwave for cell interconnection+installation	30000
Total scalable network costs (TSNC)	*313000*

Management costs		Capacity
Authentication center	500000	
Operation management center	500000	
Billing and customer management system	500000	
Total network management costs (TNMC) - 50,000 subscribers	*1500000*	50000 subscribers

BSC and Switch costs		Capacity
Base station controller and transcoders (BSC)	*1536000*	28 cell sites
Switch, 2500 Erlangs capacity	*3000000*	12 cell sites

Year	Subscribers: Adoption as % of subs.	Subscribers: Number of subscribers	Number of cell sites	TSNC (discounted at 10% per year)	Operating Costs (discounted at 10% per year)	TNMC	BSC	Switch
						discounted at 10% per annum		
Year of initial deployment - **2000**	1%	45	1	313000	27000	1500000	1536000	3000000
2001	2%	90	1	0	49091	0	0	0
2002	5%	225	1	0	111570	0	0	0
2003	12%	540	1	0	243426	0	0	0
2004	30%	1350	1	0	553241	0	0	0
2005	70%	3150	2	174479	1173541	0	0	0
2006	90%	4050	3	158617	1371672	0	0	0
2007	99%	4455	3	0	1371672	0	0	0
2008	100%	4500	3	0	1259570	0	0	0
2009	100%	4500	3	0	1145064	0	0	0
2010	100%	4500	3	0	1040967	0	0	0
Average annual number of subscribers		2491						
Total costs (US$)				646096	8346813	1500000	1536000	3000000
Total costs per subscriber (US$)				259	3350	602	617	1204
Software licensing @ $30 per subscriber (US$)	3							
Average annual capital costs (US$)	244							
Average annual operating cost (US$)	305							
AVERAGE ANNUAL COSTS PER SUBSCRIBER (US$)	551							

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