Models and Applications of Wireless Networks in Rural Environments

by

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ABSTRACT

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With the unprecedented growth of the communication industry that the world is experiencing, the demand from rural inhabitants for high quality communications at an economically affordable cost is growing. However, rural areas are rather restricted from deploying communication services due to the rough natural environment, and the shortage of rudimentary communication facilities and technical personnel. Appropriate models for building rural wireless networks and a concomitant simulation environment are, therefore, expected to enable the construction of technologically-optimal and economically-efficient networks in specified rural areas.

The research has set up two independent models, one for the economic need and the other for the technical need of building networks in rural areas. One model was the Impact of Telecommunications Model, which disclosed the importance of building a wireless network in specified rural areas by choosing an economic parameter to forecast the profitability of the network. The other was the Service Model, which collected primitive data from given rural areas and abstracted these data by flowing them through four technical layers to form the predicted technical wireless network. Both of the models had been applied to real-world cases to demonstrate how to use them.

A simulation environment was finally designed and implemented to realize the above two models for the sake of instantiation. This environment could simulate the specified rural network by constructing a wireless network on the invented areas and evaluating its quality and economic efficiency. It was written in Scilab simulation language, which was an open source.

November 2004

DECLARATION

I declare that *Models and Applications of Wireless Networks in Rural Environments* is my own work, that it has not been submitted before for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Full name ......Yang Li.......... Date ......November 2004 .....

Signed ....

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Chapter 1 INTRODUCTION

In the introductory chapter, the constraints of the wireless industry in rural areas will be made clear and the motivation for this study will be explained. Thereafter, the chapter will list the problem statements, the research approaches and methods in the aforementioned order. Finally, the organization of the entire thesis will be provided.

1.1 Background of Rural Telecommunications

With the advances in information technology, wireless telecommunications have evolved in a dramatic way within businesses and daily human life. It is profoundly beneficial to everyone in that it provides communication connectivity in rural and urban areas. Therefore, the large distances between them need not isolate rural areas from urban areas. Wireless telecommunications also play a special role in meeting data communication needs due to the spread of Internet, which has placed further demands for widely accessible and reliable high-bandwidth communication systems.

On the one hand, we need to encourage new and innovative technologies and optimum models to maximize the advantages that wireless communications provide. On the other hand, the increase in demand for mobile telecommunications has given rise to a wide array of new technologies and systems which span a very large range of frequency allocations, expected data bandwidths, high-speed data transmission and contribution to economic growth.

1.2 Constraints and Motivation

1.2.1 Focus and Constraints

Broad new underdeveloped rural markets attract telecommunication service providers and application developers (or third party) to invest in them. In this way, many African, East Asian and Latin American countries provide perfect settings for new telecommunication markets. However, rough and difficult terrain, adverse weather, scattered population distributions and low-return-benefits hinder rural areas from being explored and developed. These limitations impose critical requirements on telecommunication workers on how to supply rural people with cheap, achievable and feasible network, which is fast in various circumstances and yet profitable. Universal telecommunication access to voice and data services may help a good deal to improve living standards and aid local economies in all kinds of social groups such as schools, hospitals, stations, churches and so on.

1.2.2 Motivation of Research

In most regions, rural areas are for various reasons the last to be connected with any form of a communication network. Even when connected, they usually have to use outdated technologies and inherit equipment from urban areas. They also, at times, have to hire technical personnel to help them with their systematic sampling, rational analyzing and making correct summations, and this is at a high cost. Rural areas need a set of criteria with which to conform and an easy-operating and cheap simulation environment to help them to set up their own rural communication networks. Their potential willingness to adopt telecommunication will also help encourage the acceptance of wireless technologies.

In view of these factors, this thesis attempts to provide two solutions. The first is a business case for developing rural networks. Models are built for the case through accessing the contribution of telecommunications on the economic productivities of the areas being targeted and solving technical problems related to the construction of the wireless network in the areas. The second solution is a network design tool that requires no financial outlay in terms of licensing. It is supported mainly by freeware available on the Internet.

Not only can the theoretical aspects of this research contribute the wireless-network-planning methodologies to telecommunication carriers, but also the reference models can be of use to common wireless network planners. The software part of the research is expected to provide an operable Graphical User Interface (GUI) and a simulation environment to telecommunication providers as well as to common wireless network planners.

1.3 Statement of Problem

The main research question is "how to construct wireless network models and applications in rural areas in a systematic, flexible and economy-efficient manner?" This main question can be expanded into the following problem questions:

1. Which kinds of data do we need to collect before planning a wireless network?
2. What models do we need to set up to construct the network?
3. How do we set up and evaluate the models in an easy and reliable way?
4. Are these tasks and outcomes truly contributing to the telecommunication field?

The above questions can be explained in other ways as they are many-faceted questions:

1. How to choose and filter useful parameters scientifically.
2. How to filter out the most suitable technology and structure.
3. How to define the type of model, the number of layers and interaction between them, and the functions they supply to upper layer and the interfaces to lower layer.
4. How to construct the model with nominal knowledge, available statistical data and how to analyze it.
5. How to keep a high level of grade of service and evaluate cost-efficiency when constructing the model.
6. What wireless simulation tool can be used to test the model.

1.4 Approach and Methodology

The two models, namely the Impact of Telecommunications Model and the Service Model, will be used simultaneously to act as the theoretical prototype. In conjunction

with these models, a user-interface simulation environment in Scilab [1] will be developed and applied, with rational data collection forming the input parameters of the software tool. Network quality and economic practicability will finally be evaluated in the simulation environment to help draw a result as to whether the modeling method fits with reality and whether it is of help to telecommunications.
The main methodologies used in the research will be the Case-Study method and the Software-Development method.

1.5 Thesis Organization

The thesis consists of six chapters. In Chapter 1, the main research problem is presented, and the research approach, which addresses the research question, is set out. Chapter 2 will add to the background knowledge of the study to assist in understanding the approach taken in the thesis. The Impact of Telecommunications Model, which deals with the significance of constructing a wireless network, and the Service Model, which deals with how to set up a wireless network in rural areas, are formulated in Chapter 3 and Chapter 4 respectively. The Newcastle-impact-model using Newcastle as an example is built in Chapter 3 as an economic example of telecommunication contribution; meanwhile, the analysis of African countries by using the same economic theory is also given as a more elaborate example that is based on reliable historical data. On the side, to support the use of a Service Model, the case study of Newcastle, South Africa is discussed in Chapter 4 as a continuation of the Newcastle-impact-model in Chapter 3. It is named as Newcastle-service-model. A simulation environment written in Scilab language will be developed in Chapter 5 and applied to the Newcastle case study for demonstration purposes. Conclusions are drawn and future work is described in Chapter 6. The skeleton of the thesis can be depicted as in Figure 1.

[1] Scilab is a scientific software package for numerical computations providing a powerful open computing environment for engineering and scientific applications

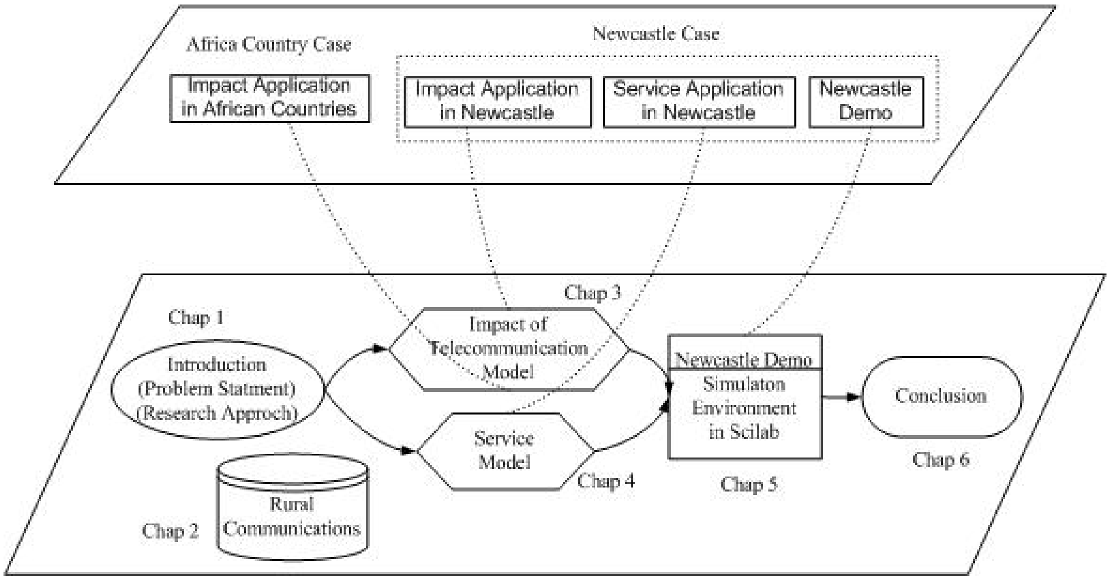

Figure 1. Organization of Thesis

1.6 Summary

Advances in wireless telecommunications and recent communication requirements of rural areas facilitate them to work in association. The way to achieve the association successfully but concisely is to be studied in the research.

This chapter mainly interpreted the motivation, problem and approache of the research in turn. The backdrop knowledge of rural communications will be reviewed in the next chapter.

Chapter 2 RURAL COMMUNICATION NETWORKS

In the previous chapter, the main concerns were outlined to clarify the research problem and the theoretical approaches were also located. Literature on rural communications will be reviewed in this chapter to enhance the background knowledge of rural communications relevant to this research. This literature covers the key factors of the definition of rural communications and the importance of building rural networks, and on-going rural-network-building projects.

2.1 Importance of Rural Communication Networks

Communication networks in rural areas are always the last to be considered because they involve difficulties such as inaccessible geographical terrains and adverse climates. They yield very little return in investment to telecommunication carriers and service providers. For the authorities, they have remained bottlenecks to both technological and economic developments. In a nutshell, the poor state of current rural communication is hindering social development.

However, the increasing need for rural areas to communicate with the outer world demands optimum global solutions to resolve the problem. The establishment of telecommunication networks in rural areas could lead to a better quality of life for rural people, which is the main objective of building telecommunication networks in rural and remotes areas. Furthermore, spreading communication networks in rural areas will generate economic activity in them, because of the lucrative feedback from phone users for telecommunication companies and the profits from service charges from network users for service providers. In addition to the generation of profits, communication networks will also infuse power to drive other industries to go forward. As an economic enabler, communication gives rise to the increasingly important industrial information, product introduction, economic trends and interpersonal communications. Its service areas span all the productive sectors including education, health and medicine, small business, emergency treatment and military.

Many programs in the developing world have been designed to help improve the quality of life for populations in rural areas. Traditional activities include health, education, small business and other community services. Recent interest is in using Information and Communication Technologies (ICTs) to help meet the goals of these rural development programs [1]. Once these programs are initiated and local people are educated adequately and start striving to improve their lives, they will rely more on communication technologies in search of information to improve themselves.

2.2 Fabric of Rural Telecommunication Systems

According to the Consultative Committee for International Telegraphy and Telephony (CCITT), a rural communication network is defined as a local exchange in conjunction with a toll exchange connected to general telecommunication networks by a transmission facility, supported by subscribers distributed in rural areas [2]. Following this, the main question relating to developing rural communications is "can wireless networks be cost effectively applied to many rural areas"?

Wireless networking appears to be a fast, cheap and feasible option in rural conditions compared with wire line. First, the initial investments are lower, and further growth can be stimulated by using radio-based technologies, which are essential to developing countries with poor underlying telecommunication facilities and a tract of future market. Second, the cost per subscriber of the cellular user will decrease with a growth in subscriber numbers, while the cost of wired infrastructure stays stable. Meanwhile, there is a favourable investment ratio of highest cost to lowest cost in wireless (2:1) than wired (10:1) [3]. Third, unlike copper parts in wired network, equipment in radio systems has a substantial recovery value. The main parts of wireless network equipment are stored in comparatively safe places, such as base stations, and they are easy to maintain and also requires less skilled personnel. Thus, wireless technologies offer more feasibility and simplicity to network structures.

Due to rough rural environments caused by severe climate and hostile terrain, the planning of rural communications, compared with other regional communications, focuses on unique network architecture and the special communication requirements of rural inhabitants. The unfavourable exterior conditions of rural areas and potential communication requirements originating from rural dwellers are described in section 2.3.1.

When building a communication network, especially in rural areas, it is essential to take into consideration both technical and economic aspects of the area as both aspects are notably influenced and determined by the network topology. Communication networks comprise three key components, namely an exchange node, a transmission network, and an access network. A snapshot of rural communications will be illustrated in the following Figure 2. In most cases, the regional communications' backbone network or transmission network uses optical fiber for high speed and large capacity information transfer, ensuring not only reliability but also satisfactory quality at the same time. Yet, when providing access to subscriber groups, which technology - wired or wireless technology - is preferred in rural areas? The use of wire lines has been universally taken as a barrier to rural communications [4]. Wire line is characterized by geographic limitations, immobility and exorbitant costs. Wireless access, on the other hand, affords abundant advantages over wire line with regards to cost, noise, coverage, switch capacity, reliability and transmission cost [5]. Wireless access technologies are elaborated in section 2.3.2.

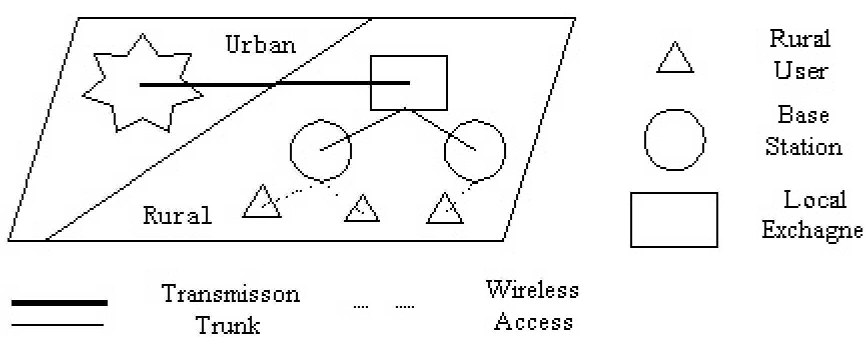

Figure 2. Fabric of Rural Communications

Economic issues surrounding communication networks include the economic significance of a network, the cost of construction and maintenance for telecommunication carriers, charges prescribed to subscribers, and returns on investment or revenue received based on the provision of services for service providers. The value chain of building a wireless network is explained in section 2.3.3, and the state of the South African economy is attached as well as a table.

Flexible operation, all-round maintenance and timely backup are also required in rural communications, but at lower levels than in other regional networks so as to meet the simple demands of universal access to voice and data. Besides those appointed administration functions, necessary platforms and feasible software are expected to develop management functions of networking further.

2.3 Key Factors of Rural Communications

2.3.1 Rural Environments

The following depiction of rural shortcomings helps the reader to understand why the research focuses on rural areas and to know more of what general information the research needs. The rural requirements section enhances the motivation of the research and looks into a broad future for rural wireless networks.

2.3.1.1 Rural Shortcomings

By the year 2000, more than half of the world's population lived in rural areas [5]. These typical rural areas are normally characterized in the following technical terms [6]:

- Difficult topographical conditions such as lakes, rivers, hills, mountains, deserts, and long distances between settlement areas, which cause the construction of wire telecommunication networks to be very costly.
- Severe climatic conditions that make heavy demands on the equipment such as the antenna and remote switch, and may add to the costs of installation as well as maintenance.

- Lack or absence of public facilities such as usable water, reliable electricity supply, access roads, regular transport, and an existing communication infrastructure.
- Underdeveloped social infrastructure such as health, education and small business, and lack of most government services.
- Low level of economic activity. The existing economic structure is mainly based on agriculture, fishing, and handicrafts. Therefore, few opportunities exist in rural areas in terms of jobs, and low-paying work leads to low family incomes and little demand for communication.
- Scarcity of technical personnel even with nominal telecommunication knowledge because of low educational level and high illiteracy rate.
- Very high demand for voice communications, such as long waiting lists, and a steadily growing demand for data communications.

The above mentioned characteristics make it difficult not only for any network operator to put up the basic network infrastructure in rural areas, but also for service providers to provide public telecommunication services with an acceptable quality by traditional means at affordable prices, while also achieving commercial viability. However, the basic objectives, to which telecommunication industries have to contribute, are to trigger and sustain structural and economic development to minimize these disadvantages and generally, improve the quality of life in rural areas.

2.3.1.2 Rural Requirements

Despite difficulties in rural areas, a wide array of existing or new telecommunication applications are being created to meet local rural requirements and are affiliated to rural development efforts, thus attracting service providers and application developers to invest in rural areas. In other words, these wireless companies intend to "give rural wireless customers better service and more choices" [7]. Examples of these specialized rural applications include [6]:

Health and Medicine

- Delivery of health information to medical professionals in the field.
- Delivery of prevention-oriented health information to rural communities.

- Entry of patient data into remote databases.
- Access to medical specialists via Tele-consultation.

Education

- Delivery of multimedia content to remote areas.
- Virtual classroom using videoconferencing facilities.
- On-line academic databases, bibliographic access and submitting tests by email.

Community Development

- Creation and dissemination of local content, such as a multilingual web site.
- Dissemination of information about government programs, subsidies and administrative matters.
- Group listening to radio broadcasts: special interests, sports, and entertainment.

Small Business Development

- Point-of-sale applications in remote tourist outposts (i.e. handcrafts).

Environment Monitoring and Protection

- Environmental information storage and exchange on the WWW.

Emergency Support and Disaster Relief

- Calling police, fire brigades, ambulance and other emergency services.
- Reestablishing communications after a disaster.

The contribution of wireless networks to universal communication access in poor rural residential areas cannot be limited to these services. The examples are mainly taken into consideration to demonstrate the value of communications in rural areas. There exist some other communication applications of wireless technologies in rural and remote areas that can be added to the list of applications.

2.3.2 Technology Issues in Rural Areas

An efficient choice of communication technologies is one of the most effective decisions for establishing telecommunication networks in rural areas. Wireless technologies are emerging as the first line of choice for rural areas due to their advantages over wired telecommunication technologies. These advantages involve low cost, the ease of building and Operation, Administration and Maintenance (OAM). Usually, wireless communication companies would like to put their resources into developing new technologies and deploying their infrastructure to earn themselves substantial benefits as well as positive publicity. A logical model of general wireless network is shown below in Figure 3:

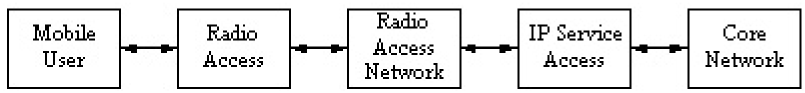

Figure 3. Simplified Logical Model of Wireless Network

As shown in the figure, an access network is fundamental for modeling a rural network. In the following part, the main access technologies suitable for rural communication networks will be the first to be discussed in section 2.3.2.1. Thereafter the criteria of choosing suitable technologies for rural areas are brought to focus in section 2.3.2.2.

2.3.2.1 A Panorama of Rural Wireless Access Technologies

The technologies that have been singled out for evaluation include High Frequency Radio (HF Radio), Point-to-Multipoint systems, Global System for Mobile communications on 400MHz (GSM400), Global System for Mobile communications / General Packet Radio Service Network in Box (GSM/GPRS NIB), Code Division Multiple Access on 450MHz (CDMA450), Personal Handyphone System Wireless Local Loop (PHS-WLL), Digital Enhanced Cordless Telephone Wireless Local Loop (DECT-WLL), and Very Small Aperture Terminal (VSAT). They are outlined and compared in the discussions that follow.

1. High Frequency Radio (HF Radio)

The HF Radio system includes Very High Frequency (VHF) radio system with frequencies from 30 MHz to 300 MHz, and Ultra High Frequency (UHF) radio system from 300 MHz to 3 GHz [8]. The HF radio system applies narrowband packet radio access systems to a network in an inexpensive way. As a result of those advantages of low cost and the ease of installation for HF radios, they have been providing rural areas with voice communications for a long time.

2. Point-to-Multipoint (PMP)

Point-to-Multipoint (PMP) is a valuable service attribute that refers to “communication configuration”. This denotes the communication process from a single source to multiple destinations in both analog and digital technologies [8] [9]. PMP systems have been traditionally applied, by using Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA), to provide rural areas with a means of connecting to national and international networks. Recently, they have been integrated with newly-emerging technologies such as PHS and DECT to cater for the fast growing communication needs of rural subscribers.

PMP systems compete with wired line systems on the basis of the speed at which their local radio points’ dissemination is performed [9]. They also prevail over other wireless networks, such as cellular or satellite systems, in service areas with a grouping factor of approximately more than 16 subscribers per point and in areas where there are few users (less than 0.0002 subscribers per km2) [10]. Generally, the systems are modular and easy to move and maintain [9].

3. Global System for Mobile communications (GSM)

Today's second-generation GSM networks deliver high quality voice capacity, and secure digital mobile voice and data services with full roaming capabilities across the world. Generally, the lower the frequency band used by the technology, the larger the coverage of its base station. Some rural regions with comparatively high user density (from 0.02 to 20 subscribers per km^2) and a low grouping factor (no more than 16 users per group averagely) are very suitable to adopt cellular systems [10]. However, the costs of cellular infrastructure are very high, and the new technologies about GSM require experts to plan, install and maintain the systems [9].

GSM400 uses frequencies in the range of 400 MHz band rather than the 900/1800 MHz bands. It therefore enables a wider area to be covered. Wide-area coverage is better suited to low density rural populations that spread over a large region. According to International Telecommunication Union (ITU) [6], GSM400 covers the same area as GSM900 using approximately half the number of cell sites. Furthermore, a typical cell in the 400 MHz band has a 40 km radius when using 2-watt mobile phone units. This system is then expected to have the capabilities to extend the range of both voice and high-speed data coverage. The specifications for GSM400 include the support for GSM Phase 2+ features such as General Packet Radio Service (GPRS), as well as Enhanced Data for GSM Evolution (EDGE).

In addition, the miniaturization of GSM equipment such as “Network In a Box” (NIB) has advanced in recent years. A GSM NIB puts all critical network elements such as Base Station (BS), Base Station Controller (BSC), Mobile Switching Center (MSC), Home Locate Register (HLR) and Visitor Location Register (VLR) in a small box, appropriately the size of a desktop [8]. Installing a NIB takes only a few hours and it is easy to operate and maintain. NIB does not allow outside roaming but inside switching and charging because of its simple form. Its low cost makes it an ideal choice to be used in wide areas such as in poor rural settings.

4. Code Division Multiple Access (CDMA)

CDMA modulates data in a specific channel with an individualized pseudo random code which is unique to service or subscriber. It enables more people to share the limited frequency spectrum at the same time with minimum interference.

CDMA450 in the 450 MHz band, rather than 850 MHz or 1900 MHz band range, provides wider coverage from each base station. More specifically, the CDMA450 covers the same area as a CDMA850 by using approximately half the number of cell sites. CDMA450 provides better cell coverage by from 50% to 70% compared with what is attainable in NMT450 networks [6]. Using a 100% overlay, CDMA450 is provided in all existing sites in an overlaid service area, resulting in a service quality that is superior to that of the existing analog systems [6]. Results for typical radio environments demonstrate that the latest version of CDMA technology, CDMA2000, can be down-banded to 450 MHz without any loss in performance [11].

Thus it can be said that CDMA450 is better suited for rural areas with its unique virtues such as having twice as wide a coverage as that of current CDMA networks, or the ability to provide an unlimited expandable capacity in theory.

5. Fixed Wireless Access (FWA)

Fixed Wireless Access (FWA) networks, also known as Wireless Local Loop (WLL), have been traditionally serving rural markets. FWA is an access technology that connects subscribers to the Public Switched Telephone Network (PSTN) using radio signals as a substitute for copper for all or part of the connection between the subscriber and the switch [12]. Fixed wireless access is used in conjunction with various forms of technologies, including cordless access systems, proprietary fixed radio access systems and fixed cellular systems. It is specifically designed to deliver quality, cost-effective services in low-density and scattered rural areas. Here, two newly-emerging cordless technologies embedded in WLL expand their individual advantages in rural areas.

One is Digital Enhanced Cordless Technology (DECT), which operates in the 1880-1900 MHz band range. It is based on the TDMA/TDD (Time Division Multiple Access and Time Division Duplex) principle. The transmission speed is 1152 kbps. It uses Dynamic Channel Assignment (DCA) that has a good performance in switching over cells. It has a cell radius of up to 3 km [13]. A DECT Wireless Local Loop (DECT WLL) is suitable for areas with high tele-subscriber density as well as rural areas where a fixed network has already been mounted. It is able to serve a wide area with a large cell radius of up to 3 km with low installation price and maintenance fee.

Another technology is Personal Handyphone System (PHS) operating within the 1895-1918 MHz band range with a bit rate of 384 kbps. It is also based on TDMA/TDD and runs under a DCA mechanism [13]. Each cell serves a range of up to 5 km with a directional antenna and a 15 km with adaptive array antenna, and is available for repeater and cell stations at a further distance [6]. Other special advantages of PHS for rural areas are its sturdiness against natural disasters and low implementation and maintenance cost.

6. Very Small Aperture Terminal (VSAT)

The term of Very Small Aperture Terminal (VSAT) refers to a small fixed earth station[2], which provides the vital communication link required to set up satellite-based communication networks that is VSAT networks [14]. VSAT networks serve rural and remote areas quite well on the basis of their capability of overcoming geographical distances and natural interference, and strong portability including being small in size and as light in weight as most outdoor equipment. According to the Harris Corporation[3] newsletter, the outer part of a VSAT network, the satellite antenna, ranges in size from between 2.4 and 4.6 m in diameter, depending on operational requirements [15]. Another company, Mitsubishi Electric[4] has developed a 30 kg portable VSAT terminal that is easy to transport and set up, and it supports voice, facsimile and data transmission. Weighing less than 4 kg, the system's indoor unit is compact and movable [16]. The network provides instant and cost-effective connectivity communities with small and light outside installations in any area where networks are either unavailable or too expensive, such as rural areas where there is a shortage of telephone services.

7. High Altitude Platform Stations (HAPS)

High Altitude Platform Stations (HAPS) is the name given to a family of new systems that provide wireless broadcasting services. These systems include aeroplanes or airships (essentially balloons, termed as aerostats). They may be manned or unmanned through an autonomous operation and manipulated via a remote control from the ground. It is recommended that they operate in the stratosphere up to 22 km above the ground [17] and each HAP station might serve an area with

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[2] Earth Station is the terrestrial portion of a satellite link, which consists of an antenna, amplifiers, and equipment for receiving and/or transmitting a satellite signal.

[3] Harris Corporation (NYSE HRS) is an international communication equipment company that focuses on providing product, system, and service solutions for commercial and government customers.

[4] Mitsubishi Electric is a global leader in the manufacture, marketing and sales of electrical and electronic equipment for home products, commercial and industrial systems and equipment products.

approximately 20 ground stations as required for backhaul purpose. HAPS are easy to install, move and maintain by simply uploading or replacing aircrafts. Thus the rolling-out fee is reduced while the cost of operation and maintenance is increased. The following table shows a comparison of the key characteristics of HAPS, terrestrial stations, and satellite stations. From this comparison more ideas concerning the advantages and disadvantages of those stations will be obtained [18].

Table 1. Comparison of Stations in Different Height Levels

	Terrestrial	HAP	Satellite
Station Coverage	< 1 km land and seashore	<= 200 km land and sea	> 500 km land and sea
Cell Size (diameter)	0.1-1 km	1-10 km	50 km
Transmission Rate	30 Mbps	25-155 Mbps	< 2 Mbps
Capacity	high	medium	low
Deployment	several base stations	flexible	many satellites
Infrastructure cost	varies	> 50 million USD	> 9 billion USD

2.3.2.2 Criteria of Choosing Technologies for Rural Areas

The following are therefore proposed as basic requirements in this research, especially in terms of technology for communication systems to be deployed in the rural areas of developing countries:

- Large coverage area with little basic wireless equipment due to the prominent natural character of vast areas, few dwellers, difficult natural environments and the factitious interference of electric waves in rural areas.
- Low cost in terms of implementation and operation in low-density population. This will make wireless access reasonably affordable for low-income rural people and tempt financial giants to invest in the underdeveloped or half-developed sectors.
- Ease of installation in remote and inaccessible locations. Radio access technologies such as microwave and infrared technologies, which are used as

medium in wireless communications, reach destination points through dense forests and over high mountains.

- Ease of system operation and maintenance with scarce support from qualified technical personnel. This depends on what technology is used in the rural area network. In reality, wireless networks are easier to maintain than fixed networks that rely more on a large number of physical instruments.
- Ease of implementation when there is an absence of basic infrastructure, such as electricity, running water, access roads and proper networks. These requirements would lean towards favouring wireless networks.

2.3.3 Economic Issues in Rural Areas

First, the economic issues, which are involved in constructing a wireless network, are briefly introduced in section 2.3.3.1 to help understand the economy relativity of network nodes in wireless network construction and choose efficient economic parameters for modeling. Then the information on the current economic state of South Africa is gleaned in section 2.3.3.2.

2.3.3.1 Economic Characteristics

Some of the following discussion derives from [10]. One critical economic question for rural network planners concerns which social member is responsible for paying for rural communications. A value chain of rural communications is considered in this research. The chain begins with manufacturers producing telecommunication equipment such as Cisco or Lucent. Then, after the service providers succeed in bidding for a rural project, they purchase products from these manufacturers and spend money in building rural networks. At the same time, information channels acquaint customers with products and services to ensure profits. Upon completing the network, users pay their bills of basic voice and data service and supplementary services to service providers and some third party service suppliers. During this period, telecommunication carriers benefit from tax for all enterprises. Exact data on the number of products to be purchased and services to be provided is difficult to find, but an ideal model about part of the relative values can be shown in Figure 4.

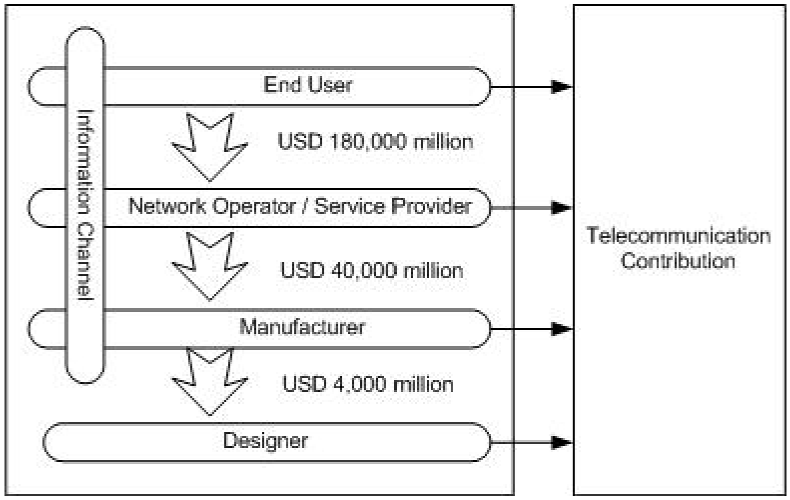


Figure 4. Value Chain of Network Construction and Contribution

The values in the chain of telecommunication procurement have been assumed according to European market. However, the four members in the chain can be applied to any network, including developing countries.

Figure 4 reflects a cash-flow relationship between any two of main social members in the value chain [10]. Here we can see large amounts of money flowing from end users to network operators and service providers. The latter takes into account many economic parameters such as the cost of capital, return on service provision and tax in order to make their profits through a suite of tariff mechanism. At the same time, all social members in the value chain contribute to the productivity of the society due to their membership of it.

2.3.3.2 Current Economic State of South Africa

South Africa is a developing country with advanced financial, legal, communications, energy and transport sectors and natural resources in abundance. Its stock exchange ranks among the ten largest in the world [19]. However, a 30% unemployment rate [19] remains an obstacle to the growth of the economy, and daunting economic problems arising from the apartheid era, especially among disadvantaged groups as well as regions with a high crime rate and a high HIV/AIDS prevalence rate, persist.

The most current economic characteristics derive from public information bulletins and are listed in Table 2 [19] [20] [21].

Table 2. Economic Characteristics of South Africa in Recent Years

Total GDP[5]	Rand 996,000,000,000	(2000 est.) [20]
GDP per capita	Rand 23,000	(2000 est.)
Real GDP growth	3.1%	(2000 est.)
GDP - composition by sector	Manufacturing 18.7% Mining 6.5% Agriculture 3.2% Currency and Finance 20.3% Trade 13.1%	(2000 est.)
Inflation Rate[6]	5.3 %	(2000 est.) [19]
Population below poverty line	50 %	(2000 est.)
Household income or consumption by percentage	Lowest 10% 1.1% Highest 10% 45.9%	(1994)
Labour force	17 million economically active	(2000)
Budget	Revenue USD 31,100,000,000 Expenditure USD 34,400,000,000	(2001/2)
Industrial production growth rate	2.4%	(2000 est.)
Unemployment rate	37%	(2001) [21]
Exports	USD 32,300,000,000	(2001)
Imports	USD 28,100,000,000	(2001)
Debt external	USD 25,500,000,000	(2001)
Economic Aid	USD 539,000,000	(1999)

[5] GDP is an acronym for the Gross Domestic Production.

[6] Inflation Rate is the rate of increase in the price of goods and services over a given period of time.

From an optimistic point of view, it can be seen from the above table that high GDP with a comparably stable growth rate of 3.1% has been spurring the communication market to develop at a faster pace. From the electricity consumption figure, we can see that South Africa bases its energy expectations on electricity, which is expected to be the least polluted and most economical energy supply for communication construction in the future.

The pessimistic side however can be seen to include the following. 1) According to the table, the Currency and Finance sector contributes the most to GDP, whereas the Agriculture sector contributes the least. This would imply an unbalanced industrial structure of South Africa. Communication, therefore, is expected to focus on serving the most favourable sector of the society. 2) Nearly 10% of South Africans barely make a living and have a very low household income. They may also live in sparsely-populated and widely-dispersed villages with small requirements, similar to other rural markets in the developing world. The affordability of communication services is therefore doubtful. 3) An extremely high foreign debt and a low economic aid do very little help to further South Africa's economic development. The low economic aid is as a result of its poor investment attractiveness to international investors due to a high crime rate including drug, robbery and a high HIV/AIDS prevalence rate. 4) Fossil fuel is the main source in producing electricity and makes up 92.74% of the total as compared to other fuel supplies. However, its high usage impacts heavily on ecological environment. For the sake of a clean environment in the future, reusable resources, such as water, solar and wind power, are strongly recommended in communication development.

2.4 On-going Rural Communication Projects and Pertinent Cases

Rural communications are of great importance to ensure a growth in the communication infrastructures and distribute the appropriate services in unfavourable rural sites. When considering rural communications, the following five orderly aspects related to [22] are used as the steps of the research procedure:

1. Determine the shortages of the physical rural situations and carry out the policy conducive to rural telecommunication development.
2. Make clear the necessity of building wireless network in research areas.
3. Choose proper technologies according to the result obtained from the first step for rural areas.
4. Set up models for serving rural and isolated communities.
5. Develop tools for the development and expansion of rural telecommunications.

What follow are the example projects of related work, which have some similarity with the above five steps of the research procedure more or less. The first project is an overview of wireless network construction where they share the same motivation as this research. The second one provides an example of the way to choose proper technologies according to real situations and official specifications. The third project teaches not only technology choosing but also the choice of parameters related to different technologies. The fourth project sets up a structural reference. The fifth project introduces a detailed economy parameter that will be used in one model of the research. The last project shows how to choose a simulation tool.

2.4.1 Nepal Rural Communication Network

The Nepal project demonstrates the stages involved in setting up rural communication networks [23].

First, an examination of Nepal was done before planning for the network. Only 9 major cities and 6 out of 75 villages were connected via analogue microwave. The average HF link length was reduced from an ideal of 90 km to 55.1 km due to mountainous terrains. A radio traffic investigation showed that 40% of radio traffic was between the capital and other cities, 40 % within all cities and 20% between towns and villages.

Second, on the basis of attained data from the above investigation, proposals for network planning were drawn on how many toll switching sub-areas were needed to ensure all subscribers were connected to at least one exchange in a major city, on how to define the main function of each toll switching, and on deciding which type of network was to be used.

Finally, the main functions and detailed characteristics of a digital radio system chain with the aim of meeting the needs of planning a network in rural areas. Those characters include frequency band, capacity, modulation system, transmission power, spectrum shaping, noise figures, auxiliary signal, transmitting system, standby system, power assumption and power source.

The description of the Nepal project explains a rural communication system for low level developing countries, which suffer most of the problems of all other rural areas. It then shows how to deal with major cities surrounded by abutting villages in order to build a network and how to choose the appropriate system, and has defined some decisive parameters of constructing a wireless network.

2.4.2 Telkom South Africa: Case Study in WLL Deployment

"Telkom South Africa: Case Study in WLL Deployment" is one of the Pyramid Research projects in rural South Africa [24]. It procured a successful rural wireless access in a PMP manner combined with DECT technology. A DECT link uses a frequency between the range of 1880 MHz – 1930 MHz and a PMP radio approach link occupies a frequency that ranges from 1.5 GHz (ITU-R Rec. 746 Annex-1), 2.4 GHz (ITU-R Rec. 746 Annex-2) and 3.5 GHz (CEPT/ERC/REC 14-03). All the frequencies are allowed to be used in South Africa by law. The hybrid network is able to supply a voice band of 9.6-56.6 kbps and a data transmission rate of 64-512 kbps. It covers the service range of several hundred kilometers by cells ranging up to 5 km. The advantages of using DECT on PMP TDMA systems in unfavourable areas involve an End-to-End wireless solution, big service areas of up to 1000 subscribers, high-quality voice and various supplementary services. Statistics show that the hybrid network not only succeeds in covering all subscribers indicated by the operator, but also guarantees a good service quality. For example, the powerful DCA mechanism of DECT allocates radio resources to systems internally with no interference from the operator. The Alternative Circuit (AC) power supply or the Direct Circuit (DC) power supply in PMP renders the network in remote areas easy to maintain as well as to retain a good quality.

As a whole, what can be learned from the Telkom project is, while designing a network in a country, the technical policies and specifications dictated by the country must be followed closely. Furthermore, this case can be taken as an example of how to choose optimal technologies suitable for preferred areas and how to evaluate them in the real world.

2.4.3 Case Study on Access Network of PMP, GSM and STAR[7]

The case study by A. Diaz-Hernandez focuses on the access network selection for a typical rural area [25]. The networks include PMP, GSM and STAR. He compares three technologies over the periods of 1992/1993, 1996/1997 and 2000 in order to highlight the growing nature of these rural technologies. The basic assumptions about the characteristics of the area and the network are as follows:

Table 3. General Assumptions

Distribution of subscribers	Uniform
Radius of surface (km)	500
Traffic per subscriber (Er/S)	0.02, 0.04, 0.1, 0.2
Rate of return per year	10
Grouping factor of subscribers	1, 8, 16, 50, 100

Table 4. Assumptions for PMP, GSM and STAR Technologies

Assumptions for PMP			Assumptions for GSM	
Num of Sub per CS	1024		Information Channel (%)	90
Max Num of Sub per SS	256		Signaling Channel (%)	10
Length btw T and SS (km)	0 – 5		Traffic per Cell (Er)	80
Length btw SS and RS (km)	15 – 30		Max Num of Sub per Cell	2000

[7] STAR is an acronym for "Satellite Global Star technologies". It is a global communications system using satellites as communicating medium.

Length btw SS and CS (km)	15 – 30	Surface of BTS (m^2)	10
Length btw RS and RS (km)	30	Surface of BSC (m^2)	10
Length btw RS and CS (km)	30	Surface of Repeater (m^2)	6
Length btw RS and Ex (km)	30	Assumption for STAR	
Surface of SS (m^2)	6	Capacity per Hub (Er)	785
Surface of RS (m^2)	6	Surface of Hub (m^2)	200
Surface of CS (m^2)	10	Number of satellites	48
Surface of Ex (m^2)	40 + 0.05 * lines	Num of transponders per satellite	1

Notes:	Num	-	Number	Ex	-	Local Exchange	SS	-	Subscriber Station
	btw	-	between	CS	-	Central Station	Sub	-	Subscriber
	Er	-	Erlang	RS	-	Repeater Station	T	-	Terminal

The conclusions reached by the author are that in the rural areas with a low grouping factor, the use of GSM and STAR technologies is on the increase and the use of PMP systems is on the decrease. However PMP will continue to be prominent in areas where the grouping factor is above 16.

From the above method of predicting the tendency of technology growth by assumption, the study will evaluate three rural technologies including PMP, GSM and STAR. Other wireless technologies such as CDMA or VSAT can be evaluated effectively in the same way. Lessons that can be learned from the case study include answers to questions such as what parameters we should adopt and which value range we should assume for these parameters. Furthermore, the findings can be used directly in the research. After having acquired the average grouping factor and subscriber density in a real research area, the appropriate technologies can be selected directly from the results of this case study.

2.4.4 Tele-Health: a Case Study Tsilitwa, Eastern Cape, South Africa

"Tele-Health: a Case Study Tsilitwa, Eastern Cape, South Africa" is another example, which takes into consideration the requirements of the local inhabitants [26]. The innovative solution implemented was a pilot project. A low-cost communication platform utilizing solar energy in a deep isolated and secluded rural community was used in the project to facilitate improved healthcare and sustainable development. GSM technology was used to link two sites, a nurse in a rural clinic and a doctor in a hospital. The audio and video demonstrations were recorded between them at regular intervals. The nurse could send a digital image of the patient and talk in text to a doctor via email, and vice versa, the doctor was able to reply to her as soon as possible. The sustainability of the project was achieved through "no cost" intranet communications and the provision of information services. Researchers expected to obtain the following objectives: 1) to develop and pilot a communication infrastructure and delivery platform using renewable energy, 2) to equip small businesses such as tele-health to achieve sustainable, integrated rural development, 3) to develop an assessment methodology for monitoring and evaluating the system.

The focus of this Tsilitwa project is how to organize the fabric of the model for a rural community efficiently. This model has wonderful modeling methods for special-interest communities in rural areas and, more specifically, it illustrates a vivid model of a rural tele-health community.

2.4.5 Economic Issues of Telecommunications Development in Hungary

Borsos has explored correlations between economic performance and the level of telecommunications development in Hungary in one of his papers [27]. According to his study of international statistical data, an approximately linear relationship can be established between telephone penetration and per capital Gross Domestic Production (GDP). The study confirms that a lack of telecommunication services will certainly stunt the development of the economy, while a growth in production will boost demands in business and residential users symptomatically. However, the impact that telecommunications have on the increase of the level of production through the propagation of information is not to be described as a linear function. A more realistic formula is written as:

$$p = x_1 \cdot g + x_2 \cdot g^2$$
$$0.2 \le x_1 \le 0.3, \quad 0.02 \le x_2 \le 0.03 \qquad (1)$$

Where "p" represents the percentage contribution of telecommunications to production in any country or area and "g" is the GDP of that area. "x_1" and "x_2" change with telephone penetration. The stronger the telephone penetration in the country is, the smaller these two parameters are.

Despite the fact that Hungary is a semi-developed country, the relationship between telecommunication growth and economic development can be applied to other countries by simply changing the telephone penetration level. As telephone penetration, GDP, and telecommunication contribution are determinately related, they influence the progress made on each other. This formula will be considered in our research when dealing with the Impact of Telecommunications model.

2.4.6 CRCnet: Connecting Rural Communities using WiFi

"CRCnet: Connecting Rural Communities using WiFi" is an on-going project performed by the WAND group at the University of Waikato [28]. It takes wireless networks operating within the ISM bands to connect rural and remote communities. WiFi was chosen to diminish the cost of equipment and to take advantage of other existent interface resources for the sake of serving rural communities with a low population and low purchasing ability. The CRCnet network is made possible by the use of open-source software. One of them is SRG - Squid Report Generator, a flexible log file analyzer for the Squid web proxy. It is fast and flexible and has been created to allow an easy integration with other authentication systems. It can also report right down to the level of individual files if requested. SRG was decided upon for use by CRCnet developers because none of the existing reports generators could provide the exact solution they needed. Therefore, they preferred to start from scratch by integrating SRG into other authentication systems, rather than modifying an existing program. Another kind of software is Darpwatch - Distributed Arpwatch, a distributed Ethernet monitoring and reporting solution.

This case exemplifies the theory of designing and implementing a wireless network in rural areas where builders should pay much attention to special rural situations. WiFi technology should be the first to be chosen due to its advantage over bandwidth.

Another important fact to highlight here is how to choose and use open source software to resolve real technical problems such as Quality of Service (QoS). This fact has been applied in this thesis through the choice of open source communication systems development software.

2.5 Summary

In this chapter, the key components of a rural communication world were specified to give a full understanding of rural communications, which was the central theme of the research. Rural communications were a set of networks built in rural areas in order to provide rural inhabitants a good communication environment. Harsh rural environments, the availability of technologies appropriate for rural areas and the method of choosing an optimal one for specified rural area, and economic issues in a wireless network chain were three factors considered for building rural networks successfully. Some on-going projects or case studies similar to the research were generalized to help in understanding the research. In the next chapter, the Impact of Telecommunications Model that shows the significance of wireless network is set out.

Chapter 3 IMPACT OF TELECOMMUNICATIONS MODEL

Why is a wireless networking always considered as a first option for communication construction in rural areas nowadays? The Impact of Telecommunication Model is used to answer this question adequately. How, then, is the wireless networking able to meet the communication needs of customers to the greatest extent? A Service Model is put forward on its heels to guide the construction of the network in terms of meeting the communication service requirements of rural dwellers, choosing the appropriate wireless technology and optimal network structure for rural areas, and solving the technical problems of constructing the wireless network.

This chapter will select the economic parameters that are most related to the Impact of Telecommunications Model and will apply them to the telecommunication networks in rural areas. Two cases will then be studied to support the Impact of Telecommunications Model. The case in section 3.2 forecasts the importance of building wireless networks in Newcastle, South Africa; another case in section 3.3 concerns the wireless world of the whole African continent. Finally, the economic issues other than the impact of telecommunications will be generalized in section 3.4 for the purpose of future work.

3.1 Impact of Telecommunications Modeling

It is important to have an overview of the economic viability of a network by using a so-called Impact of Telecommunications Model. The concern of most rural dwellers is the contribution of telecommunications to wholesome economy in order to sustain an adequate lifestyle, while the concern of telecommunication carriers, equipment providers and services providers is to make long-term profits from initial capital and operating cost. A variety of emerging technologies and powerful telecommunication infrastructures support this goal to make profit. Generally, the telecommunication operators have their own cases for communication business. Even though, this model provides a basis for a business case model.

The percentage contribution p (%) of telecommunications to the production in an area is adopted in the research to represent the impact of telecommunications to the economy of the area, because it has directly expressed the aim of the model, which is to evaluate the telecommunication contribution to certain production. In the research, the production is specially chosen as the GDP due to its popularity and all-sidedness in economic world. The following expression models this relationship [27]:

$$p = x_1 \cdot g + x_2 \cdot g^2 \qquad (2)$$
$$0.2 \le x_1 \le 0.3, \quad 0.02 \le x_2 \le 0.03$$

In this expression, g is the GDP of the area expressed in value of USD 1000. The values of x_1 and x_2 are related to telecommunication penetration to this region, which is the sum of mobile and fixed line penetration. We select $x_1 = 0.3$ and $x_2 = 0.03$ in areas where mobile line penetration is 10% or less. Later x_1 and x_2 decreases by 0.01 and 0.001 respectively when telecommunication penetration rises by 10%, until x_1 or x_2 gets to 0.2 or 0.02.

3.2 Case Study in Newcastle Area

In this case study we assume the average GDP of South Africa specifically for that of the Kwazulu-Natal area. The reasons for that are because the newest economic data of South Africa is obtainable at any moment, and Kwazulu-Natal is a typical rural area of South Africa and forms the focus of study.

It is useful at this point to review telecommunication development in South Africa over the past 20 years by using the statistical data from [29]. A sharp increase in telephone penetration, especially mobile line penetration, can be deducted in Figure 5. The trends of both the GDP and the percentage contribution of telecommunications to GDP, which is in line with equation (2), will be plotted in Figure 6 to illustrate the proportional relation between them.

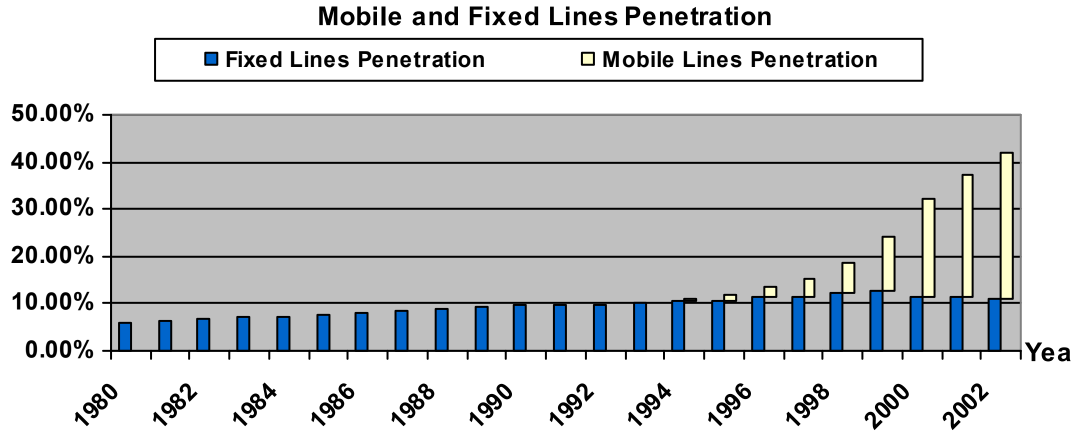


Figure 5. Mobile and Fixed Lines Penetration in South Africa

This bar chart shows that the fixed line penetration in South Africa was doubled in the year 2002 than it was in the year 1980. Despite that, fixed line penetration holds an approximately fixed fraction of the telecommunication market, whereas the mobile services have been holding a rapidly increasing part of the telecommunication market since 1994 when cellular services were first introduced into South Africa. Particularly after submitting the proposal to the Pyramid Research, Telkom SA has been relying heavily on wireless technologies [30]. In 2002, the market share of mobile services was three times greater than that of fixed lines. Nowadays, the mobile sector in telecommunications contributes an even larger proportion to the entire telecommunication market penetration in South Africa. It can be foreseen from the figure that mobile services will be leading the communication market in South Africa in the next few years.

However, what about the impact that the rapid growing mobile market, which results in a rapid growing telecommunication market, has on the GDP of South Africa? The answer can be obtained from the analysis of the following Figure 6. Telecommunication Contribution vs. GDP in South Africa.

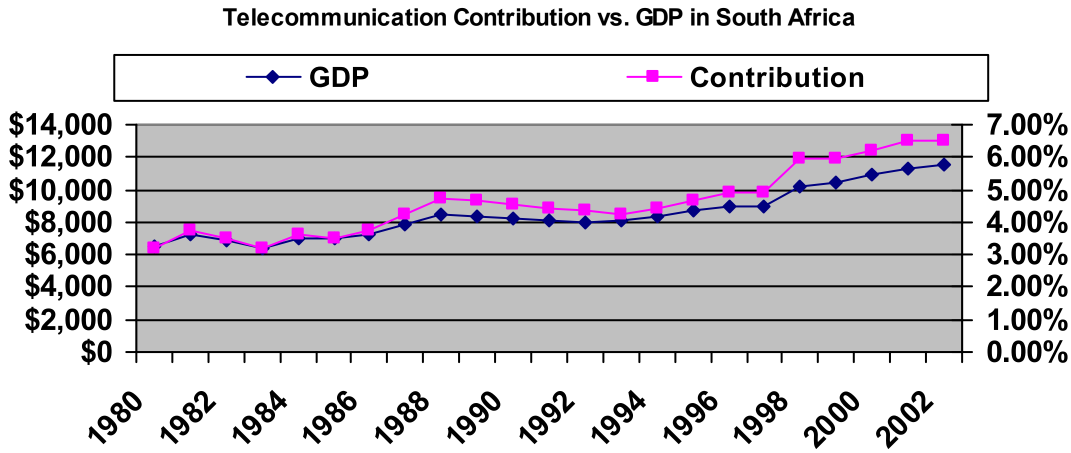


Figure 6. Telecommunication Contribution vs. GDP in South Africa

The contribution of telecommunications to GDP in Figure 6 has a similar tendency as GDP in South Africa, which indicates that an increase in the telecommunication market from Figure 5 results in a direct increase in the GDP due to the market contributing. This result may also be foreseen in the telecommunication situation of Newcastle. Furthermore, the contribution seems to have increased faster than that of GDP in the last 18 years, which can be attributed to a considerable increase of phone line penetration during this period. The slight decrease of the contribution between 1988 and 1993 came from the coalescing effects of the decrease of GDP and the leveling-off of telephone penetration, which is shown in Figure 5. The decrease of the contribution can also come from the heightened effects of international sanctions. Altogether, a positive influence of telecommunication penetration on the GDP of Newcastle can be surmised on the basis of the rising inclination of the contribution of telecommunications to GDP in the entire South Africa. At the same time, mobile services will be first considered in the construction of Newcastle communication networks due to their insurmountable leading position in the entire South African communication market.

In real terms, it is essential to consider some of the other contributions besides that of the GDP, which the telecommunication market has particularly made. One is the ease of communication, which means it is easier for people to stay in touch with one another through mobile communication. Another contribution is the enhancement of social cohesion and interaction which means that people can stay in touch more often with mobile than fixed line communications. The contribution the quicker response time makes to telecommunications and the factors such as assistance during road traffic accidents are also noteworthy.

3.3 Case Study of other African Countries

In the following example, the Impact of Telecommunications Model is applied to all African countries, in order to highlight the popularity of the contribution theory as well as give a clear and comprehensive understanding of current rural situations in developing countries by using the economic development of Africa as an example. The preceding section makes it clear that the contribution of telecommunications to GDP has a major effect on the GDP of South Africa, while the mobile and fixed line penetration only has some indirect relation with GDP. Therefore, a comparison of all African countries between the contributions of telecommunications to the GDP will be given in the following graphs. Results can be concluded from analyzing the following models. The GDP data of all African countries is obtained from [29] and presented as graphs.

3.3.1 Graphical Denotation

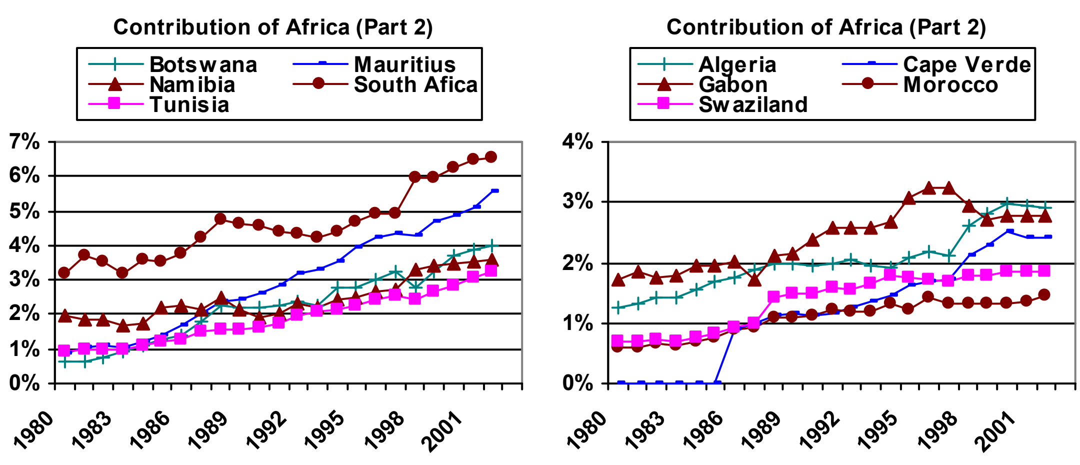
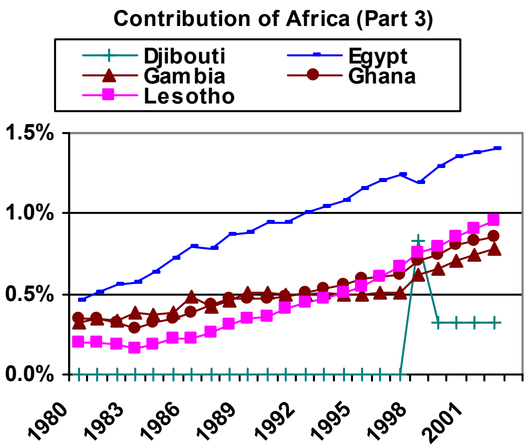


Figure 7. Economic Phenomena in Countries with Highest GDP



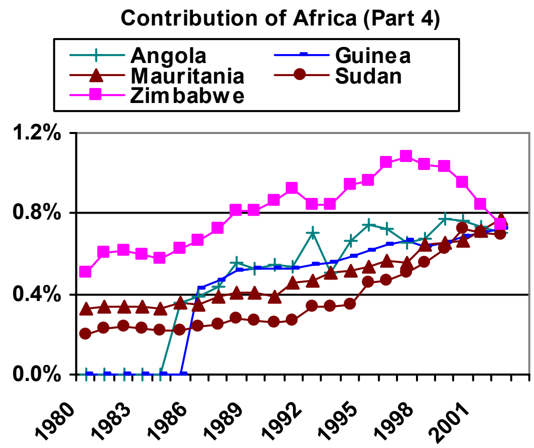
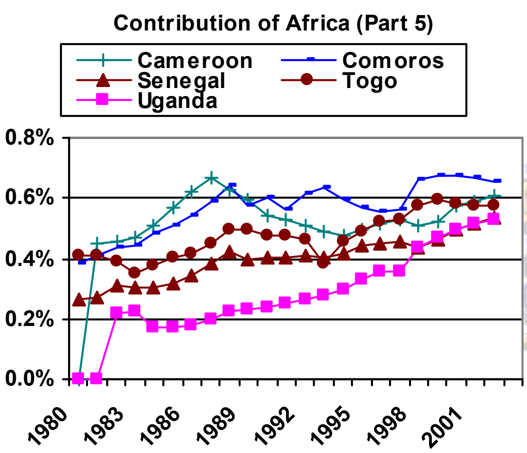


Figure 8. Economic Phenomena in Countries with Second Highest GDP



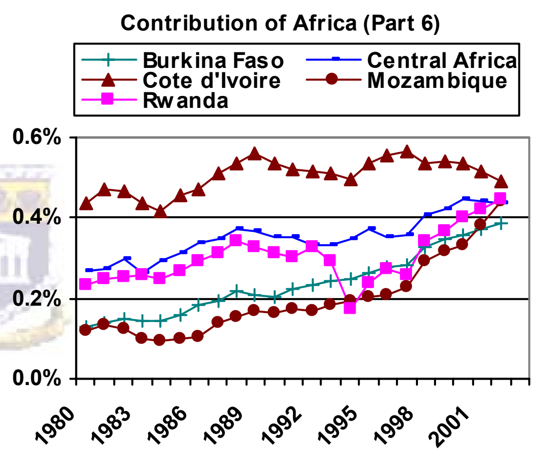
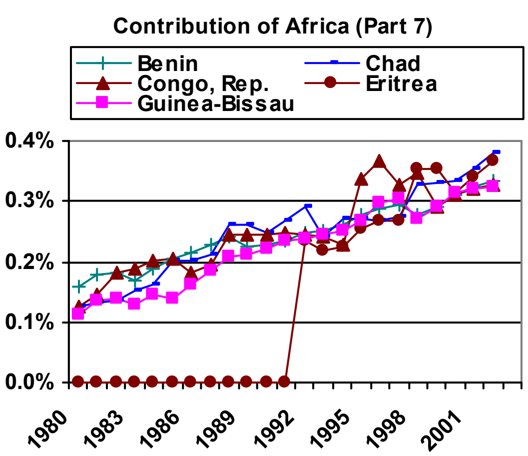


Figure 9. Economic Phenomena in Countries with Third Highest GDP



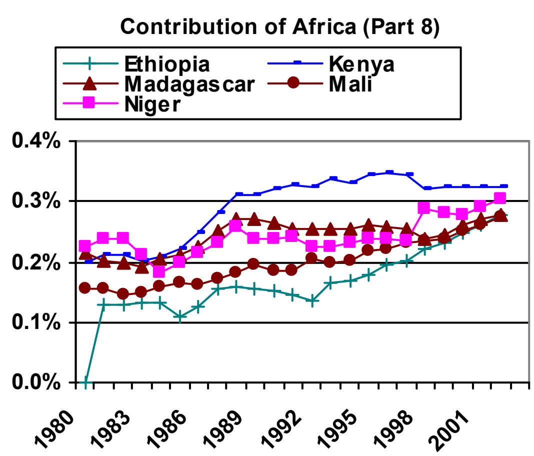
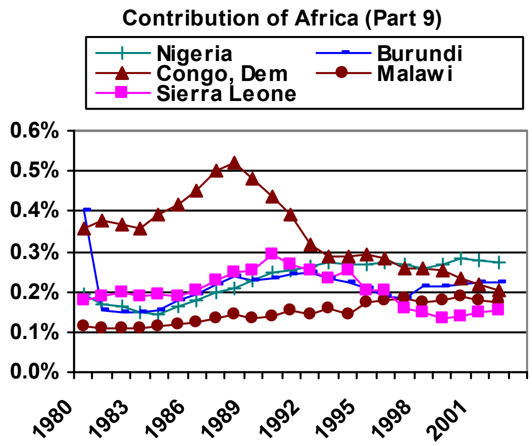


Figure 10. Economic Phenomena in Countries with Fourth Highest GDP



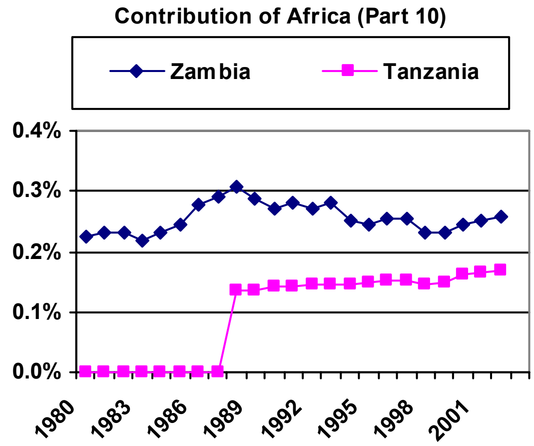


Figure 11. Economic Phenomena in Countries with Lowest GDP

"Contribution" in the title of all graphs means the percentage contribution of telecommunications to GDP. The countries of Equatorial Guinea, Liberia, Libya, Mayetta, Reunion, Sao Tome and Principe, Seychelles and Somalia are excluded from this task because of the shortage of their related data.

3.3.2 Analysis and Results

Those ten graphs from Figure 7 to Figure 11 provide some interesting data in terms of the GDP and the percentage contribution of telecommunications to GDP of African countries respectively. Many conclusions can be drawn from the analysis of these graphs and the relations between them.

1) As can been seen from Figure 9 to Figure 11, presently some African countries are still poorly equipped with telecommunication facilities, because the percentage contribution of telecommunications to the national GDP in those countries is low and no more than 1%.
2) A big gap exists between the comparatively wealthier countries and the poorer countries in Africa. For example in the year 2002, the telecommunication market in South Africa, which comes from the wealthier countries' group, contributes as high as 6.5% of the entire GDP of South Africa (see Figure 7), whereas the telecommunication market in poorer countries, such as Kenya, contributes to only about 0.3% of the entire GDP of Kenya (see Figure 10).

3) It can also be deduced from these graphs that the contribution curves of telecommunications to the GDP in most African countries have had a rising trend in recent years and this tendency seems set to continue in the near future. Especially in very poor countries with almost no telecommunication construction, the gradually increasing tendency curves that represent the contribution of telecommunications to the GDP in these poor countries seem to fluctuate arbitrarily, despite the small number of them (see Figure 11).

Actually, coupled with the same source of statistics, the tendency rules that are derived from the analysis of South Africa in the previous section can also be applied to other developing African countries. They are:

1) Only in the period between 1994 and 1998, have all African countries been enhancing their mobile construction by building mobile lines. The increased granularity, however, varies widely between countries with different types of economic development.
2) As the contribution of telecommunications to GDP in every African country manifests a similar fluctuation as that of the GDP of the country, a conclusive trend can be found. This trend is that the telecommunications have a positive and proportional effect on GDP in most developing countries.
3) In comparatively wealthier countries such as South Africa, the curve of the contribution of telecommunications to GDP has a similar fluctuation as that of GDP, even though it does not decide the movement of the GDP. However, in poorer countries, the contribution does not always conform closely to the GDP and at times. Although the type of change is the same, the amount of proportionate change is not always the same.
4) The similarity in the inclination of mobile line penetration and telecommunication penetration (mobile and fixed line penetration) represents a covariate relationship between them. That is when planning telecommunication development, especially in the past few years, wireless telecommunications are preceding wired lines and are always chosen as the first option when considering the construction of telecommunications in developing African countries. In other words, fixed to

wireless substitution is happening right from the foundations without established fixed telephone infrastructure.

3.4 Brief Economic Issues of Network

As shown in preceding chapter, economic issues, or more specifically, cash flows, involve the whole procedure of network construction. The Impact of Telecommunications Model simply proves the significance of building wireless network in rural areas. Other monetary issues, such as the calculation of initial cost, operating and maintaining cost, return of investment, third party benefit and so on, are completely ignored in the impact model. At the same time, these issues, including some economic codes and parameters, do relate to wireless network construction and do impact the operation and maintenance of networks in all aspects. For this reason, they are described in brief for the reference of future work. South Africa is used as the example in the description.

3.4.1 Pivotal Economy Parameters

Before starting to select the pivotal economic parameters, some basic codes, which can be applied to most network planning situations in terms of monetary issues, are examined first to give a general idea of what factors are of most concern in the wireless economic world [31]:

- Transparency - the open availability of information in the cost process. Information that is needed as input streams is acquirable from an open resource and easily controllable by both internal and external analysts.
- Practicability - the ability to implement a costing methodology with regards to available data source and corresponding data processing in order to keep the costing economically viable.
- Contribution to common costs - a reasonable contribution to common costs by adopting appropriate costing methodologies. It can be utilized in the research as the contribution of telecommunications to the production of the whole country.

- Efficiency - the provision of a forecast of cost reductions, which is as a result of an operable, efficient combination of resources.

The essence for a telecommunication service in terms of economy is "cost". In the perspective of an abstract economic management concept, cost is generally categorized into two parts – historical cost and current cost. The former is based on the cost price of equipment and services, whereas the latter takes into account the changing environment, which includes the falling prices of telecommunication equipment or currency depreciation. In the concrete concept of operation and maintenance perspective for telecommunication personnel, cost includes purchases from market, transport, personnel labour, taxes and levies, service charge and other operating provisions [31].

Due to the important role of these main economic parameters in the modeling process, they are defined and explained as how they are computed. Most of the information (refer to Appendix I Pivotal Economic Parameters as to the Pivotal Economic Parameters) is obtained from the ITU COSITD model [31].

3.4.2 Cost Modeling

To evaluate the costs of providing universal voice and data services to rural regions, we need open-ended and in-depth cost analyses for implementing a competitive cost-efficient wireless network in an area served by the incumbent telecommunication service provider. The model is set after the

1. Determination of the costs involved in implementing a robust backbone network, optimized switching points and an access distribution network with rational wireless access technologies for a commonplace wireless network.
2. Consideration of the serving areas, population, and current communications to identify optimal site locations. To do so, a database of the area is developed, and contains customer locations that help to identify the cost and revenue associated with network deployment.
3. Delivery of literal models that allow the client to conduct "what-if" scenarios to choose necessary cost parameters required for selecting different switching

locations, different backbone transmission sites, and assorted technologies to different serving areas.

4. Construction of indoor models and environments to simulate all-inclusive aspects of a network as well as to eliminate initial cost by using off-the-shelf freeware, with inceptive conclusions drawn from scientific, statistical samples.

Cost modeling divides the theory above into concrete steps that we are supposed to follow when doing the budget of the network cost in rural South Africa. These steps, chronologically listed below, are mostly related to universal service and adaptation to rural environments.

1. Construction of a model that accurately reflects the high cost involved in serving rural and remote areas in South Africa.
2. Determination of the inputs and sensitivities for this model.
3. Adaptation of the model to accommodate the rural nature of the serving areas.
4. Evaluation of new and different technologies that may be used in this model.
5. Determination of the most efficient (i.e., cost-effective) technology for serving each rural area and the calculation of the resulting service costs.
6. Geographical location of households and businesses for the purpose of accurately developing estimated service costs.
7. Program realization in the laboratory.

3.5 Summary

The Impact of Telecommunications Model in this research used a formula for calculating the percentage contribution of telecommunications to production to estimate the impact of Telecommunication networks on the economic development of the country or area specifically. Two cases were illustrated to validate the model. One was the telecommunication-contribution estimation of the Newcastle area and the other was an analogy with all African countries. Following this, some economic-related codes and parameters were described briefly. In the next chapter, the Service Model, which resolves most technical problems of constructing a network, will be discussed, and examples will be provided to illustrate this model.

Chapter 4 SERVICE MODEL

In this chapter, the process of constructing a Service Model is described. At the beginning, the chapter gives a brief description of the procedure involved in collecting the data. Then the definition and significance of a Service Model for constructing a rural wireless network are outlined in section 4.2 and the modeling method is expounded in section 4.3. Finally, an application of the model in rural Newcastle will be implemented in section 4.4.

4.1 Data Collection

Data is a very important ingredient of resource planning. In an on-going research project, it is necessary to continuously add to the working database abundant amount of fresh and correct data for research purposes. For that reason, the database of the project can be updated as soon as possible and changes can be tracked to make resource planning more effective. It may also, to a great extent, improve the efficiency of scheduled research management tasks and also ensure the correction of a scientific study.

Most of the useful mobile data that will be collected in this study will be attained through technology assessments, case studies, deployment reports, business strategy reviews, regulatory enterprise database updates, policy recommendations, market and service forecasts, revenue projections and trend analyses.

As the growth in mobile data represents some key interoperability challenges, consistent standards and clear interfaces for the wide range of applications are particularly proposed. More than that, data consistency and coherency[8] matters require information not only from the communication domain, but from a wide range of application fields. In this research, the wireless tele-health system in rural

[8] Everyone views the same data not different versions of the data.

Newcastle of South Africa incorporates data from the South Africa radio policy, the accounts of rural natural environments, population density and economic situations, accessible wireless technologies in rural areas, the common sense of rational simulation tools and evaluation tools. Most of the data used in this thesis are obtained from similar sources.

4.2 Definition and Category

As a key part of networks, a Service Model means more than just "service" that is commonly taken as a set of functions and facilities offered to a user by a provider [32]. The Service Model is a complex and pivotal model designed to meet the needs of customers. It follows then that the type of users determines the genre of networks in a Service Model, or services are determined by customer profiles, including their requirements, likes and dislikes, affordability and other determinants.

Customers can be universally classified as rural and urban users, residential and business users, male and female users, advantageous and disadvantageous users and so on. The most convenient user category for service providers is to design networks separately for rural and urban users due to their different communication requirements.

As shown in the Electronic Communications and Transactions Act, 2002 [33], South Africa's telecommunications strive to "promote universal access to electronic communications and transactions". The universal access, which is the main target that service providers expect of rural customers, is the accessibility and scalability of basic voice and data communications, and the necessarily cheap supplemental services. Meanwhile low-level quality requirement and fundamental correction ability, long-haul transmission and primary counter-interference are set in order to meet the universal requirements.

However, key network requirements for urban customers are more than universal access. These requirements interrelating with industries involve scalability, security, QoS and real-time availability. Accordingly, services required by those customers span a wider range than those for rural customers, such as file transfer on intranet demanding burst traffic and highly variable bit rates, high-bit-rate access to the Internet, wide videoconferencing with strong real-time constraints, and so on.

4.3 Service Modeling

A one-pipe-four-layer model, namely Service Model, is designed in the research to simulate service-modeling. A Management Pipe, an Application Layer, a Guideline Layer, a Network Layer and a Physics Layer are developed at different granularity yet work in conjunction with each other to form the Service Model. These layers should not be directly understood or equated to the context of the Open System Interconnect (OSI) Reference Model; rather they help us to discuss the various contributors to the services offered by the network.

At the top of the hierarchy, an Application Layer defines high-level services to be supported by the network. These services are interpreted by sub-services at the Guideline Layer, and each sub-service functions independently, as do the organs of a human body. For instance, fitting QoS is chosen to ensure a successful call procedure, or the capacity is set big enough to cover most parts of research areas. Following behind the Guideline Layer is the Network Layer. In the Network Layer, the overall architecture and communication strategies of the system, such as network nodes configuration, routing and rerouting, are defined by considering the constraints imposed by the Application Layer or the interfaces provided by the Physical Layer. The Physical Layer can be found at the end where it is responsible for supplying equipment and labour.

The relationship of the above pipe and layers can also be visualized as a distilling water system in Figure 12. First, one can conceive of the Management Layer as a pipe, the Application Layer, Guideline Layer, Network Layer, and Physic Layer then take their turns in this sequence, with each serving as a filter. After we have defined the input data and customer needs, data flows in the form of a stream through these filters one by one. In the end, we can get the "distillated running water".

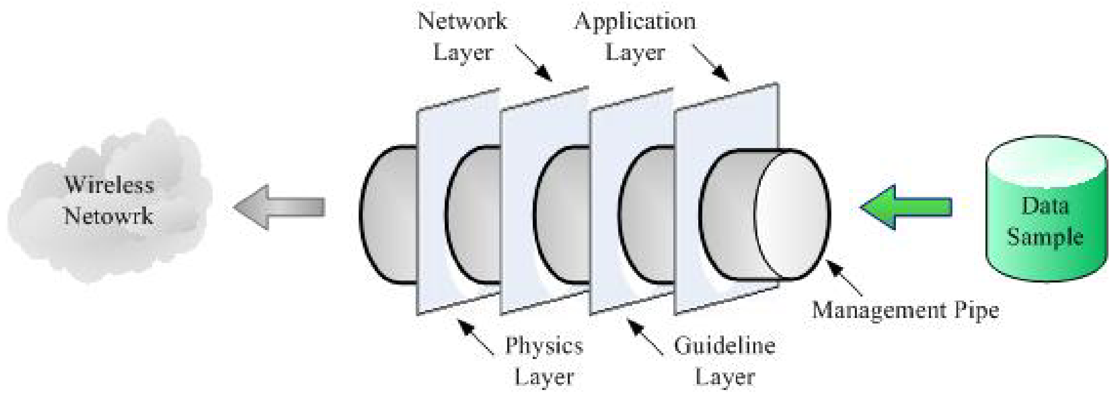


Figure 12. Service Model Guide

It is noted that the simulation procedure, however, is the reverse to that of the service design procedure. When simulating a network by using a software tool, specified equipment and labour are first chosen to set up a network topology, after which, network variables such as quality, interference, capacity and contribution are estimated. A conclusion about whether the requirements to the “service” of the whole Service Model have been met, which is the purpose of planning a Service Model, is finally drawn. This creates a function of back checks for the design of the model.

4.3.1 Management Pipe

As can be seen in Figure 12, the Management Pipe manages the four layers throughout the entire process of modeling in terms of the four system management aspects, which are functional requirement, operating system, system administration and database.

1. Functional Requirements

The following are the examples of the functional requirements that the functional Management Pipe should follow:

- Throughout supervision: By keeping the databases of all layers, the management pipe assures no loss of any data and sustains the data integrity in each layer.
- Coordination: Compatible parameters are defined for each layer for the purpose of cooperation between any two of abutting layers.

- Maintainability: Upgrade of operating systems and application software are done without affecting the availability of the system [34].
- Scalability: Modular design to each layer facilitates the actions of adding more functional modules when necessary.

2. Operating System

Network management is to be fully compatible with the operating system. The operating system comprises of an operating platform for building integrated telecommunication network management applications and many applications for operation control [34]. It allows services and data to be distributed around a network, compatible with general standards of network administration and corresponding controlling tools.

In a system, the operating platforms for servers and work stations are unified in order to get maximum performance by providing inter-processes and inter-node communication spreading across a number of computers.

The operating platform is also supposed to support high-availability clustering topologies, such as an active secondary server [34]. An active secondary server will support one or more of the following variations as "duplicate everything" when separate servers, with its own set of disks, apportion the task and duplicate each other, "share nothing" when the working server fails and another server assumes its ownership, or "share everything" when multiple servers share the same disks simultaneously to improve processing speed.

3. System Administration

Fundamental administration functions are supposed to be attainable and easily operable via GUI, such as

- System start, shutdown and reboot.
- Configuration of hardware, disks and file systems.
- Networking and communication configuration.
- Process management and log file management.

- Creation, modification and deletion of users and user groups.
- System back up and repair at certain times.

4. Database

Any database management system in the Service Model is to be a Relational Database Management System (RDBMS). "Relational" means that all databases of the four different layers stored in the Management Pipe are acting as if they are one. Data shall be infused through the interface of each layer and shared by other layers.

It will be possible to partition freely any relevant databases used by the software applications to facilitate closed user groups. For instance, in a hospital, the fraction of obtainable medicines in a database is sorted for doctors groups, while kept in the same database are user manuals of those medicines available for patients groups.

4.3.2 First Filter – Application Layer

The first layer of the Service Model aims to clarify the types and characteristics of services that the wireless network is supposed to provide to customers, and is therefore called the Service Layer. However, to avoid mistaking the Service Model for the Service Layer, the Service Layer is referred to as the Application Layer in this research. Moreover, the Application Layer differs from the application layer in OSI reference model. The Application Layer in the research is designed to help understanding the service requirements of the five communication nodes throughout the value chain, including telecommunication carrier, service provider, equipment provider or manufacturer, information channel and end user (see Figure 4). However, the OSI application layer is responsible for displaying data to end user in a legible format and interfacing with the presentation layer below it [35].

First, the relation of service-supply and service-demand between the five communication nodes is to be explained. How can a telecommunication carrier please its consumers? Service takes the responsibility. Further, for the service provider, even a successful service provider, the key to impress new users as well as to keep traditional subscribers boils down to one crucial issue, service delivery. Information channels, such as TV or a newspaper, attract customers by informing their audience and readers by an array of immediate and fresh messages about services available, and make profits from both service users and service providers. Customers, of course, require services, receive benefits provided through service advantages, and base their life joys on a variety of communication services. Therefore issues on service play an essential role in constructing a local network. The main relationship of services between communication nodes is depicted in Figure 13.

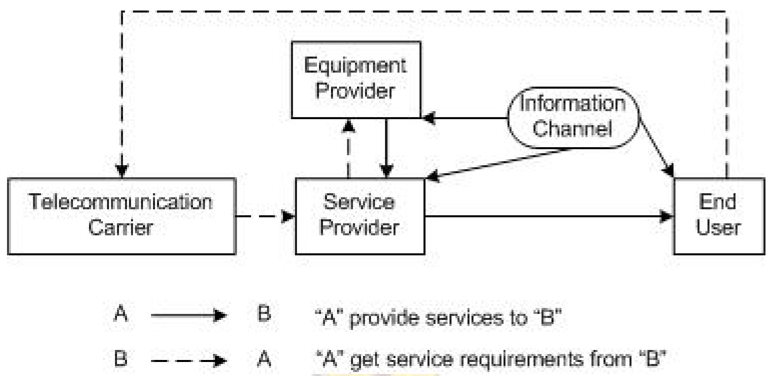


Figure 13. Service Chain in a Communication Network

The focus is on two service provisions, both from the service provider to the end user and from the equipment provider to the service provider because other services can either be expanded from or be represented as these services. The following services in this paragraph are specified as the two kinds of service depicted above. To stay ahead in the telecommunication field, the services are supposed to have prominent and peculiar traits. For instance, they must supply high performance and service variety, be fairly robust and have cost-effective connectivity among a large number of communication devices or wireless terminals and, most important of all, appeal to the customer. The services should also be able to accommodate changes in both the technologies being used and the demands imposed by application software.

The service requirements, especially those in between the five communication nodes in the value chain, are derived from local needs, yet can only be implemented by real communication network design and deployment. In addition to being clear of what services are needed, a widely-accepted open technical guideline and a clear blueprint of the network architecture are important as a first step in network planning as well.

They will create clear business interfaces and guidelines to accomplish the services, which may enable developers and third-party wholesalers to deliver those services to the market. These will be discussed in the next two sections.

4.3.3 Second Filter – Guideline Layer

The Guideline Layer gives the criteria, for reference, as to resolving technical problems when constructing a rural wireless network. Thus, services in the Application Layer are specified in the Guideline Layer as detailed technical targets. For instance, the technical targets for constructing a rural wireless network include how to render a high-quality voice communication over long distance, how to protect a network from natural calamities and the interference from man-made facilities, or how to obtain maximum advantage with limited resources. Two questions are taken into main consideration:

1. *How to choose an appropriate wireless technology according to rural situations.*
2. *What technical parameters need considering in a rural network construction.*

The two questions will be answered in details as follows:

1. How to choose optimal technology

Technologies, no matter mature or new, improved or converged with other issues, are emerging to meet the requirements of the guidelines for the telecommunication industry. Therefore, the selection of technologies for applications is important when planning a network. The criteria for choosing an appropriate technology for each planned network deployment among other things are weighed according to customers' needs, commercial viability, culture, financial budget and physical environments. The following criteria can be generally used for selecting wireless access technologies for rural areas.

Table 5. Network Character Guidelines

Category	Guidelines
Quality	High-quality voice and data
	High spectral efficiency

Large Coverage	Long-haul transmission with certain level of power consumption	
	Robust to environmental extremes by anti-jamming	
Infrastructure	Short rollout time	
	Ease of installation, operation and maintenance	
Cost	Low initial and lifetime costs (network and terminal)	
	Modularity and scalability	
Social Benefit	Variety and flexibility of service applications	
	Compatible with local wireless profiles (e.g. Frequency Spectrum)	

2. What technical parameters need considering

Since the research focuses mainly on universal access to voice and data communication services in rural areas, we must guarantee that local people get immediate access to communication when they require it and obtain clear information from wireless or Internet terminals at low cost. Therefore, QoS, Bandwidth, Transmission Speed, Network Capacity, Signal Delay and Outer Interference form the emphasis of technical problems in the Service Model.

QoS generally refers to all-sided quality requirements on communication networks. In most cases, the quality for rural communications suffers over long distances in terms of the construction, transmission, maintenance and upgrade of networks. It is therefore worth considering when planning the network in order to provide customers with an unobstructed communication environment. Certain amount of bandwidth is surely needed in any network to accommodate network traffic. A stable transmission speed affords reliable phone calls and internet surfing. Sufficient network capacity and wide network coverage provide universal access to communication for rural people who are distributed over large areas. Inner interference from the same frequency or neighboring channel is minimal due to lower user density, but outer interference hampers network quality by the long time transmission of signals (For more details of these parameters refer to [36] [37]).

4.3.4 Third Filter - Network Layer

Network topology in the Network Layer is used side by side with technology calibrations in the Guideline layer to build an ideal wireless network on paper. Ordinarily a network topology is characterized by:

1. Physical Topology (What the network looks like), which represents the physical interconnection structure of a network graph.
2. Routing Algorithm (Which route the data flows along in the network), which restricts the set of paths that signals or messages may follow.
3. Switching Strategy (How the data is carried to destination), which prescribes how data traverses a route, by circuit switching or packet switching.
4. Flow Control Mechanism (When the data gets sent), which explains when a message or portions of it are allowed to traverse a route and what happens when traffic congestion is encountered.

These four key points will be interpreted in more details as follows:

1. Physical Topology

There are two main elements, which are responsible for a Network Layer composition. One relates to software, such as the services to the protocols and the interfaces between wireless network nodes. These software-related issues supply the design mode to meet the customers' needs and work as the connection between the layers in the form of interfaces. Another element relates to hardware. That is physical topology. Depending on the manner of connection, the network consists of either a static network with an unchangeable connection or a dynamic network with a reconfigurable connection. Depending on the relationship between any two nodes, a network can be a ring network, a star network, a bus network, a tree network, a mesh network or a combination of those networks [38]. Depending on the respective function of its topology, a network can be a Public Switched Telephone Network (PSTN), a Local Area Network (LAN), a Wide Area Network (WAN), an Intelligent Network (IN), a Synchronous Optical Network (SONET) or Internet [39].

Four typical rural networks with respective virtues and practicability are listed below in Figure 14 [40].One is the network with typical architecture based on traditional cellular network. Another is the one based on the extension of fixed network (i.e. PSTN) using radio or fiber. The third one is based on satellite communication network. The fourth network possesses a self-contained networking scheme. Appropriate network topology for specified rural areas can be chosen from those usable topology types.

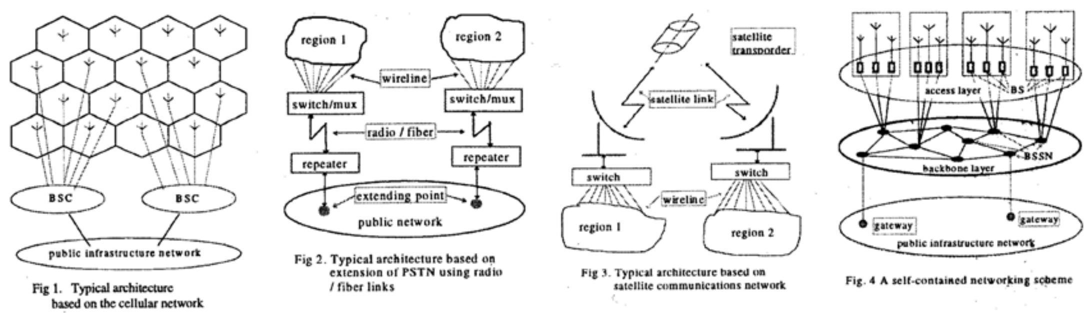


Figure 14. Typical Networks for Rural Communications

The comparisons of those different architectures are summarized in Table 6 [40]:

Table 6. Summaries Comparison of Different Network Architectures

	Cellular	FWA	Satellite	Self-contained
Capacity/Coverage	Very large	Limited	Limited	Flexible
Subscriber Density	Prefers high	Adaptive	Adaptive	Adaptive
Interface to PSTN	Complex	Varying	Simple	Simple
Mobility	Yes	No	No	Yes
Implementation	Complex	Simple	Complex	Simple
Price or Cost	Expensive	Expensive	Expensive	Reasonable

2. Routing Algorithm

Routing algorithm is used to find the best transmission route to a destination. When we say "best route," we take into consideration parameters such as the number of hops[9], time delay and the communication cost of packet transmission.

[9] Hop denotes a trip a packet takes from one router or intermediate point to another in the network.

QoS routing is one of the most frequently-used routing concepts in network world, the considerations of which may assist network planners to accommodate data flows that expect certain performance guarantees from a network [41]. Link available bandwidth, link propagation delay and hop count are three main metrics on which the "best route" in a QoS routing environment is based [42].

Moreover, from the perspective of how the network nodes gather information about the structure of network and how to analyze the information to specify the best route, two major routing algorithms are generally considered in industry: global routing algorithms and decentralized routing algorithms. In global routing algorithms, also known as Link State (LS) algorithms, every node has complete information about all other nodes in the network and the traffic status of the network. In decentralized routing algorithms, known as Distance Vector (DV) algorithms, each node has information about the nodes it is directly connected to yet it does not know other nodes in the network [43].

3. Switching Strategy

Is a time slot, a code, or a frequency used for switching? Is transmitting by circuits or packets? Switching seems to be a prominent problem for telecommunication carriers when they choose appropriate technologies for rural areas. Yet, in fact, the time-division packet-switching strategy has its obvious advantages in most prevailing wireless networks.

TDMA is preferable in rural areas because it has been widely used in wireless networks and is easy to be extended into underdeveloped rural areas from existing networks. CDMA, however, with its main aim of "expanding" the bandwidth to meet the drastic growth of various communication requirements, is not really necessary in rural areas where there are small number of customers with basic communication requirements and small portions of bandwidth demands. FDMA is not preferred in rural areas as well and it is even seldom used in entire radio world because of its limited spectrum.

On the other hand, packet-switching excels circuit-switching due to its higher radio spectrum efficiency. By using packet-switching, limited amount of bandwidth can be shared among multiple users at the same time, and a seamless, continuous connection to the network is ensured to each network user [44].

4. Flow Control Mechanism

In communication networks, flow control mechanism enables the process of adjusting data flow from one device to another in order to ensure that the receiving device can handle all the incoming data. This is particularly important where the sending device sends data much faster than the receiving device can receive data [45]. The question arises when a choice has to be made in choosing a proper control mechanism between that of a congestion flow control or a non-congestion flow control. A congestion flow control mechanism controls data flow after congestion, while a non-congestion flow control mechanism predicts congestion in advance and carries out effective flow control methods to avoid the advent of real congestion.

4.3.5 Fourth Layer - Physical Layer

The Physical Layer forms a final physical platform that is responsible for rendering a wireless network. This layer is formed after the serving targets of the network have been attained in the Application Layer, the ideally appropriate technologies have been chosen in the Guideline Layer and the network draft has been pictured in the Network Layer. Peripheral equipment works in association with the relative connections between these peripherals to interweave a functional network.

Apparatus involved with most commonly-used wireless network nodes in GSM include Local Exchange (LE), Base Station Controller (BSC), Base Station (BS), Repeater Station (RS), Subscriber Terminal (ST), and Cluster Terminal (CT). To link these apparatus which have multifarious network purposes, transmission media materials vary in terms of their working parts in the whole network, including backhaul, access, and last miles. These transmission media materials are twisted pair, cable, fiber, microwave link, and satellite. When considering the most appropriate equipment for network settings, what is always taken into account is the network availability (long-distance and resultant interference) and economic cost for rural areas.

4.4 Case Study in Newcastle Area

To illustrate the implementation of the one-pipe-four-layer service-modeling at length, a service model is set up in Newcastle, South Africa and is called as Newcastle-service-model. Before building the Newcastle-service-model, it is necessary to briefly summarize the current telecommunication-development situation of South Africa as it is the communication background of Newcastle area. South Africa is a middle-income country with a very low level of communication infrastructure, particularly in rural and remote areas. For example, the penetration of wireless services is only 22 lines per 1,000 people in rural areas due to a poorly linked infrastructure and uneven spread of telephone lines across the country [46]. However, it has a very high demand (long waiting lists) for voice communications and a steadily growing demand for data communications as most African countries [47], and has already commercially deployed mobile cellular communications in major cities. The main aim of South African telecommunication developers is to have universal communication access to most areas, especially rural areas.

Newcastle, the target area in this research, is situated in the north of KwaZuLu-Natal, a typical rural area of South Africa. The case model is named "Tele-health: A Wireless Network Planning Case Study in Newcastle, KwaZulu-Natal, South Africa", and the expected network is called "Newcastle-Health-System network" (NHS). The purpose of this model is to develop and implement an innovative community wireless network, and to facilitate improved healthcare and sustainable development in a deep rural community.

4.4.1 Newcastle Background Knowledge

First, the social and natural information of Newcastle area is gleaned to assist in determining the service requirements, the optimal technology and parameters, and the suitable network topology of this area. This information includes geography, weather, demography, transport, environment, economy, communications, and medical care, and more details about them are explained as follows:

Geography and Demography

Newcastle lies in KwaZulu-Natal to the west of south Indian Ocean, with a large number of Zulu-speaking people living in rural areas. Its total land use is 1854.60 km^2 [48]. The terrain is relatively flat with no forests. The open terrain helps in eliminating obstacles from interfering with radio signals.

The climate is generally humid with cold winters with temperatures ranging from 2 - 11°C (May - August) and hot rainy summers with temperatures ranging from 18 - 32°C (November - February). The perennial humid climates augment corresponding requirements for peripheral equipment and add to the cost and difficulties of maintenance. Limited sunshine also impacts on the use of new energy such as solar power.

The Newcastle health region has a total population of 287,260 with 55,184 households [48]. The average population density is 1.55 people per hectare. The areas of highest population density (50 people per hectare) are in the middle east of Newcastle area. The lowest population densities occur in commercial farming areas. Thus a geographic position of future subscriber market occupation can be foreseen according to the dwelling distribution of the communication customers from either low-density rural commercial farms or high-density rural centers.

Transport and Economy

Few roads are tarred and a large number of the roads are mud roads. Taxis and buses are readily available and are accessible to most people. About 30% of the population has cars [49]. On one side, mud roads add to the difficulty of building a network. For instance, it takes longer to drive on mud roads than tarred roads to transport building materials. This will increase the construction cost. On the other side, easy access to public transport nodes becomes a potential factor which spurs the establishment of mobile networks. No matter how far people travel, they need to keep in touch with each other by using mobile communication devices.

Of the Newcastle's total population, about 30% are employed, 20% are unemployed, and half are under age 15 [48]. From these figures, it could be argued that this situation leads to low annual household incomes. It is reported that only 11.7% of the population earn between R6001-R12000 per year, 16.4% earn between R2400-R6000 per year, and 58.9% have an income under R2400 per year with the rest having no income at all [48]. The very low economic development within the region prevents wireless telecommunication services from expanding to Newcastle. However, communication is still expected in the region to positively influence the growth of the economy in the future.

Communications

Most homes have private telephones and at all street corners there are public phones. Most homes have a radio. According to the year book [48], it is not made clear as to how many and to what extent mobile communication is being used in the area.

Medical Care

Table 7. Health Care Situation in Newcastle

Hospitals	Mobile Services	Clinics
Madadeni Hospital; Newcastle Province Hospital;	Madadeni Mobile Services; Newcastle Farm Mobile Services; School Health Services;	Madadeni Clinics; Majuba Clinic; Newcastle Clinic; Osizweni Clinic; Rosary Clinic; Suryaville Clinic; Sutherland Street Clinic; Thembalihle Clinic;

This information shows an organizational structure of Newcastle health care system [48]. Normally, each health region has at least one designated regional hospital, two or more district hospitals, and several primary health care centers. Newcastle, the region of interest in KwaZulu-Natal, has one regional hospital, one district hospital, eight major clinics and some health services.

4.4.2 Newcastle Service Modeling

The demonstration of the Newcastle-service-model will be carried out in the same order as how service modeling was done in section 4.3. First, the database management mechanism is chosen in the Management Pipe. Then, the service requirements, the optimal technology and reasonable parameters, the suitable physical topology, and the necessary equipment are determined in the Application Layer, the Guideline Layer, the Network Layer and the Physical Layer respectively to form the final Newcastle-service-model.

4.4.2.1 Management Pipe

A compound management mechanism of Centralized Information Management (CIM) and Distributed Information Management (DIM) is performed as the mechanism of the Management Pipe in the NHS. This management mechanism enables the setup of a pivotal control center within the regional hospital, the Newcastle Provincial Hospital, where not only physical nodes such as local exchanges are installed, but most important information, such as the profiles of the patients who are severely ill in the health care system, are also stored. The information of the patients who have minor problems is kept locally in a distributed database in separate network nodes, which are either district hospitals or clinics. All in all, the CIM manages the information transmitted between the control center and the health nodes, while the DIM administrates those health nodes locally. In the section, an explanation is given on how the information is stored and exchanged.

The Management Pipe coordinates four practical lower-level layers through a unified operating system and public database. It can collect instant data, packet them by category, and transfer them to the targeted database according to the category they belong to. In other words, the next step for data processing is supposed to be determined and performed in an intelligent way. A detailed description of the management mechanism will be stated in the following paragraph.

As displayed in Figure 15, common information such as the profiles of patients, the personal details of the medical staff and data on medicine inventory are collected and stored in the nearest node (C), and important information such as the profiles of the patients who are severely sick and the list of medicines that are out of stock in a clinic in the node will be sent to the control center at regular time intervals (B). Emergency messages such as urgent consultation and the request for emergency medicines are relayed as soon as possible (A). The kind of emergency information will not, at any time, be stored in the database of each node. Once the information of type A and B have reached the control center, it will be kept as emergency information to be dealt with. Then the control center will transmit the required information back to the demanding node immediately after it has been requested (A'). The center will disseminate health-related knowledge to all nodes when necessary (D). As the CIM is only used between the control center and the health nodes and DIM in between these health nodes, there is no information exchange between any two nodes. They keep and update their own databases (C). However, some nodes may take on the responsibility of a transfer node for other nodes in order to transmit information to the control center node, which is dependant on the topology of the system. The topology will be explained when discussing the Network Layer.

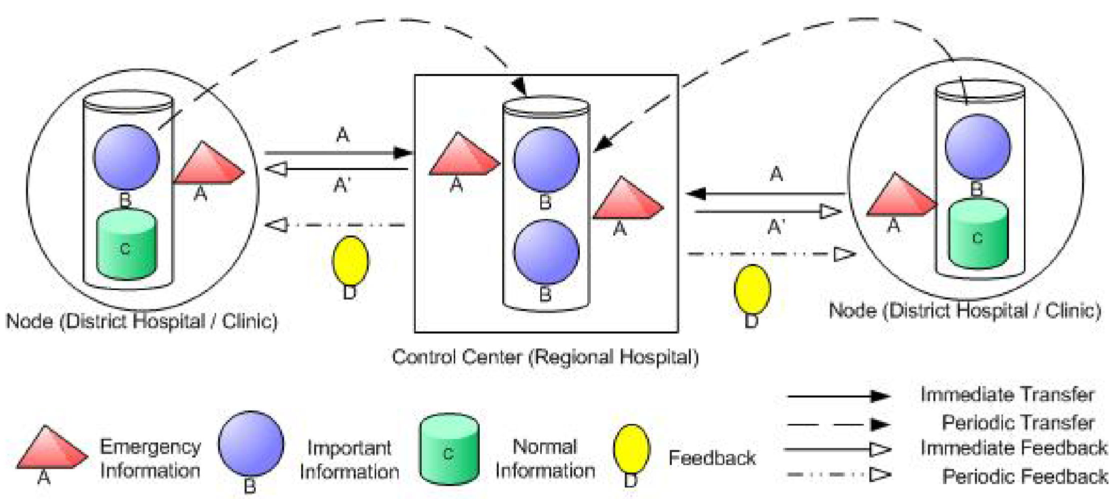


Figure 15. Database Management of Newcastle-Health-System

Why choose a hybrid database control with both centralized and distributed management? First, as only around 300 thousand people live in the rural Newcastle area, it might be easy to apply a CIM system to the medical system for the pure purpose of dealing with the special cases of the seriously sick persons. Second, a uniform CIM to sub-areas simplifies administration procedures. For example, an integrated database mainly about the details of the serious illness cases, is therefore easy to be categorized and proofread, searched and altered when being kept in the control center node. This means in other health nodes, there is no need to keep detailed profiles of the patients who become seriously ill. Some necessary and newly-updated information on those patients' situations and urgent operations, and some general administrative information such as the number of all current patients are all that is necessary in the information transmission between the control center and the health nodes. This will save on corresponding hardware, management and labour. Third, at each health node, the health information of the common patients who live in the vicinity around the node is stored locally. Therefore, this information can be called on, enquired and renewed immediately and accurately.

To meet the administrative requirements in a Management Pipe, which has been explained in section 4.3.1, the hybrid network management system in the research must, at first, be compatible with the operating system. To realize the function of uniform management, a proper unified platform system is supposed to be designed by the network planner to enable the scalability of providing inter-process and inter-communication across workstations in the regional hospital, the district hospital and the health care centers. The platform should also support health information backup through an active secondary server in case of a sudden breakdown of the main server. Furthermore, a simple yet categorized database is advised here due to the small population and the numerous types of disease in the Newcastle rural area. Assorted application software is supposed to collaborate with each other, and be fully functional under normal situations and malfunctioning situations such as the breakdown of the main backup server.

4.4.2.2 Application Layer

The Application Layer in the Newcastle example, without saying, concerns medical care services that benefit dwellers more than businessmen. Thus, what rudimentary communication between nodes can be supplied and how to store radical data are more important. Furthermore, some common, would-be services can be applied to health and medicine system in rural areas such as the following [1] [6]:

- Delivery of health information to medical professionals in the field.
- Delivery of prevention-oriented health information to rural communities.
- Entry of patient data in remote databases.
- Access to medical specialists via Tele-consultation.
- Relay of different kinds of medicine information.

In the NHS as shown in Figure 16, we have the Newcastle provincial hospital serving as a regional hospital node, Madadeni hospital as a district hospital node, and all other clinics nodes distributed in the nearby vicinity. Network services interflow between them. Therefore, Newcastle service can be represented as achieving the following:

- Gather and send health information from district hospital or clinics to professionals in regional hospitals, which enhance the reach to the limited number of South African doctors. As reported, many South African rural doctors choose to work in foreign countries for higher salary. Thus the shortage of professional doctors renders their assembling only in big hospitals. (A)
- In contrast, prevention-oriented health information, for example that of how to abstain from HIV/AIDS, is delivered to rural communities to help the rural people take precautions, especially when it comes to infectious diseases. (B)
- Doctors or nurses, no matter where they are, have access to patients' basic data stored in local health node, to important data in a remote database which is set up in regional hospital, and to medical specialists at health nodes to whom they can make verbal enquiries. (C)

- To disseminate health knowledge over the entire rural population in this area, radio broadcast is preferred in rural residential clusters due to the cheap price and portability of the terminals. (D)

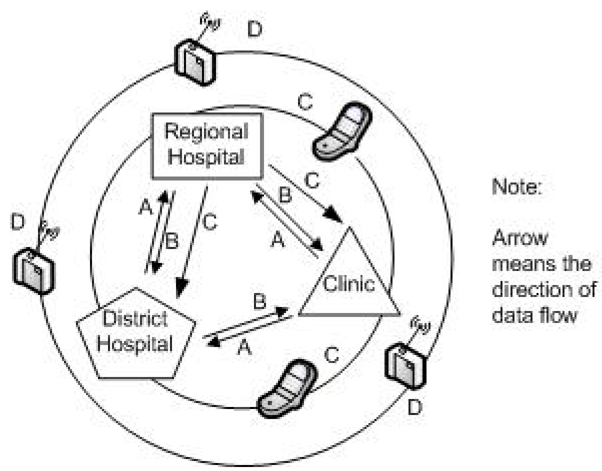


Figure 16. Applications Structure of Newcastle-Health-System

Thus, as shown in Figure 16, the main functions of offering health services to local people, especially the functions about the intercommunications between the control center and all the health nodes, are to be realized by means of building and restructuring a elementary wireless network.

4.4.2.3 Guideline Layer

Two conclusions are drawn from section 4.3.3 and taken into consideration in the Guideline Layer. One is to choose optimal technologies for NHS; the other is to pick some important parameters to evaluate the quality of the network. This section discusses those conclusions further.

1. Optimal Technologies

In this research, cellular-based GSM rural radio systems and cordless-based DECT wireless local networks are proposed to be widely deployed in NHS in order to achieve faster, more economical and practical service provision.

The use of GSM took off in South Africa as early as in 1994, and is now the largest GSM market outside Europe. All of the network providers such as Vodacom, MTN and Cell C have GSM networks. Even though cellular services in Africa are generally concentrated in major cities due to their installation along major transport trunk routes, rural areas are also benefiting from the services by being connected through the main routes to major service areas. Therefore, applying GSM in new service areas reduces the expenditure of initial investment and makes it easy for rural areas to be part of the widely spread network. As referred to in Chapter 2, a typical cell of GSM400 cell has a 40 km radius when using a 2-watt mobile phone unit. This characteristic of GSM meets the need for a large coverage within rural area quite well. Moreover, through easy implementation and maintenance, applying GSM NIB in the form of simple equipment facilitates the network development in rural areas which are short of technical personnel. GPRS technology, with its attributes of larger bandwidth supply and "forever on-line" connection, is also suggested in NHS to facilitate the wireless communication between medical personnel and to ensure the transmission of emergency information.

On the hand, the DECT technology can be used in collaboration with WLL to serve the clustering rural centers and their own vicinity respectively. Many advantages can be suggested for deploying DECT in NHS – fast developing speed, low cost, and redeployment ability especially in fast-growing user areas such as rural commercial farms. Furthermore, the installation of wireless local loop systems using a DECT air interface standard is meeting its license obligations, which deals in particular with the frequency limitation stipulated by law in the 1900 MHz band (see [45]). In 1997, Telkom awarded a contract within the Pyramid Research for the installation of 420,000 DECT-based access lines in South Africa [30]. That makes it easier for Newcastle area to adopt DECT as it can obtain well-prepared technical and financial supports from Telkom.

As a whole, GSM400, GSM/GPRS in a box and DECT WLL are preferred data communication technologies for rural South Africa due to their own technical advantages for rural areas and South Africa offering excellent development potential of wireless service in its long-term development and reconstruction efforts within the wireless technology field.

2. Considerable Parameters

The Guideline Layer also seeks to establish a set of parameters that indicate the state of the network. As described in section 4.3.3, some criteria are used to estimate the performance of the network, including QoS, Bandwidth, Transmission Speed, Network Capacity and Signal Delay (Link Delay and Routing Delay). Outer Interference is excluded in the NHS because it is most influenced by natural circumstances other than the issues which human can control.

- QoS is mainly discussed as latency here because other child parameters of QoS, such as bandwidth or transmission speed, will be discussed separately on heel. Latency in transmission time is acceptable to some extent because we merely need the transmission of very important data such as the data of the patients for urgent operation. Other data such as the final results of normal checkups at health nodes, however, are stored at self node. It is essential, however, to make sure that the correct data are being transferred. This fact is related to the need for accuracy concerning the error rate of interconnecting links.
- Since NHS is mainly designed for exchanging emergency medical information, large amounts of common data stay at the local health node. Therefore, no large amounts of data need transferring at the same time, which makes lower demands on bandwidth.
- Transmission speed counts for little when enquiring about a medical situation. In rural clinic areas, doctors and sisters help cure the patients by using their mobile terminals to keep in touch with specialists. This does not need to transfer large amount of data and does not happen frequently. Therefore, a high transmission speed is unnecessary in the NHS.
- Network capacity is normally defined as the user number per unit coverage area that a communication system can serve. The coverage area in squared kilometers, the traffic density in the area, the fraction of inter-node traffic and the average

number of links for a route are main characteristics of a rural network. Network capacity is the main requirement, or reason, of establishing a network or penetrating an existing network in the rural Newcastle to meet the universal communication requirements of habitants there.

- The average routing delay is not critical for rural networks since the main concern is not the QoS, rather the availability of service. However, if the network is to be used to carry delay-sensitive information such as a video of a patient, link or routing delay becomes an issue that can impact on the reconstruction and reproduction of information in a timely manner.

Altogether, to maintain a long life sustainability of this health system, the above variables are pertinent for rural network designers more or less.

In the following paragraphs, some important network parameters involving factors described in the previous paragraph are chosen to evaluate the performance of a wireless network. They will be applied to the wireless network simulation programmed in Scilab language for the Newcastle area in Chapter 5.

Since no special requirement is made on QoS, the objective of the network design is therefore to ensure that most calls get through. To make this possible, incoming network traffic "A", and the probability of a call blocking "B" or Grade of Service (GoS) are considered. The former parameter is assumed to be less than 0.25 per km^2 for rural Newcastle [50] and the latter one is supposed to be less than 0.05 [51]. They are related by the following equations [52]:

$$A = S \cdot \lambda$$

$$B = \frac{A - A_0}{A} = \frac{\lambda - \lambda_0}{\lambda} \tag{3}$$

$$A_0 = \textit{successful incoming traffic in Erlang}.$$

$$S = \textit{average occupying time of each call}.$$

$$\lambda = \textit{the number of calls per hour, calls / hour}.$$

Furthermore, the M/G/1 system and the Go-Back-N (GBN) protocol are selected to simulate the traffic environment in which the network bandwidth "B_s" and the average route delay "T_s" can be obtained. The M/G/1 system is a simplified production system in which arriving jobs are grouped into different classes and these job classes have different processing times [53]. It aims to meet the variety of all kinds of jobs. Moreover, incoming calls in a communication network happen to have this kind of variety due to their random arrival time and service duration. An M/G/1 queue is therefore assumed for each routing path to simulate a call procedure, which includes call arrival and call service. In most call traffic models, the call-arrival-rate is assumed to be a Poisson distribution and the service time of each call to be an exponential distribution [54]. Meanwhile, each link obeys a Go-Back-N protocol (GBN) to process the calls that arrive at a Poisson distribution [50]. In the GBN, only a fixed number of arriving calls can be processed immediately. This is done within the processing ability of this link. Some calls will be blocked if they arrive at the time when the network is fully occupied. In this assumed communication environment, network bandwidth "B_s" and average route delay "T_s" can be expressed as:

$$
\begin{aligned}
& B_s = 40 \cdot \alpha \cdot \beta \cdot C \cdot L \cdot \frac{1+(a-1)\cdot p_e \cdot L}{1-p_e \cdot L} \\
& T_s \le 4 \cdot n_{av} \cdot \frac{L}{B_s} \cdot \frac{1+(a-1)\cdot p_e \cdot L}{1-p_e \cdot L} \\
& \alpha = \textit{fraction of the internode traffic.} \\
& \beta = \textit{traffic density } (Erlang/km^2). \\
& C = \textit{coverage area } (km^2). \\
& L = \textit{number of bits for each signaling message.} \\
& a = \textit{window size of GBN protocol between messages.} \\
& p_e = \textit{bit error rate of the interconnection links.} \\
& n_{av} = \textit{average number of links for a successful path.}
\end{aligned}
\tag{4}
$$

The network capacity "C_{nw}" and network efficiency "E" can be represented as in the following formulae [31] and will be calculated in section 4.4.3.2 with regard to the real data of the rural Newcastle area.

$$C_{nw} = \frac{tr_{BS} \cdot n_{BS} \cdot (1 - p_b)}{tr_{AV}} = \frac{tr_{CH} \cdot n_{CH} \cdot n_{BS} \cdot (1 - p_b)}{tr_{AV}}$$

$$E = \frac{C_{nw}}{C_t} = \frac{C_{nw}}{n_{UR}} \cdot 100\%$$

$$tr_{BS} = \max imum\ traffic\ of\ BS.$$

$$tr_{CH} = \max imum\ traffic\ of\ channel.$$

$$n_{BS} = number\ of\ BS. \quad (5)$$

$$n_{CH} = number\ of\ channels\ perBS.$$

$$n_{UR} = number\ of\ present\ users.$$

$$p_b = probability\ of\ capacity\ objected$$

$$C_t = toal\ network\ capacity.$$

Notably, these formulae will set criteria for evaluating the performance of wireless network in Scilab software environment in Chapter 5.

4.4.2.4 Network Layer

According to the criteria of constructing network topology in section 4.3.4, four key points will be discussed in turn as follows to accomplish the Network Layer construction in NHS.

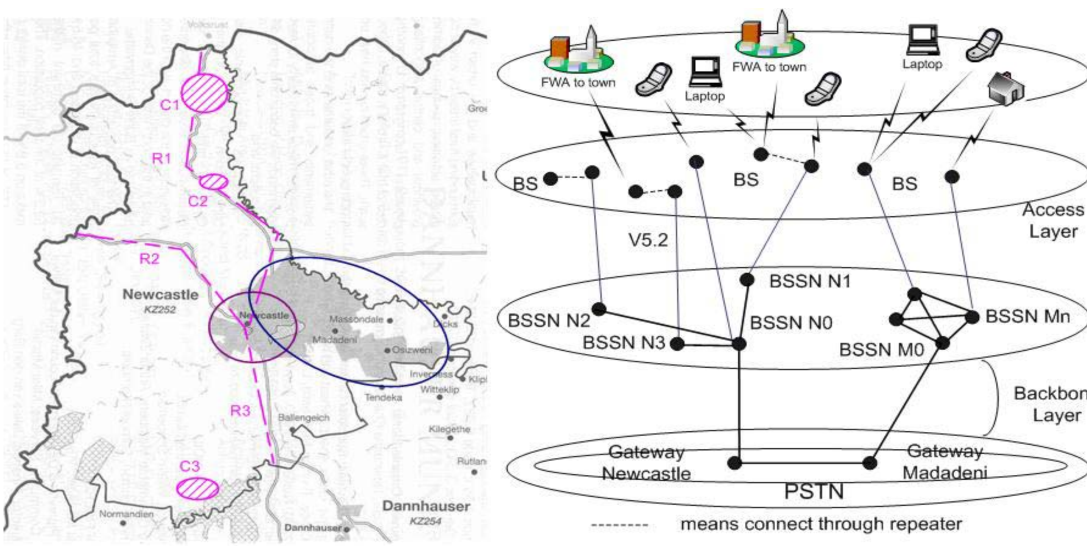
1. Physical Topology

A self-contained network with a combination of tree-structured and mesh-structured physical topology is designed in the Network Layer for rural Newcastle areas. The self-contained structure is able to offer flexible coverage and capability for each node and is cheap to deploy and easy to maintain, it is therefore most fit for rural wireless network construction.

Referring to Figure 17(b), regional hospital, district hospital and mobile health services are found in the second layer from bottom as nodes for Base Station Switching Node (BSSN). Take the BSSNs group around Newcastle town as an example. The BSSN at Newcastle town controls the BSs in its vicinity and has a gateway connected to a public telecommunications network, such as PSTN. Other BSSNs in the group control their own BSs and connect with the BSSN at Newcastle town to access public network. All the BSSNs and GWs form the network backbone for Newcastle town and its vicinity. Access nodes in the third layer provide interfaces for customers in the top layer to exchange health information with specialists and central databases, which are lying in the backbone layer.

As the unique nodes for network backbone, BSSNs play the most important role in the Newcastle network and their functions are explained as follows by referring to Figure 17(a). One of the main functions of these BSSNs is to administrate the communication traffic between the Newcastle center node (see the non-filled circle) and other network nodes, especially the rural center nodes (see the line-filled circles). Another function of these BSSNs is to administrate the communication along three main roads (see the dashed lines). Similarly, other BSSNs in the Madadeni area support the calls of Madadeni area (see the non-filled ellipse) and communicate with the Madadeni control center node at Madadeni town.

The diagram below is a simple snapshot of the network topology. It is noted that, in Figure 17(a), the rural centers “C1”, “C2” and “C3” are located according to Appendix II Newcastle Population Regional Settings as to the regional settings of Newcastle population, and represent the rural centers “Hilda”, “Ingogo” and “Lookop” respectively. Three main national roads the “R1”, “R2” and “R3” are marked out along the roads as well.



(a) (b)

Figure 17. Network Topology of Newcastle-Health-System

2. Routing Algorithm

A shortest-path-algorithm with directional flooding is expected in the Service Model to shorten routing delay and save network capacity, for it creates the shortest route between the source node and the destination node in a mesh-structured network. The shortest-path-algorithm is a simple form of QoS routing as it only takes into consideration the hop-count matrix of QoS routing. In that way the software simulation in Chapter 5 can be simplified, but the calculation accuracy of network quality will be diminished.

Furthermore, considering how a node in the network gleans information, a DV routing algorithms with mere neighbour information kept in a local node is preferred in the NHS for two reasons. First, since this model focuses on a health system which covers the entire Newcastle region more than a local area network such as a WLAN, there will be so many network nodes in need of administration. Second, as data transfer is only needed between the control center and the health nodes, there is no need for each node to keep the addresses of all other nodes. However, keeping the address information of neighbour nodes is compulsory for self node because the information of the self node has to be transferred to the control center via neighbour nodes if no direct connection exists between the self node and the control center.

3. Switching Strategy

As two optimal technologies, GSM/GPRS and DECT have been chosen as the candidate technologies for rural Newcastle, the TDMA technology is predictably selected along with them. Considering the migration to next generation networks, packet-switching is preferred other than circuit-switching due to its obvious high radio spectrum efficiency, seamless connection and favoured multi communication services, such as high-speed video transferring and picture message delivery. These multi-services are able to help medical personnel examine patients from different aspects and exchange ideas on treatments with each other anytime, anywhere.

4. Flow Control Mechanism

Non-congestion flow control mechanism is to be used in the Network Layer of NHS. Since a compound management mechanism of CIM and DIM is used in the NHS, the main traffic exists between the control center and the distributed health nodes. Therefore, the NHS attempts to meet a main requirement of the transmission of important information, such as the update of patients with severe illness (see the transmission of information "B" in Figure 15), and the dissemination of health information such as HIV/AIDS precaution (see the transmission of feedback "D" in Figure 15). These two kinds of transmission do not need the calculation of the traffic in advance to avoid network congestions. They can be done at regular times or when network bandwidth is available. The network traffic in Newcastle will be estimated in section 4.4.3.2.

Another kind of information, such as emergency operations in a flash, do need an immediate transfer without any congestion (see the transmission of information "A" and feedback "A' " in Figure 15). However, the transfer of this kind of information does not happen that frequently, and a highest-priority can be issued to this category of information to ensure that a significant amount of bandwidth is reserved for it.

4.4.2.5 Physics layer

The physical settings of the NHS are determined mainly by the self-contained topology of the network and the natural environments of rural Newcastle areas. First, a physical structure with main functional nodes shows the types of equipment that the Newcastle network needs. After that, a simple wireless network with major equipment will be set up in rural areas around Newcastle town.

1. Physical Functional Structure

With regard to transmission medium, the use of microwave and cable becomes possible due to their comparatively low cost and the ease of installation in the flat Newcastle region. Satellite is seldom used in this research due to the high cost of renting a satellite channel and the lack of rudimentary facilities in Newcastle.

Moreover, HAPS are most used in important, temporary situations other than basic communication such as infrastructure construction in rural areas, for they have difficult to provide long-term yet stable communication services due to their self-mobility.

Fundamental wireless exchanges at BSSN (switching part), where a gateway is set up to access public communication networks when necessary, and access equipment at BS (access part) are combined with the transmission aspect to form the physical structure of Newcastle area as is shown in Figure 18:

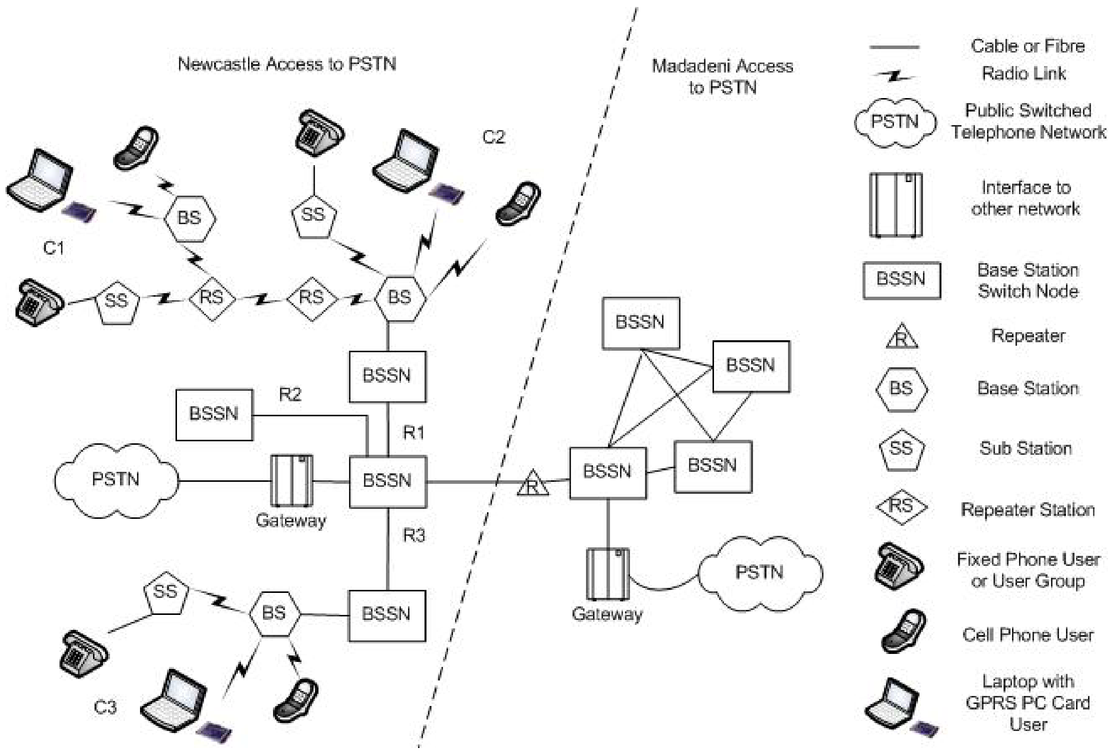


Figure 18. Physical Function Structure of Newcastle-Health-System

This graph illustrates the physical connection of the Newcastle-service-model and the equipment determinants for this model can be listed as follows [40] [45]:

- Gateway (GW), is a router that is embedded in a mobile switching node, from which the NHS has access to other networks.
- Base Station Switching Node (BSSN), manages several base stations and provides links to other BSSNs with its own capacity, coverage and connectivity according to the distribution of users in the vicinity.

- Base Station (BS), is an interface unit between the BSSN and Subscriber Terminals (ST) by radio.
- Subscriber Station (SS), is an interface between a user cluster of either wireless or fixed local area network and the wireless network, and it is connected with the wireless network by access points.
- Repeater Station (RS), is a radio signal repeater between network nodes such as BSSN, BS and SS, and it communicates with those network nodes by radio.
- Repeater (R), amplifies signals and diminishes noise between wire line nodes.
- Subscriber Terminal (ST), has a function which supports the single subscriber instrument.
- Cable or fiber, are used as the medium in a transmission network.

To simplify the system analysis, the research focuses on three major network nodes, which are the GSs, the BSSNs and the BSs.

2. A Simple Physical Network

In rural Newcastle, most rural traffic is assumed to happen in the rural centers and along the three main roads. The network is therefore located in these areas with an expectation to diminish the amount of equipment used and to ensure a comparatively complete coverage of all customers. The distance between BSSNs is assumed as 10 km rather than 10 miles (about 16 km) [40], to cut down the use of repeaters. Actually repeaters will not be calculated as the elements of a wireless network due to the thoughts of simplifying network design. Moreover, assuming that each BS serves an area as far as 500 m - 2 km. Based on the preceding assumptions, the simple physical network of the Newcastle rural areas can be shown as following:

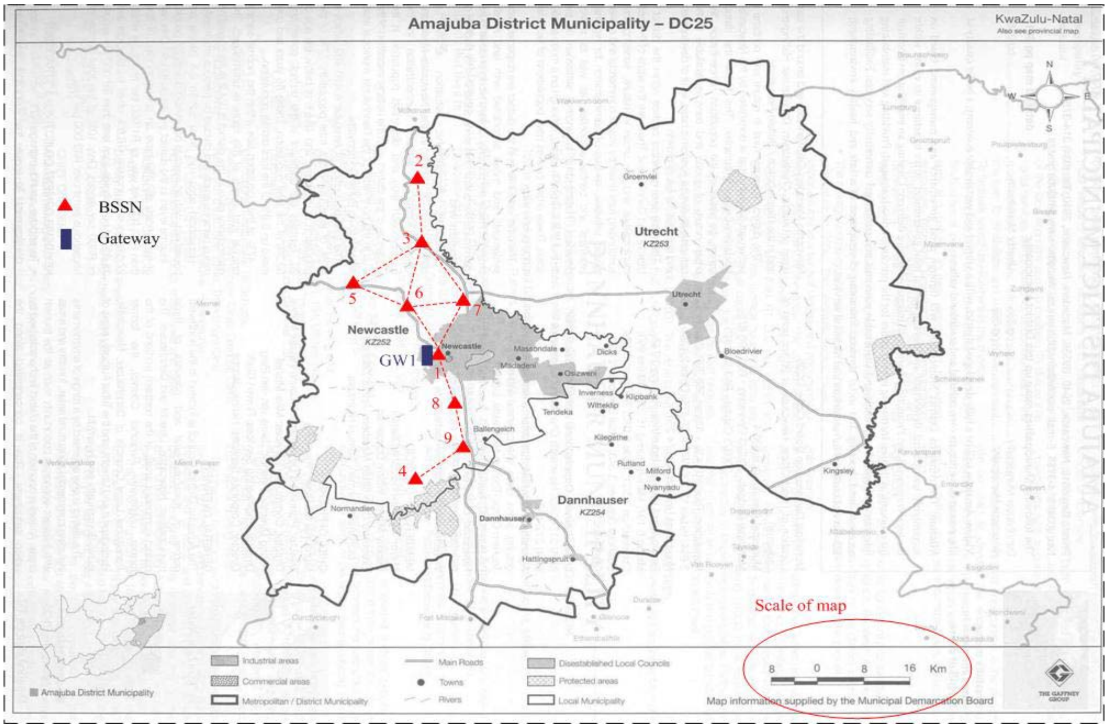


Figure 19. Physical Structure of Newcastle-Health-System

As can be obtained from Figure 19, one GW and nine BSSNs are set up to build the backbone of the wireless network in rural Newcastle, which occupies almost the entire left half of the Newcastle area. The GW is embedded in BSSN 1 and acts as an access point between the wireless network and the public network such as PSTN in urban areas. BSSN 2/3/4 serve three rural centers and process most rural traffic, while BSSN 5/6/7/8/9 are destined for serving road traffic.

4.4.3 Newcastle Service Model

In this section, a bird's-eye view of the service model in Newcastle is first taken, and then network capacity, which is one important performance of a network, is calculated by taking into consideration the constructed network and some reasonable assumptions.

4.4.3.1 Model Summary

In conclusion, in the Newcastle-Health-System, the Newcastle-service-model has been set up to provide customers both in rural centers or rural commercial farms and along the three main roads with wholesome medical treatment services. A compound management mechanism of CIM and DIM was proposed in NHS according to the different service requirements of different network nodes. Optimal technologies, such as GSM400, GSM/GPRS NIB and DECT, were chosen under the communication background of South Africa, and six parameters were picked to evaluate network efficiency, including network traffic "A", the probability of call blocking "B", bandwidth "B_s", average route delay "T_s", network capacity "C_{nw}" and network efficiency "E". Moreover, a self-contained network topology was selected, coupled with a DV routing algorithm, a TDMA packet switching strategy and a non-congestion flow control mechanism. Finally the three main physical network nodes - GW, BSSN and BS, were entered in the Newcastle-service-model on the basis of the self-contained network topology and special rural Newcastle environments.

4.4.3.2 Network Capacity Estimation

There are 55,184 households in Newcastle area and each of them represents a user. As is known, 56% of the Newcastle population lives in rural areas [55], and we assume that 80% of these rural people cluster around three rural centers: Hilda, Ingogo and Lookop, and travel along three main roads (see Figure 19). Since Hilda contains two rural centers (refer to Appendix II Newcastle Population Regional Settings as to the Regional Settings of Newcastle Population), half of the Newcastle rural population is allocated in Hilda, and the remaining is distributed approximately equally in Ingogo and Lookop. The average user traffic at peak hour in rural Newcastle is supposed to be 0.015 Erlang, which is half of that over all areas in reference [31]. It is also assumed that Newcastle town and the three main rural centers hold most of the traffic in rural Newcastle, and the remainder is distributed along the three main roads. What is more, 2% of the traffic is assumed to be blocked at each BS. This is reasonable because it agrees with a requirement of GoS, which is no more than 5% in the network.

Table 8. Network Capacity Estimation in Newcastle

Name		Formula	Value	Mark
Total Area		$\left(km^2\right)$	1854.60	TA
Newcastle Rural Area		$TA \times 80\% \quad \left(km^2\right)$	1483.68	TAN
Total User		Newcastle households	55,184	TU
Newcastle Rural User		$TU \times 56\% \times 80\%$	~ 24,722	n_{UR}
Region Population	Hilda	$50\% \times PR$	~ 12,361	nH_{UR}
	Ingogo	$52.5\% \times 50\% \times PR$ (A bigger town)	~ 6,490	nI_{UR}
	Lookop	$47.5\% \times 50\% \times PR$	~ 5,871	nL_{UR}
BSSN Number (rural area)		$BSSN\ 2 \qquad 8 \times BS$	1	H
		$BSSN\ 3/4 \qquad 4 \times BS$	2	IL
		$BSSN\ 5/6/7/8/9 \qquad 0 \times BS$	5	R
BS Number (rural center)	Hilda	$BSSN\ 2$	8	nH_{BS}
	Ingogo	$BSSN\ 3$	4	nI_{BS}
	Lookop	$BSSN\ 4$	4	nL_{BS}
Total Number of BSs		$8 \times H + 4 \times IL + 0 \times R$	16	n_{BS}
BS channel		$4\ or\ 8$	4	n_{BSCh}
Max Traffic per BS		$nBSCh \times 8 \times 0.7 \quad (Erlang)*$	22.4	tr_{BS}
Average Traffic per User		$(Erlang)$	0.015	tr_{AV}
User Traffic Density		$\left(tr_{AV} \cdot n_{UR}\right)/TAN \quad \left(Erlang/km^2\right)$	~ 0.2499	β
Probability of Capacity Rejected			2%	p_b
Network Capacity		$\dfrac{tr_{BS} \cdot n_{BS} \cdot (1-p)}{tr_{AV}}$	~ 23,415	C_{nw}
Expected Network Capacity		n_{UR}	24,722	C_t
Network Efficiency		$C_{nw}/C_t = C_{nw}/n_{UR}$	~ 94.72%	E
Network Efficiency Hilda		$\dfrac{tr_{BS} \cdot nH_{BS} \cdot (1-p)}{tr_{AV}} \Big/ nH_{UR} \times 100\%$	~ 94.72%	E_H

Network Efficiency Ingogo	$\frac{tr_{BS} \cdot nI_{BS} \cdot (1-p)}{tr_{AV}} \Big/ nI_{UR} \times 100\%$	~ 90.20%	E_I
Network Efficiency Lookop	$\frac{tr_{BS} \cdot nL_{BS} \cdot (1-p)}{tr_{AV}} \Big/ nL_{UR} \times 100\%$	~ 99.71%	E_L

Notes:

Mark "*" means the formula or value derives from [31].

As can be deduced from the above table, by applying a network constructed in the research to the rural Newcastle area, the communication requirements will be met fairly adequately and the network efficiency of the entire network is around 94.72%. With regard to local network efficiency, the user communication requirements are also met as it is as high as 94.72%, 90.20% and 99.71% in Hilda, Ingogo and Lookop respectively. When the average user traffic is not that high as 0.015 Erlang during normal time, the network efficiency is closer to 100% and better.

Additionally, the user traffic density of 0.2499 is quite near to 0.25, which is the general assumption of user traffic density for rural areas [50]. This means the user traffic assumption is reasonable.

Further, it needs clarifying that the calculation of network capacity is disregarded for the main roads because they hold a little amount of communication traffic.

4.5 Summary

This chapter depicted the Service Model that was administrated by the Management Pipe and made fully functional by the Application Layer, the Guideline Layer, the Network Layer and the Physical Layer, all working together. After this, a real example of the Newcastle health system, which was the continuation of the Newcastle-impact-model in Chapter 3, was considered in order to provide an illustration of the theoretical service model. In the next chapter, a software simulation environment is to be developed to model the Impact of Telecommunication Model and the Service Model, using Newcastle example as a demonstration.

Chapter 5 SCILAB SIMULATION

Open-source Scilab has a distinct preponderance over other open sources in the simulation of telecommunication network planning. Its major technical advantages include visible graphic user interface and potent signal processing toolboxes. Furthermore, Scilab software is easy to acquire and use in environments such as laboratories. Therefore it has been chosen in the research to simulate a network topology and make calculations as to the network states and their quality and so on.

In this chapter, after a system design to a rural wireless communication network is discussed, an experiment is performed whereby a precise analysis is done. By using the example of a network construction in Newcastle, the experiment explains all the functions of the simulation environment and indicates the how the environment operates.

5.1 Introduction to Scilab

Developed at INRIA[10] [56], Scilab targets systems control and signal processing applications. It is made up of three distinct parts namely an interpreter, the libraries of functions (Scilab procedures) and the libraries of Fortran and C routines, and can be freely distributed in source code format.

A key feature of the Scilab syntax is its ability to handle matrices. Basic matrix manipulations such as concatenation, extraction or transposition are immediately performed as well as basic operations such as addition or multiplication. This is done in Scilab by an array of lists which allow for a natural symbolic representation of complicated mathematical objects such as transfer functions or graphs.

[10] INRIA - Unit´e de recherche de Rocquencourt - Projet Meta2
Domaine de Voluceau - Rocquencourt - BP 105 - 78153 Le Chesnay Cedex (France)

Polynomials, polynomial matrices and transfer matrices are also defined, and the syntax used for manipulating these matrices is identical to that used for manipulating constant vectors and matrices.

Scilab has an open programming environment where the creation of functions and libraries of functions are completely in the hands of the user. Functions are recognized as data objects in Scilab and thus, can be manipulated or created as other data objects. For example, functions can be defined inside Scilab and passed as input or output arguments of other functions.

In addition, Scilab supports a character-string data type, which in particular allows the on-line creation of functions with fixed input parameters and output parameters. The matrices of character strings are also manipulated with the same syntax as ordinary matrices. In Scilab, matrices are transmitted between functions no matter whether the elements they carry are integers or strings. However, in another language such as C, strings or characters are normally processed in a special way other than carrying digital parameters.

The general philosophy of Scilab is to provide the types of computing environment where data types are varied and flexible, and a particular syntax is adopted to make the environment natural and easy to use. Scilab is also to provide a reasonable set of primitives which serve as a basis for a wide variety of calculations, and have an open programming environment where new primitives are easily added.

Since Scilab provides the user with an array of virtues both in available functions and in flexible programming methods, it is appropriate for the simulation of rural wireless communication networks that are studied. 1) Its main programming virtue is the provision of powerful functions. The strong graphic functions provide a way in which to simulate exterior rural area settings, whereby network elements can be marked on a rural map and manipulated easily by a programming code. Existing mathematical functions help simulate network traffic and calculate the complicated network parameters. It is marked that large numbers of useful functions of Scilab are illustrated by its demonstrations through open codes. 2) A second programming virtue of Scilab is that it uses basic data types and simple syntax inherited from

Fortran or C, which is widely used nowadays. Readable primitives can also be derived from simple English to assist in fast programming. Scilab code can be written and modified in any text editor. Due to its designed aim for education as an open source, this off-the-shelf freeware eliminates the initial cost of software acquirement and network dimensioning. At the same time, it can also be shared as open source for other fellow colleagues majoring in the same field. However, there exist some disadvantages in using Scilab, which include difficulty to debug, lack of manuals and case samples, and limited running speed.

5.2 System Design

The Scilab simulation environment for the research was set up and named as ***BrwsLi***. It stands for "a Bridge to Rural Wireless Simulation by yang Li".

5.2.1 High Level Design - Prototype Design

The essence of the high level design is to provide a function base of the ***BrwsLi*** system. Altogether 8 main function modules are developed and illustrated as in Figure 20.

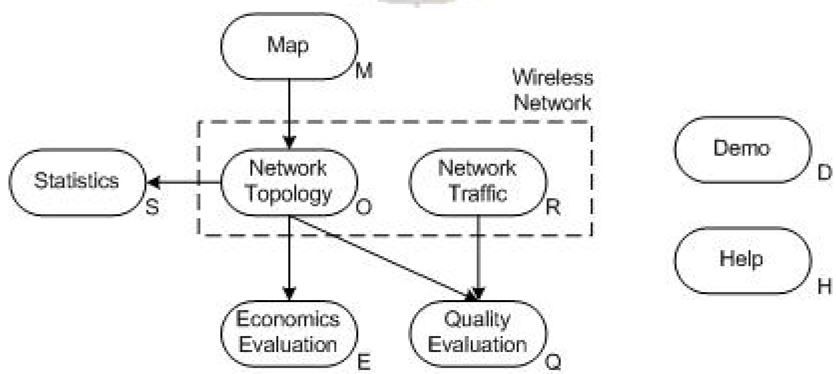


Figure 20. Module of High Level Function

After drawing the map "M" of the specified area for research with a detailed distribution of the rural regions, the physical structure of the wireless network "O" can be developed. Meanwhile the daily network traffic "R" can be assumed. Initially, the wireless network topology and traffic is simulated, and then the network is evaluated in terms of both the network quality aspect "Q" and the network economy aspect "E". The network nodes and their relations can also be viewed in the statistical database "S". Finally, the whole construction and evaluation procedure is exemplified in the demonstration "D" and some wireless theories are given in help "H". The sub-files are written in Scilab in order to realize the above mentioned eight modules and are listed as follows:

Table 9. Sub-files in *BrwsLi*

Sub-file	Description	Module
network.dem	construct network topology (controlling file)	O
drawMap.sci	draw background map	M
draw.sci	draw network elements such as GW, BSSN and BS	MO
characters.sci	insert/delete/move/update network elements in database	O
findPath.sci	complete nepotism between nodes and find out the shortest/all paths between them	OQ
calculate.sci	calculate network cost and service area	OE
stimulateCall.sci	simulate daily traffic and calculate related parameters	RQ
quality.sci	work out network-quality-evaluating parameters	Q
economics.sci	work out network-economy-evaluating parameters	E
writeStatHelp.sci	get statistical information and display help information	SH
demo1.dem	draw the map of Newcastle	D
demo2.dem	show how to insert/move/update/delete network nodes	D
demo3.dem	insert GW/BSSN/BS for Newcastle	D
demo4.dem	browse the statistical data of Newcastle network nodes	D
demo5.dem	simulate Newcastle network traffic per day	D
demo6.dem	evaluate quality with attained network parameters	D
demo7.dem	evaluate the economic efficiency of Newcastle	D

5.2.2 Low Level Design - Basic Functions Design

The low level design provides a detailed view of the network including the display of the databases in ***BrwsLi***, the function entity description in each sub-file, and the solutions to some critical problems during programming.

Before having a look at these functions and their descriptions, the characteristics of essential network nodes, which are also the main metrics transferred between these functions or between the sub-files, are listed to help the reader know more about the design.

5.2.2.1 Characteristic Matrices of Essential Network Nodes

Matrices are used as the containers of the characteristics of network nodes and help transfer the information between function entities. These characteristic matrices make up the database of ***BrwsLi*** and function as operands in all sub-files at the same time.

Table 10. Database Definition in *BrwsLi*

Position	1	2	3	4	5	6	7	8
BSSNCharList	name	posX	pos Y	assoGW	BSnum			
GWCharList	name	pos X	pos Y	assoBSSN				
BSCharList	name	pos X	pos Y	masBSSN	MTnum	radius	start angle	increased degree
ReBSSN	name	assoGW	maxBSnum	BS 1	BS 2	BS 3	…	
ReBS	name	masBSSN	maxMTnum					
PriceList	name	node num	unit price					

Notes:

pos - the relative position on the map

assoGW - the name of the gateway that this BSSN collaborates with

masBSSN - the master BSSN of this BS, because each BS is a child node of a BSSN

BSnum - the maximum number of BSs that a BSSN can connect

maxBSnum - the current number of BSs that are affiliated to this BSSN

MTnum - the maximum number of MTs that a BS can connect

maxMTnum - the current number of MTs that are affiliated to this BS

5.2.2.2 Main Functions in Sub-files

These function entities are mainly used in the sub-file in which they are defined. However, as each of them is able to realize the function independently, they can also be used in other sub-files to complete the same function according to Scilab syntax.

Table 11. Functions in "calculate.sci"

Function Name	Description	Essential Notes
addArea	add to service area when new a BS	avoid adding/cutting more times when the radium of BSs overlap
cutArea	cut service area when cutting a BS	
calServiceArea	calculate total service area	Mosaic simulation
calTotalCostInit	initiate PriceList[][]	equipment and service
addTotalCost	add to total price when adding an element	
cutTotalCost	deduct total price when deleting an element	

Table 12. Functions in "characters.sci"

Function Name	Description	Essential Notes
delElementChar	delete element from “Character” table	
delReGW	delete GW from GWChar and BSSNChar	
delReBSSN	delete BSSN from ReBSSN and BSSNChar	BSSN, assoGW, child BSs
delReBS	delete BS from ReBSSN and BSChar	

Notes:

GWChar - stands for “GWCharList” in later contexts for the sake of simplicity

BSSNChar - stands for “BSSNCharList” in later contexts for the sake of simplicity

Table 13. Functions in "constructNetwork.sci"

Function Name	Description	Essential Notes
insertElement	insert GW/BSSN/BS	modify database show on map (by using “handle”) mark connections between network nodes
deleteElement	delete GW/BSSN/BS	
moveElement	move GW/BSSN/BS	
updateElement	update GW/BSSN/BS	

Table 14. Functions in “draw.sci”

Function Name	Description	Essential Notes
DrawGW	draw GW	
DrawBSSN	draw BSSN	
DrawBS	draw BS	given height of antenna and obliquity
DrawBS	draw BS	given radium of BS
DrawNeighborGW	draw connecting lines between connected GWs	
DrawNeighborBSSN	draw connecting lines between connected BSSNs	

Table 15. Functions in "drawMap.sci"

Function Name	Description	Essential Notes
drawMap	draw background map	
redrawAreas	redraw urban/rural areas	after the change of network nodes
redrawMarks	redraw GW/BSSN/BS marks	

Table 16. Functions in "economics.sci"

Function Name	Description	Essential Notes
inputUnitPrice	input price for equipment and service	
getTotalCost	get total cost	
ContributionToProduction	get the contribution of telecommunications to production	Formula (2)
NetworkEfficiency	get the efficiency of wireless network	

Table 17. Functions in "findPath.sci"

Function Name	Description	Essential Notes
getPathAuto	get shortest/all paths automatically	
getPath	get shortest/all paths manually	
inputMatrix	set mesh nodes by matrix	easy
inputNode	set mesh nodes by node	complex

RoutingAlgorithm	define the algorithm of routing	
checkNode4All	get outgoing nodes and the newly-changed route of the node	a modified flooding routing algorithm [50]
getNodeByType	get SN/DN/TN[11] ID from type 1/2/3	
getDigitOfInt	get the bit number of an integer	
str2int	get matrix from string to integer	
int2str	get matrix from integer to string	
int2matrix	get matrix from the bits of integer	
inverseMatrix	inverse matrix	
extremumMatrix	get the extremums of matrix	shortest/longest string minimum/maximum integer
fillNeighbor	fill in the neighbour relationship for GW/BSSN	connection is shown in matrices by digit "0" and "1"
delRowCol	delete row or column from matrix	

Table 18. Functions in "stimulateCall.sci"

Function Name	Description	Essential Notes
stimulateCall	stimulate the process of calls in certain duration	calls arrive at Poisson distribution calls hold at Exponential distribution Formula (3)
statBlockedCall	get the statistical data of blocked calls	Formula (3)
picNormalCall	draw a picture of normal calls	
picBlockedCall	draw a picture of blocked calls	
picCall	draw a picture of all calls	
Factorial	calculate Factorial	
delElement	delete an element from a list	
addElement	add an element to a list	

[11] "SN", "DN", "TN" stands for "Source Node", "Destination Node" and "Transfer Node" respectively.

Table 19. Functions in "quality.sci"

Function Name	Description	Essential Notes
ServieRate	get the reciprocal of service rate "μ"	
InternodeTraffic	get total inter-node signaling traffic on each unidirectional link "λ"	
AverageLinkDelay	get mean link delay "E[T]"	
Bandwidth	get bandwidth "Bs"	Formula (4)
AveRoutingDelay	get average routing delay "Ts"	Formula (4)
getParameter	get preliminary parameters for the calculation of E[T], Bs and Ts	
picAverageLinkDelay	get and draw the figure of link delay	E[T] vs. throughput
picBandwidth	get and draw the figure of bandwidth	Bs vs. message length
picAverageRoutingDelay	get and draw the figure of routing	Ts vs. Bs

Table 20. Functions in "writeStatHelp.sci"

Function Name	Description	Essential Notes
StatGeneral	display general statistical data	
StatRelation	display relation between network nodes	
StatElements	display the character information of a node	
writeHelp	show information about ***BrwsLi***	all nouns and formulae

5.2.3 Interface Between Modules

The interfaces between ***BrwsLi*** and the user, which are operable graphic interfaces, play a part in the simulation results. The following experimental results section will show how these interfaces appear and behave, and how the user controls them. Furthermore, the interfaces between modules refer to three elements. One is the transfer parameters of these modules; another is the artificial functions that can be used in modules other than the module in which they are constructed; the third is the matrices between functions, which work as database that keeps the characteristics of network nodes. They are shown in Figure 21.

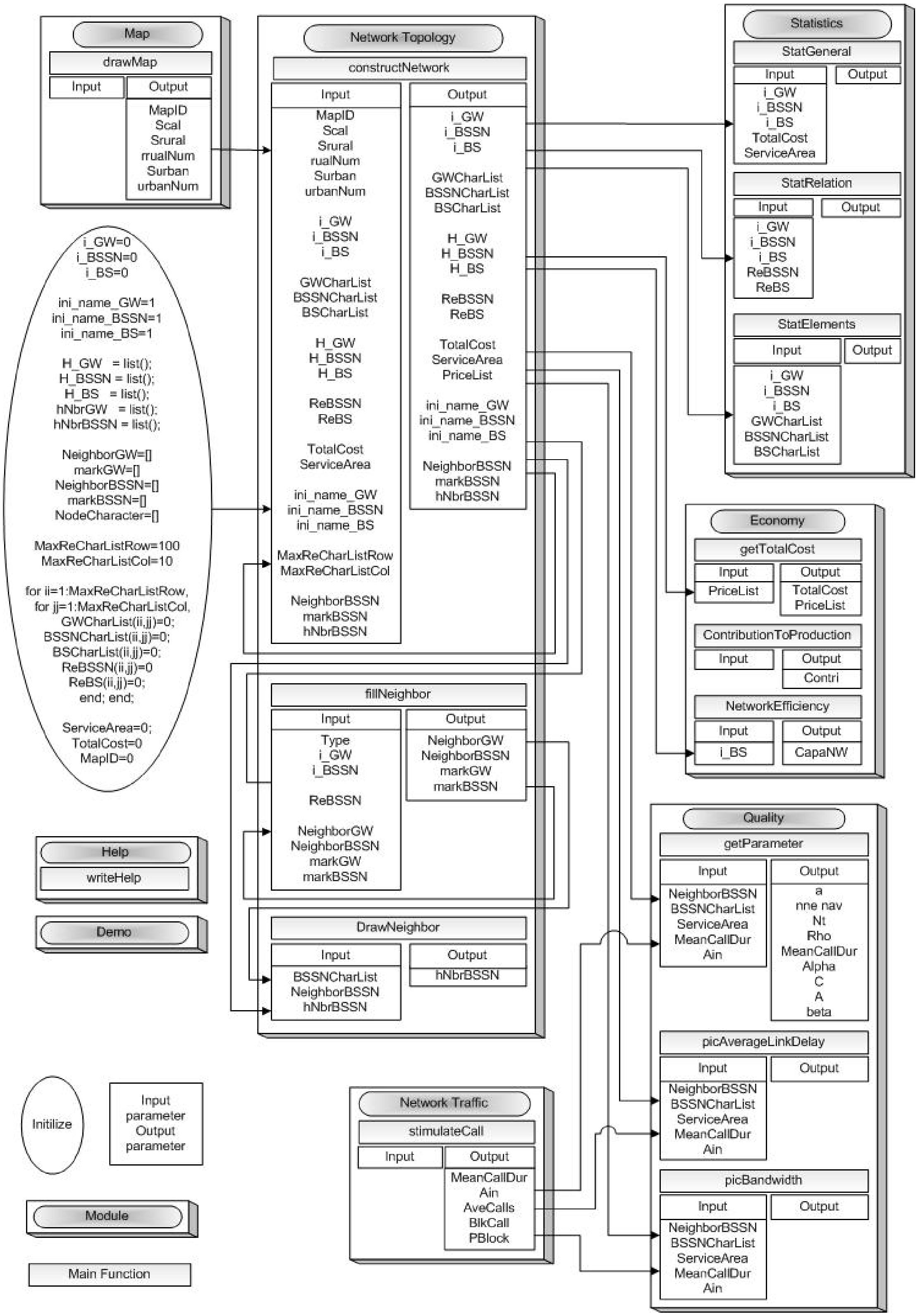


Figure 21. Interfaces between Modules in *BrwsLi*

5.2.4 Software and Hardware Environments

The ***BrwsLi*** simulation environment operates in the following hardware and software environments and is selected because of their simplicity, easy operation and easy availability at the beginning of the experiment.

Table 21. Development Environment in *BrwsLi*

Name	Description
PC	Intel Pentium 4, CPU 1.6Ghz, 256M RAM, 40G Hard driver
OS	Microsoft Windows 2000, English Version
Ethernet network	100M bps, TCP/IP, Network adapter 100M, PCI
Software	Scilab-V2.7 (1989-2003, INRIA/ENPC)
Editor	UltraEdit-32 Professional Text/HEX Editor Version 9.00a

5.3 Software Simulation

The simulation software environment for planning a wireless network of a typical rural area is developed in Scilab and uses the network construction in Newcastle, South Africa as an example. Two reasons account for this. First, various Scilab windows will provide how the proposed system designs the functions and deals the data processing in the software. Second, the simulation result will process and produce a simple wireless network topology of rural Newcastle areas and will meet reasonable theoretical criteria for constructing a wireless network in rural areas. Two user controllable interfaces are given, which are choosing-list and multi-dialogue.

In the following section 5.3.1, the main menu, which includes all operations of the simulation software, will be shown and explained. After having chosen the graphical view of the Newcastle area in section 5.3.2, the manner in which to construct a network in terms of putting in physical network nodes will be introduced in section 5.3.3. Thereafter, in section 5.3.4, the communication traffic of Newcastle area will be simulated. Then section 5.3.5 and section 5.3.6 will follow to illustrate the technical-appraisal and economic-appraisal of the constructed network respectively.

The statistical data concerning the constructed network in Newcastle and general help information about the software will be listed in section 5.3.7. Finally, the contribution of the Newcastle experiment in the Scilab simulation environment to the entire rural wireless network of Newcastle will be highlighted in section 5.3.8.

5.3.1 Main Menu

An example of the Main Menu for the network planning tool ***BrwsLi*** is presented in Figure 22. In the example, a user can choose from eight options which are setting up rural environment, constructing network topology, stimulating network traffic, evaluating network quality and productivity, reading statistical data, browsing a demonstration of how to perform optimal network planning, and displaying information as to the software.

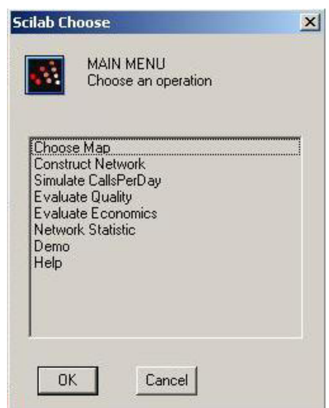


Figure 22. *BrwsLi* - Main Menu

5.3.2 Choosing a Map

In the first step of the experiment, a user clicks on the "Choose Map" item and obtain the map of Newcastle as shown in Figure 23, where notes on the x axis and the y axis represent the proportionally reduced geographical scale of the area. The Newcastle map shows how the rural and urban regions are distributed and the position of the national roads. The sum of the cost of the network equipment and labour is also shown in the upper-right corner as well as the valid coverage areas. Iconic marks and textual explanations are also supplied to three elementary network nodes: GS, BSSN and BS. The scaling is marked in the lower-right corner.

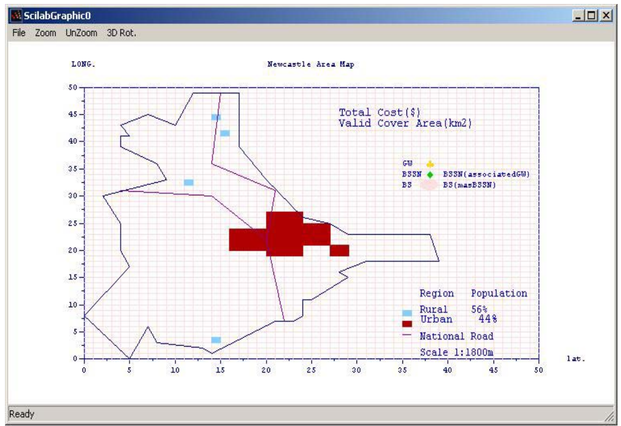


Figure 23. ***BrwsLi*** **- Newcastle Map**

Once the map of Newcastle is displayed on the screen, the user may construct the wireless network for the specified rural area, and evaluate it afterwards. To do so, four elementary steps need to be followed. They are network construction, traffic simulation, quality evaluation and economic evaluation, and they will be explained in order in the following sections from 5.3.3 to 5.3.6.

5.3.3 Construction of Network

The user may construct the network topology by choosing the "Construct Network" item in the Main Menu. He may also change any available network node to obtain a final Newcastle network topology as in Figure 24 where the theoretical rural areas are covered or overlaid with minimum network equipment (refer to Figure 19).

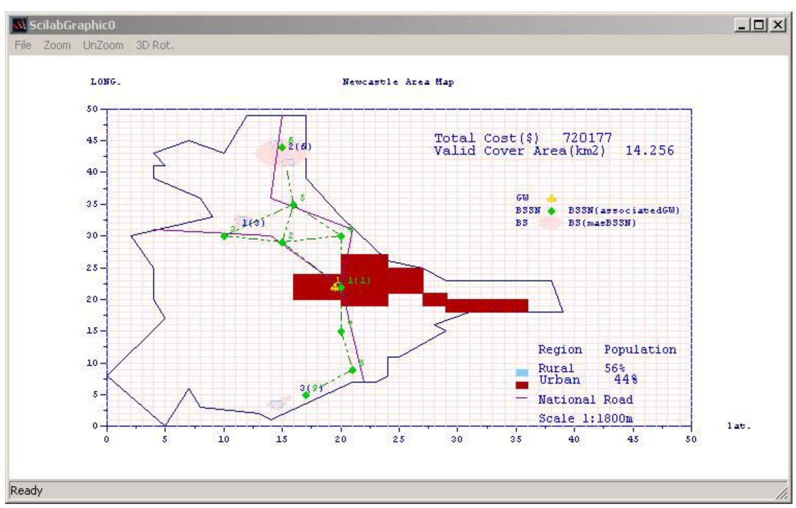


Figure 24. ***BrwsLi*** **- Newcastle Network Topology**

In ***BrwsLi*** three main network objects are assumed in a self-contained network. They are GW, BSSN and BS. Four operations of insert, delete, move and update are adopted to manipulate those network objects. The operating relation between them is shown in the following table:

Table 22. Relation between Operation and Network Nodes

Network Node \ Operation	insert	delete	move	update
GW	X	X	X	X
BSSN	X	X	X	X
BS	X	X	X	X

Notes:

X - "Operation" can operate on the "Network Node".

To accomplish the Newcastle infrastructure as the one shown in Figure 24, the user is first supposed to fill proper node parameters to insert nodes appropriately. An example of this procedure is given in Figure 25. Then he has to appraise equipment and services as shown in Figure 26. Finally, the connection between independent network nodes is built by constructing a 2-dimension matrix with all BSSNs as the labels on the x axis and the y axis, which can be seen in Figure 27. The "1" in the data items means "a connected state between the two nodes in row and in column separately" and "0" means "a non-connected state".

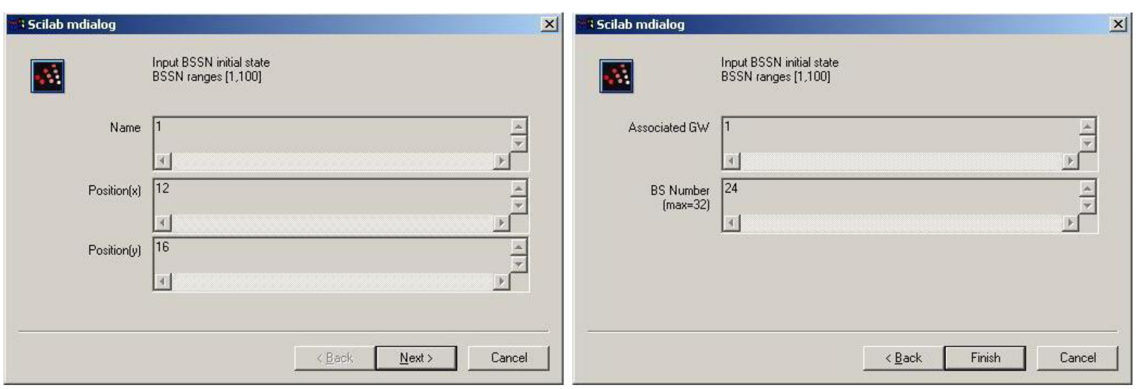


Figure 25. *BrwsLi* - Insert Network Node

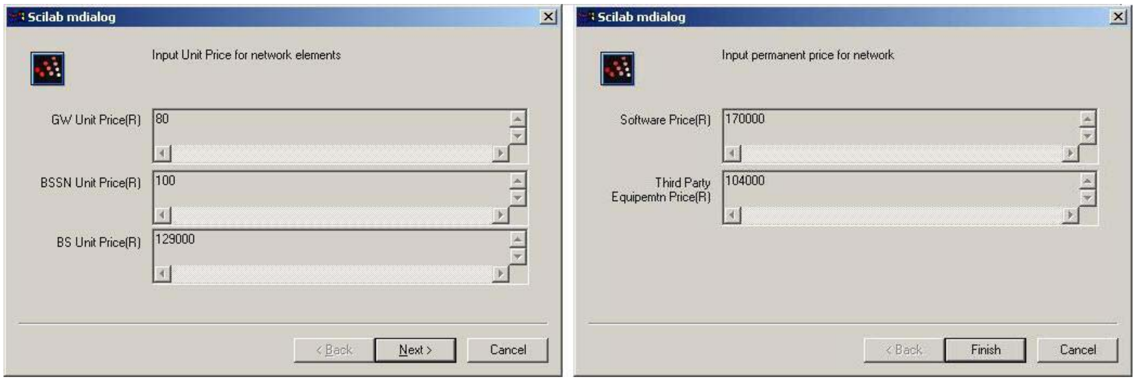


Figure 26. ***BrwsLi*** **- Insert Equipment Cost and Labour**

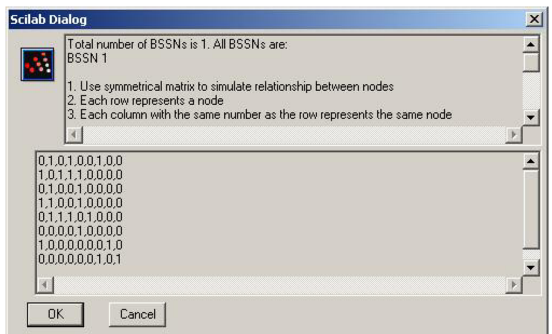
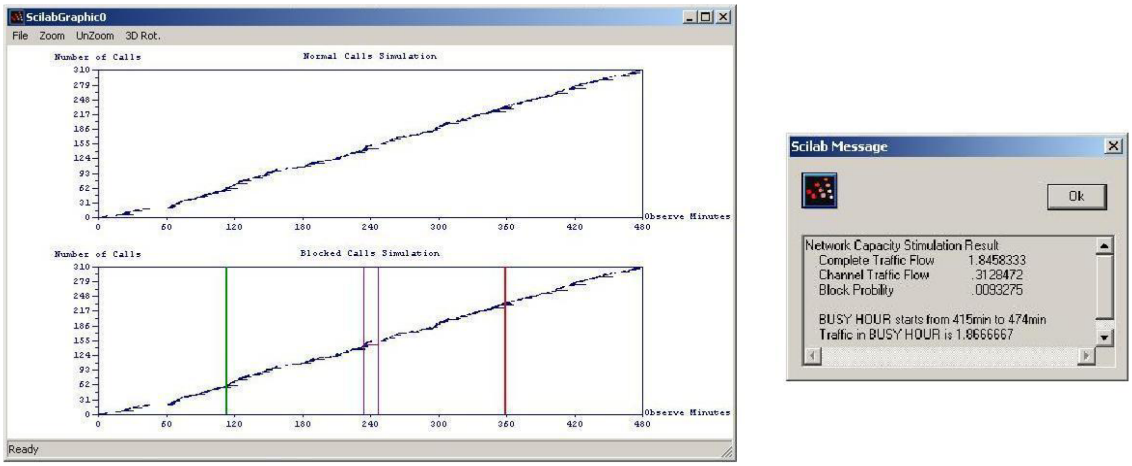


Figure 27. ***BrwsLi*** **- Fill Neighbour Connection between Nodes**

5.3.4 Simulation of Traffic

Following the topology construction of the Newcastle wireless network, network traffic is simulated. This is done on the condition that the network is observed 8 hours a day, 280 calls arrive at a Poisson distribution in the observing hours and the call holding time is distributed exponentially, on average 6 channels are available at a time, and the mean call duration is 3 minutes. The reason for choosing these parameters is that "8 hours" is the most common number of business hours for rural health service providers, such as hospital and clinic. The assumption that calls arrive at Poisson distribution and they hold at Exponential distribution is also widely tested and used in a call traffic model [54]. The mean call duration that is supposed to be "3 minutes" follows most of the statistical data in [57]. Notably "6 channels" means an average proportion of occupation of channels. For example in a network which has two BSs, one BS supplies a 4-channel capacity while another one can provide 8 channels at the same time. Therefore, their average channel occupation is 6 channels.

It is noted that the channel number is assumed different from that in Table 8 but closer to reality. Thus, after entering all the assumed parameters, the simulation results can be obtained in Figure 28 and the zoomed result of Figure 28(a) is illustrated in Figure 29.



(a) (b)

Figure 28. ***BrwsLi*** **- Traffic Simulation Results**

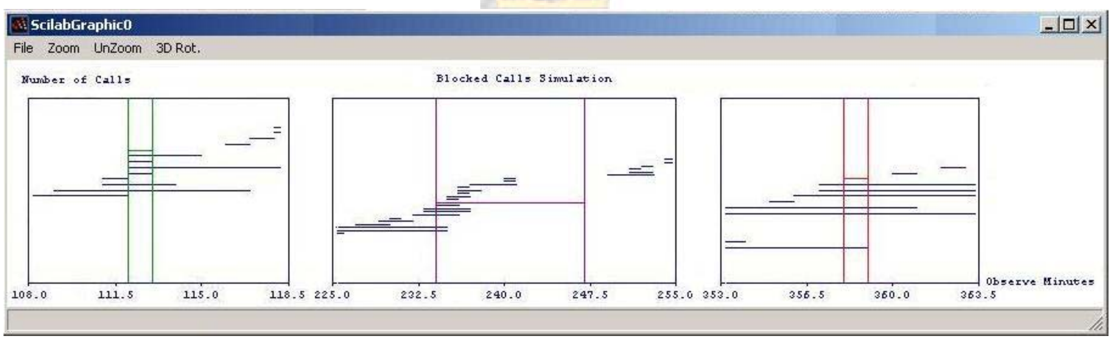


Figure 29. ***BrwsLi*** **- Traffic Simulation Results Zoomed**

As can be seen in Figure 28(a) and Figure 29, three calls out of 280 calls are blocked when 6 channels are fully occupied. These 3 call attempts were blocked at the 112th min, 234th min and 358th min in turn in Figure 29 and their assumed call holding times are 1 minute, 13 minutes and 1 minute respectively. Moreover, in Figure 28(b), the completed traffic, which is 1.8458333 Erlang, is achieved after having accumulated these simulated calls, and will be used in the following network quality assessment. The block probability or the GoS of 0.0093275 is smaller than 0.01, which is the threshold target that a network operator wants to meet [51]. Busy Hour between from the 415th minute to the 474th min and its Busy Hour Call Attempt (BHCA) of 1.8666667 Erlang are shown to help the network planner know more of network traffic states. It is noted that the traffic in busy hour is higher than the average completed traffic and it is universally correct.

5.3.5 Appraisal of Network Quality

After having built the network topology and simulated network traffic, the entire self-contained network is ready for appraisal. Some technical formulas are widely used to calculate the essential quality characteristics of wireless networks. The network parameters that are considered in the research include average link delay, bandwidth and routing link delay. This is done to demonstrate the network state concerning bandwidth requirements and transmission delays of the network whose topology and traffic were set up previously.

5.3.5.1 Preliminary Parameters

The preliminary parameters related to these three key parameters, which include average link delay, bandwidth and routing link delay, are illustrated in Figure 30:

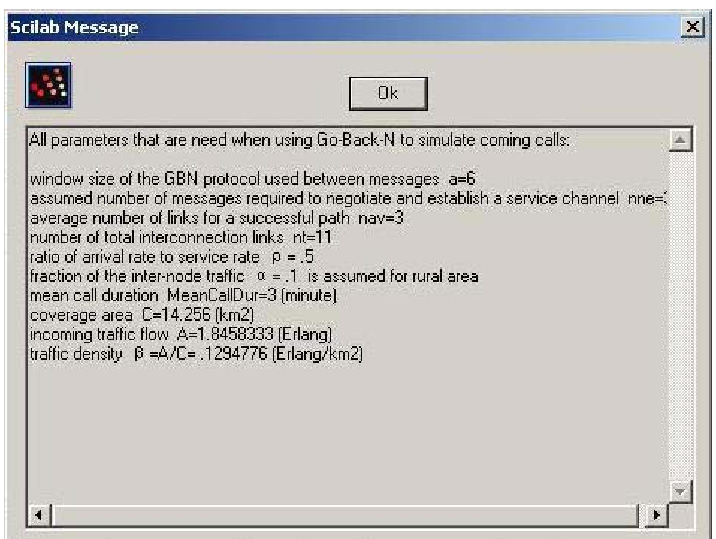


Figure 30. *BrwsLi* - Preliminary Parameters for Quality Evaluation

Some preliminary parameters are determined by network topology which includes the areas covered by the network, the number of network nodes BSSNs and the connecting states between these nodes. Assume that the GBN queuing mechanism is used for call process in the research. Therefore, the window size used in GBN between two network nodes “a”, the average number of links of a successful path “nav”, the number of total links “nt” and service area “C” are among the parameters determined by the network topology. Other preliminary parameters that are determined by network traffic include the mean call duration “MeanCallDur” and the completed incoming traffic flow “A”. The rest of the preliminary parameters were assumed for rural network planning, including the number of messages for negotiating “nne”, the ratio of call-arrival-rate to call-service-rate “ρ”. It is noted that the last parameter in Figure 30, traffic density “β”, is 0.1294776 Erlang per km^2 as a result of network traffic and coverage area. The value is less than 0.25 Erlang per km^2 that is normally assumed for rural areas [50], so the assumed network traffic is reasonable when the coverage areas of the research area are fixed.

On getting all preliminary parameters, average link delay “E[T]”, bandwidth “Bs” and average routing delay “Ts” will be studied in turn in the following sections.

5.3.5.2 Average Link Delay

The preliminary parameters used to calculate the average link delay have been set in previous steps. The neighbour relationship of all BSSNs and their consequent parameters such as the window size used in a GBN protocol in the self-contained network “a” are obtained from constructing the network topology. Other parameters such as the product of bit-error-rate and message length are supposed to be filled manually by the user. The formula for calculating the average link delay is normally printed on the top of input window to help choose a proper value of input parameters. In the thesis we only concentrate on the calculation result of the average link delay, as is shown in Figure 31:

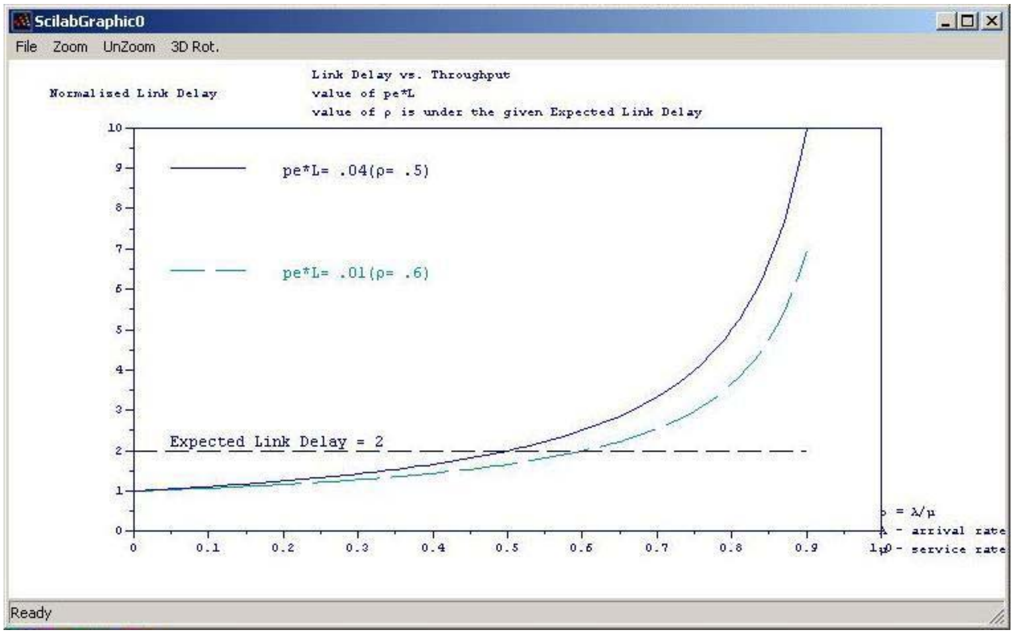


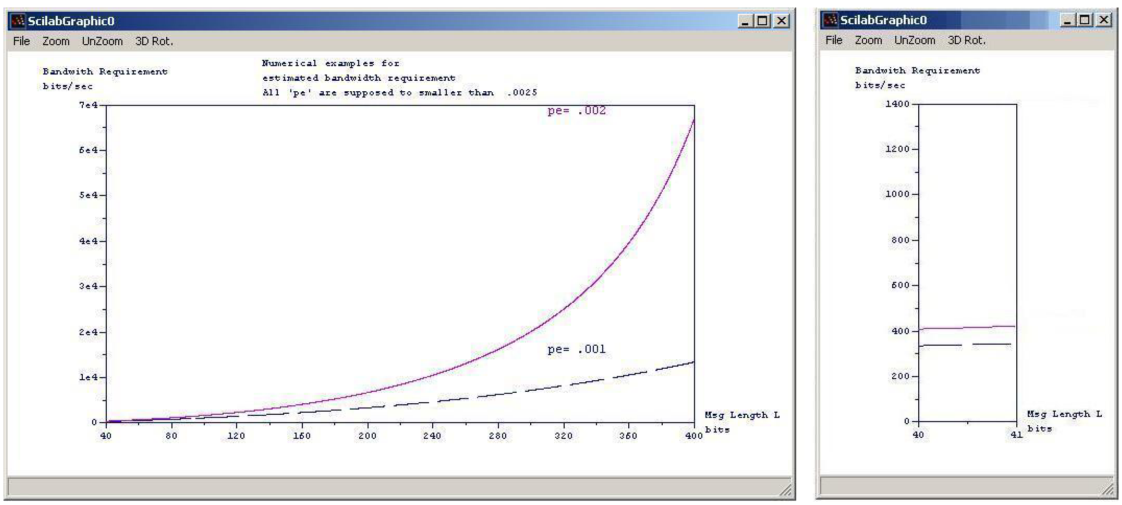
Figure 31. ***BrwsLi*** **- Average Link Delay Result**

*The x axis indicates the ratio of call-arrival-rates to call-service-rates, and the y axis indicates in seconds the average link delay. To be more detailed, in the x axis, the call-service-rate is estimated at 1 call per unit time, the call-arrival-rate "pe" ranges from 0 to 1 call per unit time. The relationship between the average link delay and the division of call-arrival-rates to call-service-rates is drawn under different products of bit-error-rate and message length (pe*L). All the theoretical ratios "ρ" of call arrival and call service are marked in brackets on the upper-left corner of the graph behind the marks of the product of bit-error-rate and message length (pe*L).*

As can be obtained in Figure 31, when the rate of incoming calls is very low, the average link delay increases slowly. The nearer the call-arrival-rate reaches the call-service-rate (1 call per unit time), the more the increased amount of the average link delay per unit of the ratio of call-arrival-rate to call-service-rate. If the expected link delay is entered as a positive digit, for example "2", a line which represents the value of expected link delay will overlap with the inclination curves of the different product of bit-error-rate and message length (pe*L). For instance, when the expected link delay is set to 2 as shown in Figure 31, a theoretical ratio of call-arrival-rate to call-service-rate shall be 0.5 if the product of pe and L is 0.04. It can also be 0.6 if the product of pe and L is 0.01.

5.3.5.3 Bandwidth

Just as the entering of parameters can be done for attaining the result of the average link delay, the same process of entering parameters can be done for attaining the movements of bandwidth with message length under different bit-error-rates coupled with precise calculation. Among the preliminary parameters of bandwidth, the "C", the "nt", the "nav" and the "a" are obtained from constructing a network topology. The "MeanCallDur" and the "Acmp" are obtained from stimulating network traffic. Since message length and bit-error-rate are manually entered by the user, he can choose what kind of results he would like to view. The change in bandwidth requirement with message length can be obtained in the following Figure 32 after accurate calculation:



(a) (b)

Figure 32. ***BrwsLi*** **- Bandwidth Result**

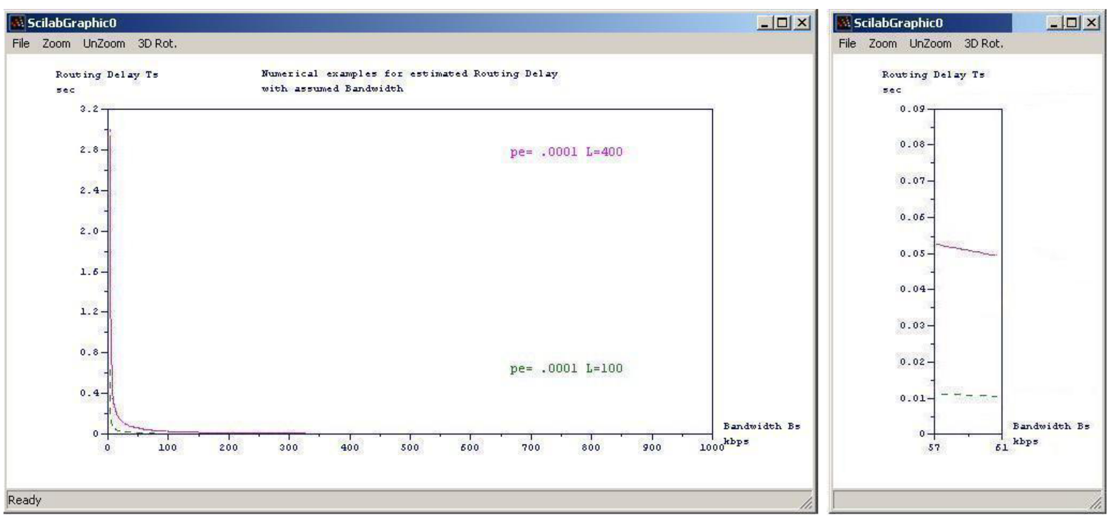
As can be seen from the above figure, although the required bandwidth always has a rising tendency in order to carry the longer message, the amount of increase differs when different bit-error-rates are expected. In the Newcastle wireless network, for example, when a message contains 40 bits on average, if the current bit-error-rate is 0.001, theoretically the network is demanding a bandwidth of 0.33 kbps to carry the message without any error, while to tolerate a bit-error-rate of 0.002, a bandwidth of 0.41 kbps is needed. The amount of increase is as little as 0.08 kbps, which can be seen from Figure 32(b). However, in Figure 32(a), when messages with an average length of 400 bits are sent, the entire network requires approximately 67 kbps of bandwidth if it wishes to tolerate a bit-error-rate of 0.002, and it only asks for a bandwidth of a little more than 11 kbps with the bit-error-rate of 0.001. The gap now is 56 kbps, which is more than 700 times the average amount when the bits of messages are 40 bits. Thus, it can be seen that if a better bit error tolerance, or a higher value of "pe", is expected for network planning, the bandwidth requirement with the gradual increase in message length goes up more rapidly than that of a lower value of "pe". This is true on condition that message length increases the same amount. Furthermore, once the average message length is foreseen and the bit-error-rate tolerance is assumed, the expected bandwidth of the network can be obtained from the graph directly.

What needs to be pointed out here is that, as can be seen from Figure 32(b), when needing to carry a message with 40 bits and tolerate a bit-error-rate of 0.001, a bandwidth of 0.33 kbps, which is 330 bits per second, is theoretically required. Is it a waste to carry 40-bits information with 330-bits bandwidth? The answer is no. From formula (4) in section 4.4.2.3 we can see that an actual bandwidth is not only determined by message length and bit-error-rate tolerance requirement, but also another three parameters. 1) The first is the fraction of the inter-node traffic "α", which is assumed to be fixed at the value 0.1. 2) The second parameter is network traffic, which is the product of traffic density and coverage area (β*C). Once a communication network for a certain area has been set up, the network traffic remains as a fixed value because both its factors are fixed in the network. 3) The third parameter is the window size between two nodes in a self-contained network "a". Once a network topology has been ensured, this parameter is obtained from the calculation of the network topology and is therefore unchangeable. For example, in the Newcastle case, the "α" is 0.1, the "β" is 0.1294776 Erlang/km2, the "C" is 14.256 km2, and the "a" is 6. A combination of these parameters may render the expected bandwidth increasing many-fold besides the bit-error-rate and the message length. However, since they are set once the network has been set up for a certain area, it is useless to discuss them with regard to the tendency of network bandwidth.

The research simply concentrates on the variability of the bandwidth with bit-error-rate and the length of a message, both of which have a dynamic effect on network bandwidth, while omitting the impact to bandwidth from other parameters.

5.3.5.4 Average Routing Delay

The last parameter to be evaluated is the average routing delay “Ts”. The preliminary parameters of “Ts” are obtained in the same way as obtaining the preliminary parameters of the average link delay and the bandwidth. The average routing delay is theoretically determined by the average number of successful links “nav”, the bit-error-rate “pe”, the message length “L” and the required bandwidth “Bs”. However, “Bs” is the unique parameter that is chosen to be the determinant of the average routing delay in the research because the rest of the preliminary parameters have less effect on the change of the average routing delay than that of bandwidth.



(a) (b)

Figure 33. ***BrwsLi*** **- Average Routing Delay Result**

As can be seen in Figure 33, with a fixed “pe” and “L”, there is a sharp fall of the average routing delay by seconds when the supplied bandwidth is comparatively low. The average routing delay then goes nearer to but never reaches zero with the increase in bandwidth. For instance, the average routing delay decreases from 3 seconds (see Figure 33(a)) to almost 0.01 seconds (see Figure 33(b)) as the bandwidth increases from 1 kbps to a little more than 60 kbps with “pe” as 0.0001 and “L” as

100 bits. After that, no matter how high the bandwidth reaches, such as 1 Mbps, the average routing delay decreases with an amount that is up to 0.01 seconds at the most. The product of the bit-error-rate and the message length (pe*L) also contributes to the average routing delay, especially "L". As can be seen from Figure 33(a), when "L" is assumed to be 100 bits the network may produce a low average routing delay of around 0.65 seconds at 1 kbps bandwidth, while an average routing delay of 3 seconds, which is almost 5 times that of 0.65 seconds, is produced when "L" is assumed to be 400 bits at 1 kbps bandwidth.

From the relation graph of the bandwidth and the average routing delay of the Newcastle network, the value of the average routing delay can be obtained easily if a fixed bandwidth is supplied to the network, and if a certain average routing delay is required, the amount of bandwidth that shall be applied can be determined with ease.

5.3.6 Appraisal of Network Economy

Considering the practicability of the simulation, economic efficiency is evaluated in ***BrwsLi*** as well. Three parameters of the total cost on network construction, the contribution of telecommunications to GDP, and the network efficiency are chosen in order to complete the evaluation of the economic efficiency in the research. In fact, the contribution of telecommunications to GDP has little to do with the network constructed in previous sections. However, the calculation of the contribution requires simple data collection, such as the local GDP and the penetration of telecommunications, from the research area where the network was built. It is therefore chosen to show why the wireless network construction is needed, in the first place, in rural areas with poorly developed communication facilities. The calculation of economic efficiency can be compared with the total network cost to analyze whether the ratio of the economic efficiency and the cost of network construction, both of which come from the network construction in the research area, are consistent with the telecommunication contribution in the real world.

After putting in the price per unit for all hardware, the total cost of the Newcastle rural wireless network is calculated as can be seen in Figure 34. The item "Cost of

Service" is assumed, through a common sense of network construction, to be one third of the cost of all peripheral equipment. Even though the total cost calculated is not completely accurate as in real terms, it gives an estimate of the network costs.

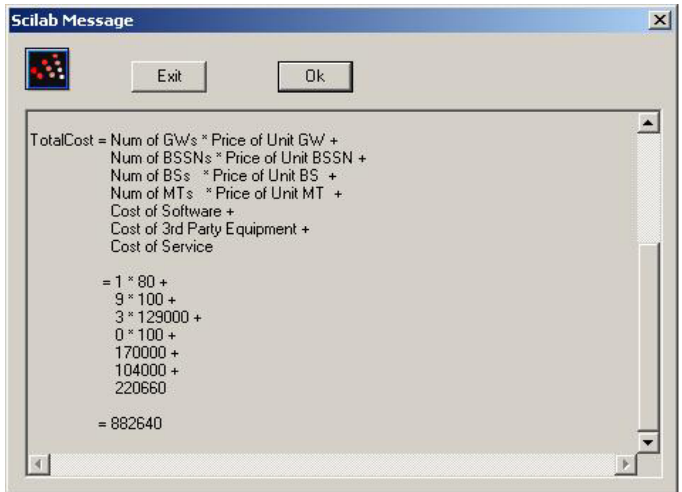


Figure 34. *BrwsLi* - Total Cost

The preliminary parameters used to calculate the contribution of telecommunications to GDP and the calculation result can be seen in Figure 35. As Newcastle is a typical rural area of South Africa and there is a shortage of economic data on Newcastle, the data concerning the telecommunication penetration and GDP of South Africa is used here to represent those of Newcastle.

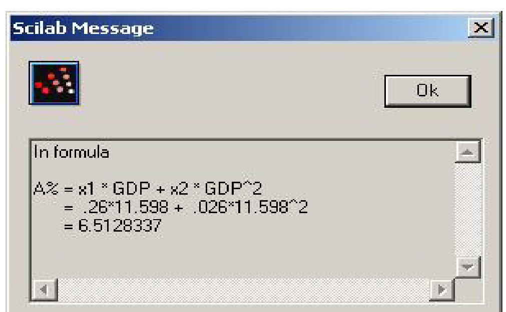
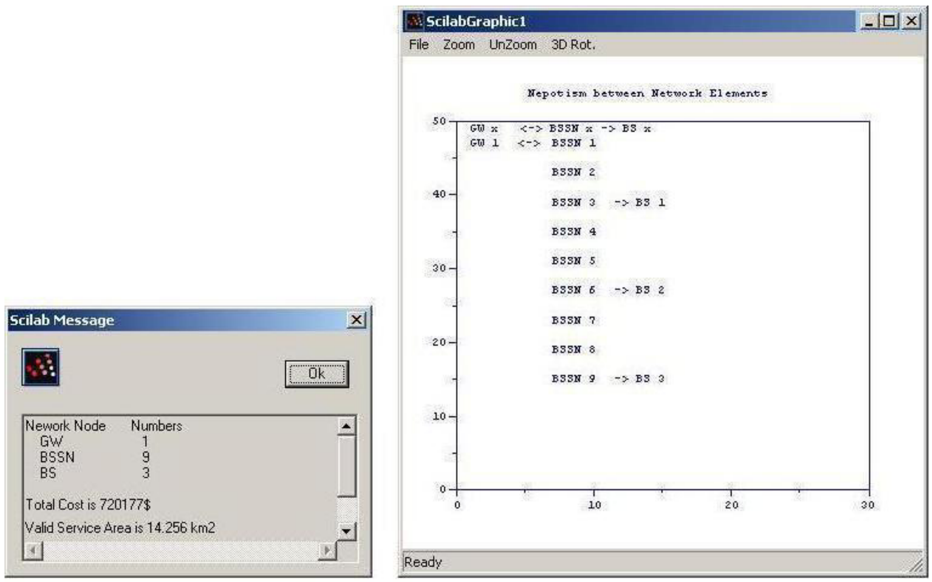


Figure 35. *BrwsLi* - The Contribution of Telecommunications to GDP

5.3.7 Statistics and Help

The statistical data of the network is captured in Figure 36 and Figure 37. They are generated automatically to provide the software user some instrumental information of the network on which he is working. General statistics which include the number of network nodes in Figure 36(a) are related to network service area and network cost. The relationship between network nodes in Figure 36(b) will inform the user about the dependent relations between network nodes. For example, if he wants to delete "BSSN 3", "BS 3" will be deleted automatically because "BS 3" is affiliated to "BSSN 3". Characteristic information in Figure 37 helps to modify node characters such as the coverage radius of BS, or the position of BSSN.



(a) (b)

Figure 36. ***BrwsLi*** **- Statistics (General and Relationship)**

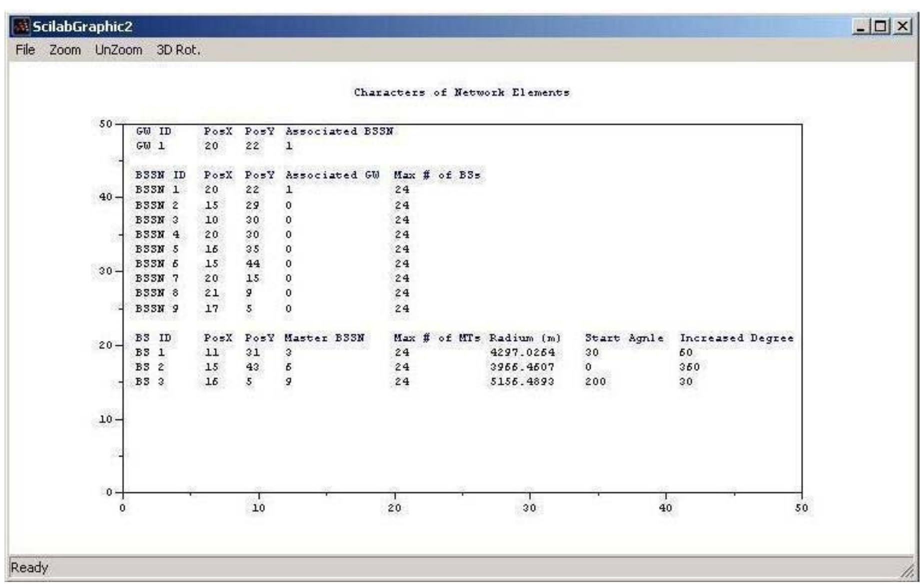
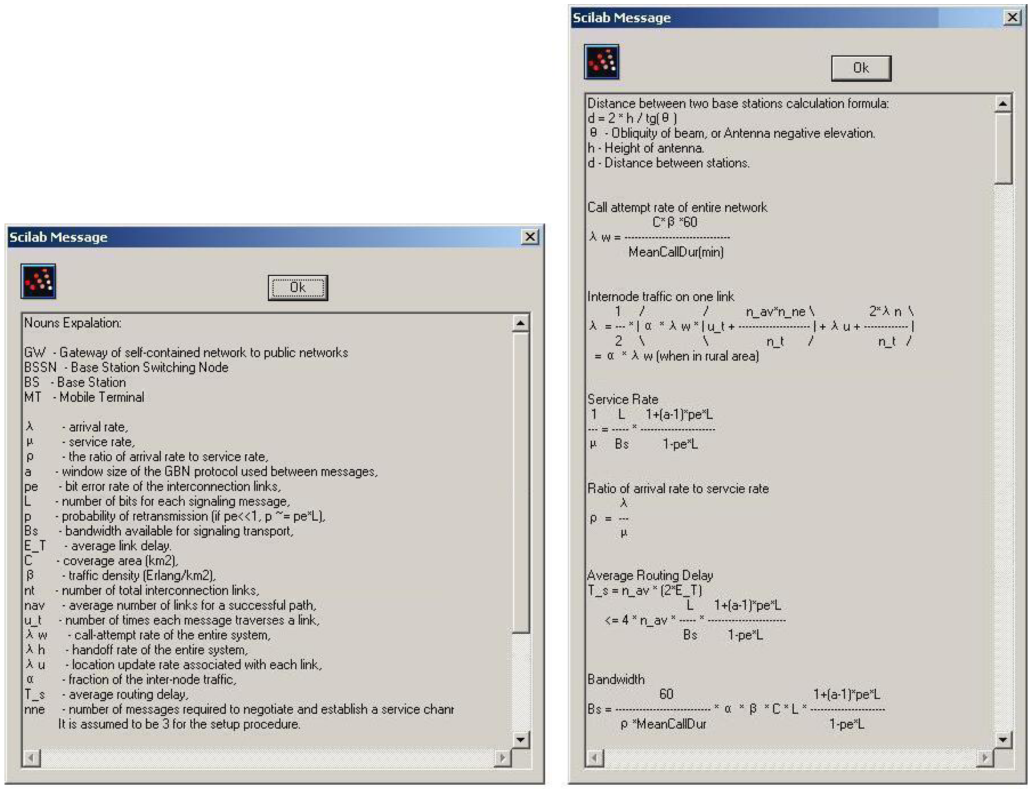


Figure 37. ***BrwsLi*** **- Statistics (Characteristic)**

Finally, the help information contains not only the explanation of primary parameters and essential formulas but also the contact details of developer. An example of these details is displayed in Figure 38.



(a) (b)

Figure 38. ***BrwsLi*** **- Help Information**

5.3.8 Contribution of Simulation to Real-case

At this point, a complete procedure of constructing a wireless network planning has been illustrated through the use of the simulation and a network evaluation of a network. The proposition of the network structure and the network traffic for rural Newcastle in this experiment has been proven to be adequate for various reasons. These reasons are that the constructed wireless network covers all rural regions of Newcastle (see Figure 24), and succeeds in simulating a call density of less than 0.1295 Erlang per km^2 for rural areas (see Figure 30). It provides a practical ratio of call-arrival-rate to call-service-rate (0.5 [50]) when a comparatively high product of bit-error-rate and message length of 0.04 and a proper average link delay of 2 are met (see Figure 31). Moreover, such a network requires low bandwidth, which is normally seen as a problem for the network construction in rural areas when the average length of message through the network is not particularly high. For instance, the bandwidth requirement is less than 10 kbps when "pe" is less than 0.002 bps and "L" is 250 bits per message (see Figure 32). It also costs approximately as little as Rand 882,640, which is about USD 135,000, for the sets required for the whole network system (see Figure 34).

5.4 Future Work

Most parts of the system design have been achieved, as can be seen from the description of the experiment. However, there are still a few necessary functions that have not been accomplished and there are more valuable parameters, especially for the construction and evaluation of rural wireless network, which still should be considered but have been omitted due to the limited time and labour in this research.

First, the shortest-path-algorithm, which considers only one aspect of QoS routing metrics, was used in ***BrwsLi*** to determine the "best" route between the source node and the destination node. The use of this kind of routing algorithm has, therefore, diminished the accuracy of the evaluation result of network quality due to not considering other aspects of QoS routing except hop-count.

Some unfinished work has been designed for the system but is still in the process of being coded. Unaccomplished calculations related to the work are the calculation of network efficiency due to the lack of a real dataset of Newcastle.

Some work that is vital for concerning network planning is to be added into the high-level system design. The most important network parameter we missed in the system design is interference, which covers the interferences either from the signal transmission inside the network, or from the rough topology and weather in rural areas outside the network.

An important module about rural wireless technology comparison should also be taken into consideration in future. In fact, a network using GSM technology (using basic MSC, BSC and BS) has been developed in the research, but a proper method is expected to compare the networks that are constructed in the environment of cellular system or self-contained system respectively.

Due to the limitation of experiments-in-a-laboratory, the network traffic, which is supposed to be obtained from the real statistical traffic data for the Newcastle communication network, was only done by software simulation in the laboratory. Thus the accuracy of the experiment is diminished and the simulation of the Newcastle area is not as close to real life as we intended.

5.5 Summary

In Chapter 5, an outline was given as to how the rural wireless simulation environment, ***BrwsLi***, was enabled using Scilab language. The high-level system design, low-level function design and interface definitions were described. An experiment of the constructing a rural wireless network in Newcastle illustrated those abstract designs, and thorough analysis and conclusions followed. Finally more research work to be undertaken on ***BrwsLi*** is discussed. The conclusions of the entire research are narrated in the next chapter.

Chapter 6 CONCLUSIONS AND FUTURE EXPECTATIONS

The aims of the thesis were several-fold. First, the thesis attempted to set up the Impact of Telecommunications Model and the Service Model for planning rural wireless networks. Thus the two models are contributing the modeling methods of planning and devising rural wireless networks to wireless network planners. Second, the thesis sought to provide the network planners with the skeleton of wireless models for rural areas in the form of a software-simulating environment. Through this, network planners can build their rural wireless network applications in the real world by incorporating the statistical data of the researched area into the skeleton of the wireless model. It also enables rural dwellers with little expertise to contribute at no cost to the design of wireless communication networks in their localities by using the planning tool.

In Chapter 6, the research questions posed in Chapter 1 will be revisited and answered in terms of the research in Chapter 2, Chapter 3 and Chapter 4. Following this, the limitations of the research will be discussed. Finally, future research on the construction of rural networks and the extension to the simulating environment will be described.

6.1 Research Question Resolutions

The research questions, which were outlined in section 1.3 will be revisited in the same order as follows according to the full scope of the research study in the previous chapters:

1. Which kinds of data do we need to collect before planning a wireless network?

To implement rural communications, the planners need to be aware of many essential elements of rural communications. As can be ascertained from Chapter 2, the rural environment is the element that needs to be clarified first. This includes determining the natural and artificial difficulties of penetrating wireless services in rural areas and collecting the most pertinent requirements for wireless communications from inhabitants in rural areas. This is followed by determining the technology issues, which demands the awareness of all appropriate wireless technologies that can be applied to rural areas and the criteria for choosing the most appropriate wireless technologies for a certain research area. This step is absolutely necessary for planning a rural wireless network. Economic issues are the last but not the least to be considered, as the whole procedure of communication network construction and operation involves money. Economic issues that are concerned in the research include the economic constituents of the value chain when constructing a wireless network. The state of the economic development of South Africa is also concerned due to its importance for evaluating the network viability in underdeveloped regions.

2. What models do we need to set up to construct the network?

Two models were proposed in the research on how to construct a fully functional wireless network in rural areas. One was the Impact of Telecommunications Model and the other was the Service Model. The Impact of Telecommunications Model was treated as an effective economic model in Chapter 3. Its main contributions were to show network planners what network attributes could be considered before building the wireless network, what economic parameters were worth concentrating on for rural wireless communication, and how to analyze the resultant data which was obtained from the Impact of Telecommunications Model. Yet the Service Model, as viewed in Chapter 4, aims to build a rural wireless network in terms of meeting the communication service requirements of rural dwellers and solving the technical problems of constructing a wireless network. It was conceived as being similar to the process of distilling water, whereby the input water was filtered by different filters with divergent filtering functions in order to get pure water. First, the crude data of the research area was collected to obtain the wireless-related information of the research area. Then the data flow ran through the Management Pipe, along which it was filtered by the filters of the Application Layer, the Guide Layer, the Network Layer and the Physical Layer in turn. At the output of the Application Layer, the technical and economic targets of the network were clarified, which helped to determine other technical and economic issues in the process in the following layers. Then the most suitable wireless technologies for the network were chosen according to the criteria for choosing the technology set in the Guideline Layer, and specified technical parameters were selected as well to evaluate network quality. The Guideline Layer was followed by the Network Layer, where the topology of the network was formed. Lastly, on inserting the basic network nodes, which contained equipment with special functions in the Physical Layer, a wireless network was formed.

3. How can the models be set up and estimated in an easy and reliable way?

In conclusion to the thesis, there are three elementary steps that need following in order to set up the models for a specific purpose. Firstly make it clear what the targets are to set up the models; secondly collect all the necessary information and to gain the knowledge of modeling; thirdly illustrate the model by introducing the modeling procedure to the user. Furthermore, two concrete methodologies were applied to evaluate the practicability of the models in an easy and reliable way. 1) The Case-Study method illustrates the theoretical models by demonstrating the way to apply the models in a real world. This is therefore an easy means of evaluating and comparing the attainable technical and economic performance of a simulation work to a real one. 2) Another methodology is Software-Development method. The resultant software simulation environments, which are developed from the idea of the combination of proper software development tools and the theoretical models with the correct principles, can be offered to network planners to make their work easier and more reliable. This is done by constructing a variable network topology and by evaluating the technology and economy efficiency of the network automatically in the simulated environments.

4. Are these tasks and outcomes truly contributing to the telecommunication field?

The contribution of the research to the wireless network planning research field can be evaluated and narrated at length as follows:

1. The social value of the research is significant. Since rural populations constitute large proportions of national populations and their communication requirements are increasing every day, governments, communication network operators and service suppliers take active interested in the construction of rural wireless networks. However, the tough natural environment and poor construction of telecommunication networks has been restricting the development of communication industry. This will even negatively influence the economy of the whole country. The research seeks to encourage the development of wireless communication networks in rural areas and provide network planners a reference modeling procedure of wireless networks in rural areas.
2. A solution of planning a network has been carried out. Two practical models have been set up to make technical and economic criteria of building a rural wireless network, and their applications in the real rural world have been performed and analyzed to demonstrate the two theoretical models. Furthermore, the simulation environment has been developed and functionally tested, which enhances the two models by making them accessible and operable for normal network planners.
3. New ideas of planning a network have been produced. First, The Impact of Telecommunications Model selectively involves one technical parameter that is telephone penetration, and one economic parameter that is gross domestic product, to provide a snapshot of the usefulness of the constructed network to planners. Second, the research supplies the Service Model with a "layering" concept that was posed in OSI at the beginning. Last, the research adopts the open source of Scilab, which has been designed for the purpose of the simulations especially in the field of mathematics and signal processing, and has rarely been used for wireless network planning as far as it is known. The software tool developed is novel in terms of the items modeled.
4. The integrity of the scheme of planning a network is ensured. Both the economic model and the technical model have been set up in order to ensure the complicity of a network construction in the real world. This will ensure that the construction of a network is both technically and economically viable. After building the two

models, the case study methodology and the software development methodology were used to evaluate the practicability of the models.

6.2 Limitations

The economic parameters of the Impact of Telecommunications Model that were taken into consideration for evaluating the network efficiency were selective. Many economic issues relevant to network construction are worthy of consideration but were ignored in the research for the sake of focus. These economy-related forecasts, which are the reasonable estimation on the basis of the network states, include 1) total cost spent on physical settings, labour, tax and so on, which has been expected to be covered by the budget of initial investment and is most beneficial to network operators, 2) network operating and maintaining fees, which is responsible for the decision on whether to perform an incremental investment for network operators, 3) return from new licenses, service charges, regular repairs and maintenance, which can be compared with real data in order to help adapt the operating manner in time for both telecommunication carriers and service providers, 4) monetary risk originating from the dynamic mobile market, which has effects on all aspects of a network, such as whether more investment is needed, whether tariffs should be changed and whether a new service is mature enough for changeful mobile market, and so on.

In the Service Model, an all-inclusive reference table of parameters is absent. The table is expected to contain most of the technical information of wireless networks, such as the conditions or ranges of reference parameters that reflect the general technical knowledge for all wireless transmission technologies and access technologies. It might also be expected to contain the reference parameters that describe the ability of any network to be administrated, operated and maintained. Therefore, the reference table is expected to be very helpful when making decisions about implementing some technical issues in the Service Model. Moreover, since the Newcastle-service-model was devised in a lab and realized in a programming language, the validity of the resulting data has not been tested by being compared with real data from the real world.

The main limitations of the Scilab simulation environment relate to two factors. One is the shortage of the calculation of interference parameters. These parameters concern the damage that interference sources do to radio signals. The other limitation is the unaccomplished functions, which have been originally anticipated in the system design but not realized in the coding. For example, the economic parameter of "network efficiency" was not included in the coding because the wireless world is devoid of an exact definition, such as what the threshold value of the ratio of the real network capacity to the expected network capacity is.

6.3 Future Research

Despite widespread GSM and DECT networks in South Africa, CDMA is the technology that is the most valued for wireless network planning in rural South Africa because of its optimal coding mechanism and wide coverage capability. The value of using CDMA access technology is made clear in the following four paragraphs by factors such as economic development, social issues, government policy, market research, skills requirement, and technology [9].

1. Deploying CDMA is economically viable because the cost of network infrastructure and user equipment is comparably low owing to the large-scale production of CDMA and its ability to allow for incremental investment [6].

2. CDMA might well take up the opportunity to be a competitively-priced technology because the licensing of a novel technology, which is expected to be issued soon, is anticipated to enhance competition, thereby allowing cheaper calls and improved service. Despite the dominant GSM presence, the South African Telecommunications Regulatory Authority (SATRA) has declared that it will NOT prescribe, favour or EXCLUDE any digital wireless technology or the network architecture for the third cellular license [30].

3. CDMA is believed to be the preferred technology in rural areas where the need exists for a basic voice service rather than roaming. This is because CDMA covers a bigger area with fewer base stations. However, GSM is better suited for urban areas

where it can provide high-quality and secure voice communication services, and offer fast telecommunication data services.

4. CDMA leads the wireless world with its powerful attributes. It provides customers with the high-quality voice service, continuous call holding due to its soft-switch ability, easy connecting ability obtained from the spread spectrum ability and code-division multiple access technologies, excellent security through the collaboration of authority, digital format, low transmitting power of no more than 200 million watts, and an ability to offer multiple services such as call forwarding, call waiting, three-party conference, short message and voice mailbox [58] [59].

As CDMA has so many advantages in all aspects, a CDMA-based network is anticipated in future network construction in rural South Africa. Hence, in future research, the Newcastle application is to be implemented by adopting CDMA, and more parameters concerning CDMA network performance is to be selected to evaluate the CDMA network. In the mean time, a comparing mechanism will be embedded into the ***BrwsLi*** in order to compare any two networks, such as GSM-based network, CDMA-based network, or even a convergence of these networks. The comparison can be concentrated on, for example, the amount of equipment, the coverage for each base station, or the unit cost of peripherals and terminals. The simulation results will assist network planners in choosing a suitable technology for their rural wireless-network in terms of the network quality and the services that can be offered to customers.

6.4 Summary

Two reasonable and functional network models were set up for planning wireless networks in rural areas and a simulation environment in Scilab was implemented to realize those models. However, some limitations still existed and future research concerned with enhancing the modeling of rural communications was proposed. This would lead to a comprehensive and easily-operable modeling system for rural wireless networks.

Appendix I Pivotal Economic Parameters

Adjusted Depreciation

Currency depreciation is a decrease or loss in the value of communication equipment owing to age, wear, or market conditions. Linear Depreciation is the most prevalent method widely applied in the accounts of telecommunication operators. However, it is possible to take into account the natural evolution of the price of equipment and services in specific markets, and therefore use Adjusted Depreciation accordingly.

Currency Depreciation "ε" is taken into account by:

$$\varepsilon = 1 - \sqrt[n]{\frac{C_0}{C_n}}$$

C_0 = *the value of one SDR in the national currency in the year of acquisition*;

C_n = *the value of one SDR in the national currency in the year N*.

So the adjustment to current cost is attainable from the formula:

$$ACC = AMO \cdot \left(\frac{(1+\tau)^{D/2}}{(1-\varepsilon)^{D/2}} - 1 \right)$$

ACC = adjustment to current cos*t*;

AMO = amortization allowance;

τ = *annual average grouth rate in the price of equipment*;

ε = *average annual rate of currency depreciation*;

D = depreciation period.

Whereas risk premium that is linked to currency depreciation is calculated as follow:

$$\frac{n\varepsilon\left[1 + \frac{n+1}{2} \cdot i_F\right] - 1 + \frac{1}{(1+\varepsilon)^n}}{n - \frac{1}{\varepsilon}\left[1 - \frac{1}{(1+\varepsilon)^n}\right]} - i_F$$

n = *average duration of loan*

ε = *currency depreciation*

i_F = *resk − free money rate*

Efficiency

Network efficiency is calculated by combining installed capacity, utilized capacity, average annual growth rate in a number of subscribers and in the replenishment period and is calculated as follows:

$$K' = Max(0; \Delta K - K_u \cdot ((1+\tau)^N - 1)$$

$K' = \textit{the idle capacity};$
$\Delta K = \textit{the difference between the installed capacity and the utilized capacity};$
$K_u = \textit{utilized capacity};$
$\tau = \textit{annual average growth rate in the number of subscribers};$
$N = \textit{the necessary extension time.}$

Cost of capital

Abundant examples of cost from capital are obtainable, such as the combined effect of debt and equity, creditors demand interest and owners demand dividends.

The ratio $\frac{net\_profit}{equity}$ denotes a current return on equity. However, now that investors often demand a return that is keeping up with the international financial market, the minimum return on equity "σ" in a given market is determined as follows:

$$\sigma = i_F + \beta \cdot (r_M - i_F)$$

$i_F = risk\_free\_rate$
$r_M = market\_return$
$\beta = sensitivity\_to\_market\_risk$

The essential components of the cost of capital are expected to be set and calculated to adjust to local conditions.

Profit tax

An operator's profits are allocated by government through the statutory taxation of profits and shareholders through return on capital. Shareholders often demand an after-tax return on capital.

$$L_{benefits} = \frac{\tau_{levy}}{1-\tau_{levy}} \cdot \rho_{capital} \cdot Capital$$

$$L = profit\ estimated$$
$$\tau = corporation\ tax$$
$$\rho = \exp ected\ return\ on\ equity$$
$$Capital = shareholders'\ capital$$

Contribution to universal service obligations (USO)

A government may deduct an operator's revenue for the purpose of financing USO costs. USOs may or may not be combined with the access deficit where applicable and are calculated as follows:

$$USO = \rho_{uso} \cdot \left(L_{benefit} + \sum_{i=1}^{n} k_{si} \cdot T_i \right)$$

$$\sum_{i=1}^{n} k_{si} \cdot T_i\ is\ services\ ch\arg ed\ directly\ to\ users.$$

Access deficit

An access deficit may occur when the regulatory authority opposes cost-orientated adjustment of the following components: the connection charge, the monthly subscription, the price per minute of a local call, and the price per minute of a trunk call. Before redistributing the access deficit, it must be born in mind that only local users pay the connection charge and monthly subscription. The charge per minute for outgoing calls should be reduced as follows:

$$\left(\Delta Parc \cdot R_{conn} + msf \cdot Nb_{subscr} \cdot 12\right) \cdot \frac{k_{si}}{\sum_{j=1}^{n'} T_j k_{sj}}$$

$$\Delta Parc = growth\ in\ number\ of\ subscribers$$
$$R_{conn} = connection\ ch\arg e$$
$$msf = monthly\ subscription\ fees$$
$$Nb_{subscr} = average\ number\ of\ subscribers$$
$$\frac{k_{si}}{\sum_{j=1}^{n'} T_j k_{sj}}\ is\ services\ ch\arg ed\ directly\ to\ users.$$

The amount of the access deficit is obtained by the following formula:

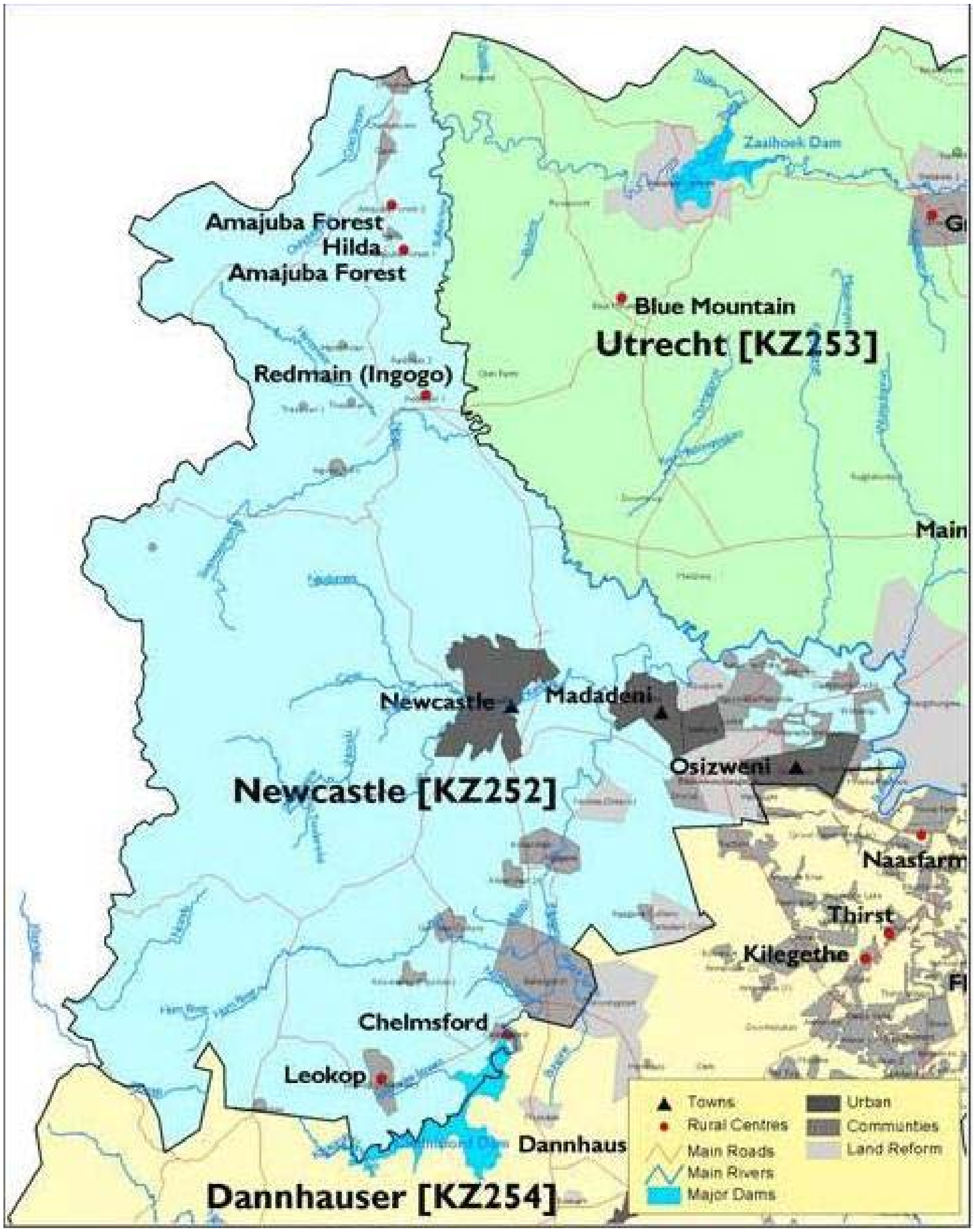
$$D = T_{local} \cdot (k'_{local} - p_{local}) + T_{trunk} \cdot (k'_{trunk} - p_{trunk}) - DomIneff$$

If $D > 0$, the access deficit is positive and reallocated to all telecommunication services provided by an operator. If $D = 0$, there is no deficit; the surplus may therefore be allocated to local and trunk calls in order to reduce or rebalance tariffs.

A generic formula calculating the profit tax, the access deficit, and the contribution to universal service obligations must be allocated to the appropriate services for the distribution of other tariff elements:

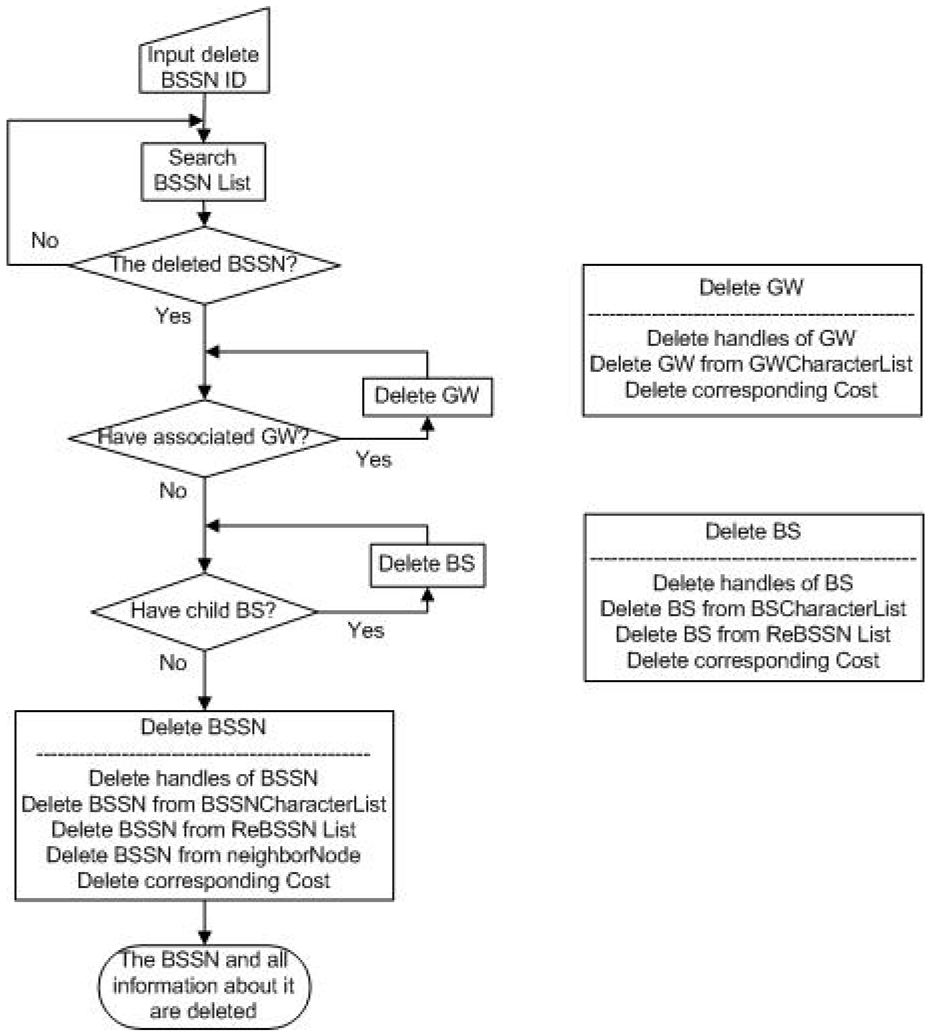
$$Share_{si} = \frac{Tariff_{element}}{\sum_{j=1}^{n} k_{sj} \cdot T_j} \cdot k_{si}$$

Appendix II Newcastle Population Regional Settings



This figure shows the regional settings of people in Newcastle area and derives from reference [60].

Appendix III A Example of Data Flow in BrwsLi



Delete_BSSN Data Flow

This paragraph sets a data-flow example of deleting a BSSN node in BrwsLi. It can be easily seen that both the connected GW and the child BSs will have to be deleted with the deletion of a BSSN.

GLOSSARY ITEMS

Group A (Author-created)

BrwsLi (a Bridge to Rural Wireless Simulation by yang Li) is the name of the software environment that has been designed in this research to simulate the construction and evaluation of a rural wireless network.

NHS (Newcastle-Health-System) is the name of the service model of the Newcastle example.

Group C (Company)

Cell C (Cell C (Pty) Ltd South Africa) is the third cellular operator in South Africa and Cell C service provider. http://www.cellc.co.za.

MTN (MTN (Pty) Ltd South Africa) is South Africa's second-largest cellular network operator and MTN service provider. http://www.mtn.co.za.

Pyramid Research is a division of the Economist Intelligence Unit, which specializes in telecommunications research and consulting in emerging markets.

Telkom SA (Telkom South Africa) is the South Africa's leading integrated communications operator on both wire and wireless. http://www.telkom.co.za.

Vodacom (Vodacom (Pty) Ltd South Africa) is a pan-African cellular communications company providing a GSM service. http://www.vodacom.co.za.

Group E (Economy-related)

GDP (Gross Domestic Product) is a value measure of the flow of domestic goods and services produced by an economy over a period of time, such as a year.

USD (United State Dollar) is the ISO 4217 currency code for the United States Dollar.

Group H (Hardware)

BS (Base Station) is the interface between the BSC and the Subscriber and/or CTs.

BSC (Base Station Controller) serves as an interface unit between the ET and the BS.

BSSN (Base Station Switching Node) manages several BSs and provides some links to connect adjacent BSSNs in a self-contained networking scheme.

CT (Cluster Terminal) interfaces with the BS and can support more than one subscriber instrument.

ET (Exchange Terminal) interfaces with the LE and the BSC connected to it.

GW (Gateway) is a hardware or software set-up that functions as a translator between two dissimilar protocols.

LE (Local Exchange) interfaces between the access network and backbone network.

RS (Repeater Stations) is a radio signal repeater between the BSC and the BS.

ST (Subscriber Terminal) interfaces with the BS and supports single subscriber.

Terminal Radio-A and Terminal Radio-B are offered in any point-to-point system.

Group T (Technology)

BHCA (Busy Hour Call Attempt) is he number of call attempts during the busiest hour (largest call volume) in a business day.

CDMA (Code Division Multiple Access) is a multiple access communications technology in which the data is transferred over the whole bandwidth by using a unique pseudo code.

CIM (Centralized Information Management) is a database management mechanism in which the database in the whole system is central-controlled by one node.

DCA (Dynamic Channel Assignment) is a allocate channels dynamically by change the time, frequency, code or space.

DECT (Digital Enhanced Cordless Terminals) is a standard governing pan-European digital mobile telephony based on advanced TDMA, and covers cordless PBXs, telepoint and residential cordless telephony and performs within limited areas.

DIM (Distributed Information Management) is a database management mechanism in which the database in the whole system is controlled in distributed nodes.

DV (Distance Vector) stands for the decentralized routing algorithms where each node has information about the nodes with which it is directly connected.

FDMA (Frequency Division Multiple Access) is a multiple access communications technology in which multiple user channels can be carried on one physical circuit by dividing frequency into narrower bands.

GNB (Go-Back-N protocol) allows the sender to transmit a fixed number of multiple packets without waiting for an acknowledgement.

GoS (Grade of Service) defines a metric that represents the probability that a telephone call cannot be completed on a given call attempt, on a business day, during the facility's busiest hour, which is also known as network traffic block probability.

GSM (Global System for Mobile Communications) is a digital cellular standard that uses TDMA to carry eight simultaneous calls on the same frequency.

LS (Link State) refer to the global routing algorithms where every node has complete information about all other nodes in the network.

NMT (Nordic Mobile Telephony) is an analogue public mobile communications system based on a common agreement between the Nordic countries on preparing and drawing up technical specifications.

PHS (Personal Handyphone System) is a digital mobile telephone system according to Japanese standard in the frequency range 1900MHz.

PMP (Point-to-Multipoint) is a radio system concept wherein a radio site communicates with more than one sites on a radio channel.

PTP (Point-to-Point) is a radio system concept wherein two sites on a radio channel communicate only between themselves and with no other site.

STAR (Satellite Global Star technologies) is a global communications system using satellites as communicating medium.

TDMA (Time Division Multiple Access) is a multiple access communications technology that uses a common channel for communications among multiple users by allocating each a unique time slot.

WiFi (Wireless Fidelity) is an interoperability standard developed by WECA, which is also known as IEEE 802.11. Hardware that displays the WiFi logo claims that 802.11 compliance should interconnect seamlessly.

Group N (Network)

IN (Intelligent Networks) is a sophisticated network capable of recognizing the profile (authorization, chosen services) of its users or subscribers and it centralizes a significant amount of intelligence rather than installing this intelligence individually.

Internet is a global network linking millions of computers that all use the TCP/IP protocols for communications purposes. It is a packet and overlay network.

LANs (Local Area Networks) are limited-distance network connecting a defined set of terminals with the speed of 10 -100 Mbps. Bus, Ring, Star, Extended Star, Hierarchical, and Mesh are the common physical topologies of LANs.

PSTN (Public Switched Telephone Network) is structured as a hierarchy of switching system. The most basic form of hierarchy of switching system consists of five classes of offices: regional (class 1), sectional (class 2), primary (class 3), end office (class 4) and subscribers (class 5).

SONET (Synchronous Optical Network) is a particular set of standards that allow the interworking of products from different vendors. It usually embodies a fiber-optic ring that will permit transmission in both directions.

WANs (Wide Area Networks) cover much larger areas, spanning several countries and continents. They have more complex topologies and connectivity, so direct connections between machines would be unmanageable and expensive.

Group O (Organization)

CCITT (Consultative Committee for International Telegraphy and Telephony) is an international consultant committee and standards organization that creates communications protocols for the transmission of voice, data, and video across all computing and telecommunications equipment. It was replaced by ITU in 1993.

FCC (Federal Communications Commission) is a government agency responsible for regulating telecommunications in the United States.

IEEE (Institute of Electrical and Electronics Engineers) is an international organization that sets standards for electrical and electronics industry and computer engineering.

ISM (Industrial Scientific and Medical band) uses the bands that encompass unlicensed frequency ranges to make the technologies that operate on these frequencies cheaper and less limitation to transmit.

ISO (International Organization for Standardization) is a worldwide federation of national standards bodies that develops international standards.

ITU (International Telecommunications Union) is a United Nations organization that establishes standards for telecommunications devices, like ISDN hardware, modems, and Fax machines. It was known as CCITT before year 1993.

SATRA (South African Telecommunications Regulatory Authority) is the regulation of telecommunications sector of South African that was taken over by the Independent Communications Authority of South Africa (ICASA) in July 2000.

WECA (Wireless Ethernet Compatibility Alliance) is an organization to certify the interoperability of IEEE 802.11 wireless LAN products and to promote standard for markets. It was renamed the WiFi Alliance in October 2002.

Group P (Parameter)

QoS (Quality of Service) is an item to express the performance of a communication channel or system. Depending upon the communication system, QoS may relate to service performance, SNR (Signal to Noise Ratio), BER (Bit Error Ratio), maximum and mean throughput rate, reliably, priority and other factors specific to each service.

Bandwidth is the width of the range of frequencies that an electronic signal occupies on a given transmission medium. Bandwidth is usually measured in bits-per-second.

Transmission Speed is defined as the amount of bits that are transmitted successfully in a second.

Network Capacity is the cell size for which system can reliably serve the cell users.

Delay reveals the physical reliability or communication reliability of a network.

Interference is balanced by transmitting the information over the link, while keeping the error rate fixed and not to exceed a nominal value preset for the entire network.

Group U (Unit)

bit is the smallest unit of computerized data and represented as “0” or “1”.

bps is bits per second.

Erlang is an international unit of the average traffic in a busy hour. One Erlang is equal to the product of the number of call per hour and the average call duration.

Hz (Hertz) is an international unit for measuring frequency, equivalent to the older unit of cycles per second.

KHz (One kilohertz) is one kilo hertz.

MHz (One megahertz) is one million hertz.

GHz (One gigahertz) is one billion hertz.

kg (One kilogram) is one thousand grams.

km (one kilometer) is one thousand meters.

min (Minute), sec (Second)

Group Z (Others)

AC (Alternating Current) reflects a voltage or current of which the amplitude characteristic of an electrical signal reverses repeatedly.

AIDS (Acquired Immune Deficiency Syndrome) is a serious disease of the immune system transmitted through blood products.

DC (Direct Current) reflects a voltage or current that does not vary with time.

GUI (Graphical User Interface) is a computer terminal interface, such as Windows, that is based on graphics instead of text.

HIV (The Human Immunodeficiency Virus) is recognized as the cause of or a major contributor to AIDS.

Scilab is the name for Scalable Coherence Interface development software for simulation.

WWW (World Wide Web) is a collection of information servers linked together through a language called hypertext.

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