Dissertation Title

CDMA Performance for a Rural Telecommunication Access

Submitted By

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Declaration

I, Poloko Freddy Rasello, Student Number 9608660, hereby declare that the dissertation entitled **CDMA Performance for a Rural Telecommunications Access** is a result of my own investigation and research, and presents my own work unless specifically referenced in the text. This work has not been submitted in part or in full for any other degree or to any other University.

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LIST OF SYMBOLSAND ABBREVIATIONS

2G	Second Generation Cellular Systems
2.5G	Second and Half-Generation Cellular Systems
3G	Third Generation Cellular Systems
AGC	Automatic Gain Control
AMPS	Advanced Mobile Phone System
APD	Avalanche Photodiode
ATM	Asynchronous Terminal Mode
AWGN	White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
BSC	Base Station Controller
BTS	Base Transceiver Station
CDMA	Code Division Multiple Access
DECT	Digital Encoder Telephone
EMI	Electromagnetic Interference
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FSK	Frequency Shift Keying
GPS	Global Positioning System
GSM	Global System Mobile
IBA	Independent Broadcasting Authority
ICT	Information and communications technologies
ICASA	International Authority of South Africa
IIC	International Institute of Communication
IM	Intermodulation frequency
IP	Internet Protocol
ITU	International Telecommunications Union
ISI	Intersymbol Interference
KZN	Kwazulu-Natal

LAN	Local Area Network
LMDS	Local Multipoint Distribution System
LOS	Line of Sight
MAI	Multiple Access Interference
MMDS	Multi channel Multipoint Distribution Service
MVDS	Microwave Video Distribution System
MOU	Minutes of Uses
MSK	Minimum Shift Keying
MMSE	Minimum Mean Square Error
MS	Mobile Station
MSC	Mobile Switching Centre
NLOS	Non Line of Sight
NPV	Net Profit Value
PSDN	Public switched telephone networks
PTP	Point-to-point
PMP	Point-to-multipoint
PSK	Phase Shift Keying
PIN	Positive Intrinsic Negative
PN	Pseudo-noise
QPSK	Quadrature Phase Shift Keying
RDP	Reconstruction and Development Programme
RIARC	Reseau Des Instances Africaines De Regulation De la Communication
SATRA	South African Telecommunications Regulatory Authority
SDI	Spatial Development initiatives
SF	Spreading Factor or processing gain
SNR	Signal-to-Noise Ratio
SIGA	Simplified Improved Gaussian Approximation
TDD	Time Division Duplex
TDMA	Time Division Multiple Access

TRASA	Telecommunication Regulatory Association of Southern Africa
VSAT	Very Small Aperture Terminal
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunications Systems
USA	Universal Service Agency
WAN	Wireless Area Network
W-CDMA	Wideband Code Division Multiple Access
WTO	World Trade Organisation
WLL	Wireless local loop

i. ABSTRACT

Reviews of possible telecommunication services that can be deployed in the rural areas are highlighted. These services range from narrowband to broadband. The aim of these services is to target rural Kwazulu-Natal areas that are without or with limited telecommunications infrastructure.

Policies that govern telecommunications in South Africa are also reviewed with emphasis on Universal Service Obligation. The importance of telecommunications infrastructure in rural areas is also reviewed to the benefit of Kwazulu-Natal.

FDMA, TDMA, CDMA, VSAT, MMDS and MVDS are compared for a possible use in rural areas. Cost comparison of GSM and CDMA is conducted with emphasis on fade margin, path loss and penetration rate.

CDMA system design and coverage areas are discussed for rural Kwazulu-Natal. Lastly bit error rate graphs and power control algorithms are presented for Kwazulu-Natal scenario.

ii. PREAMBLE

In South Africa, rural areas do not have access to telecommunications infrastructure. In this thesis different types of systems that can be used in rural areas are introduced, advantages and disadvantages are highlighted. Microwave, optical fiber and CDMA systems are compared in terms of cost and performance. Lack of telecommunication infrastructure in rural areas makes this project an important one. Rural areas of Africa have limited access or no access to telecommunication infrastructure.

Most of the systems highlighted above can be deployed in rural areas. The most worrying factor about rural areas is the spatiality in populations, which in turn affect the telecommunications traffic. The traffic that is currently generated in rural areas is mainly voice with little data. The above points clearly highlight the fact that we do not need a high bandwidth system in rural areas.

Rural people are perceived to be poor and are overlooked when new systems are introduced to urban areas. Historical wire line systems take time to deploy due to the fact that conductors are expensive and it is usually difficult to cover long and hilly areas. Wireless backhaul systems are preferred to wire line backhaul systems because of quick time of deployment of the former compared to the latter.

Due to the fact that most microwave links are broadband systems, they are not really necessary for rural South Africa. In FDMA system users are allocated different frequency band and this creates a problem because when the circuit is not it use it is idle and cannot be used by someone else. FDMA has low bandwidth as each channel supports only one circuit. In TDMA each signal uses the entire frequency band of the system for a fraction of time. TDMA has a predetermined time slot and if all time slots in the cell are already occupied the call might be dropped.

In South Africa, mobile service providers use TDMA system and are currently encountering problems with idling network. Users are given slots but they are not making use of them. The number of subscribers has gone up but slots are always idling.

In CDMA all users share the same frequency band. CDMA has soft handoff and idle handoff, when the cell is fully occupied then other users can be move to the next available cell site. Compared to TDMA, CDMA has a bigger bandwidth of 1,25 MHz compared to 200 kHz. CDMA system is a relevant system for rural area because it is a narrow band system that can accommodate digital voice and data.

Unlike TDMA, users are not given permanent slots but they share a channel. CDMA is a 2.5G network and can be expanded when the population increases. Currently telecommunications evolution is moving towards Internet Protocol (IP) and CDMA can be transported over IP or ATM. In areas when ATM exists, we can transport CDMA over ATM or move to IP. CDMA system is secure because of the spreading codes and is also immune to intentional interference.

As clearly stated, CDMA is a 2,5G network and it is recommended to go through 2,5G before moving towards 3G systems. It will be relatively easy to move from CDMA to WCDMA when the traffic increases. This is so because of the experience that would have be gained in the 2.5G systems.

CDMA has some difficulties with the near far problem, so we calculated the number of base stations and the maximum number of trunks available for rural Kwazulu-Natal. Simulations were then done on the system for conventional power control and minimum mean square error (MMSE) algorithms. MMSE power control performs better when the system is fully loaded (N= 405). When the number of users is less than 250, then we can use conventional power control algorithm.

The speed of convergence for MMSE power control is better compared to conventional power control and MMSE power control can reach a targeted SNR with the system fully loaded. We also showed that CDMA is capable of accommodating many users, as there is no need for channel allocation for each and every user. All users are allocated one frequency band, which eliminates frequency planning. When the number of active users increases, the noise floor also increases. Thus the performance of the system degrades with increase in number of users. In other instances, users might need to transmit signals simultaneously at different data rates.

Simulations show that signals transmitted at higher data rates perform badly while at lower transmission rate performs better. This will enhance the status of CDMA since it can accommodate different data rates. This also stems the fact that CDMA is ideal for digital voice, of course, data is also an issue but in rural areas our main focus is telephone infrastructure. This can be upgraded at a later stage to fairly accommodate data as well as video.

CHAPTER 1

RURAL AREAS IN KWAZULU-NATAL

1.1 INTRODUCTION

This thesis focuses on the CDMA performance for rural area telecommunications access. Chapter 1 introduces rural areas of Kwazulu-Natal, highlights population distribution and patterns of rural settlement, because they might affect the type of system to be implemented. Mode of operation in rural areas of Kwazulu-Natal is presented, this helps in establishing whether the community will be able to afford telecommunications infrastructure. Agriculture plays a major role in the economy of Kwazulu-natal and most of the rural communities are employed in this agricultural sector thus it is discussed at length.

Kwazulu-natal has two ports, in Richards bay and Durban. This port contributes significantly in the provincial economy. There are frequent trips between Richards bay and Durban, as a result, rural areas between these cities cannot be neglected. Most people employed in Richards bay and Durban ports are also from rural parts of Kwazulu-natal and for that reason, these ports are presented in this chapter.

Telecommunication infrastructure enhances development and growth. Different types dwelling within the province and dwellings with and without access to telecommunication infrastructure are presented. This is done to show the necessity for telecommunication infrastructure in rural areas. Telecommunication traffic patterns in rural areas and urban areas of Kwazulu-Natal are compared; this is done to also show the need for increased access to rural areas.

1.2 KWAZULU-NATAL CANONICAL AREA

Kwazulu-Natal (KZN) province, formally known as Natal province, occupies the South-eastern portion of the country. Kwazulu-Natal is bounded on the east by the Indian Ocean, on the south by the Eastern Cape province, on the west by Lesotho and the Free State province, to the northwest by the Mpumalanga province, and to the north by Swaziland and Mozambique as shown in figure 1. The provincial capital is Pietermaritzburg.

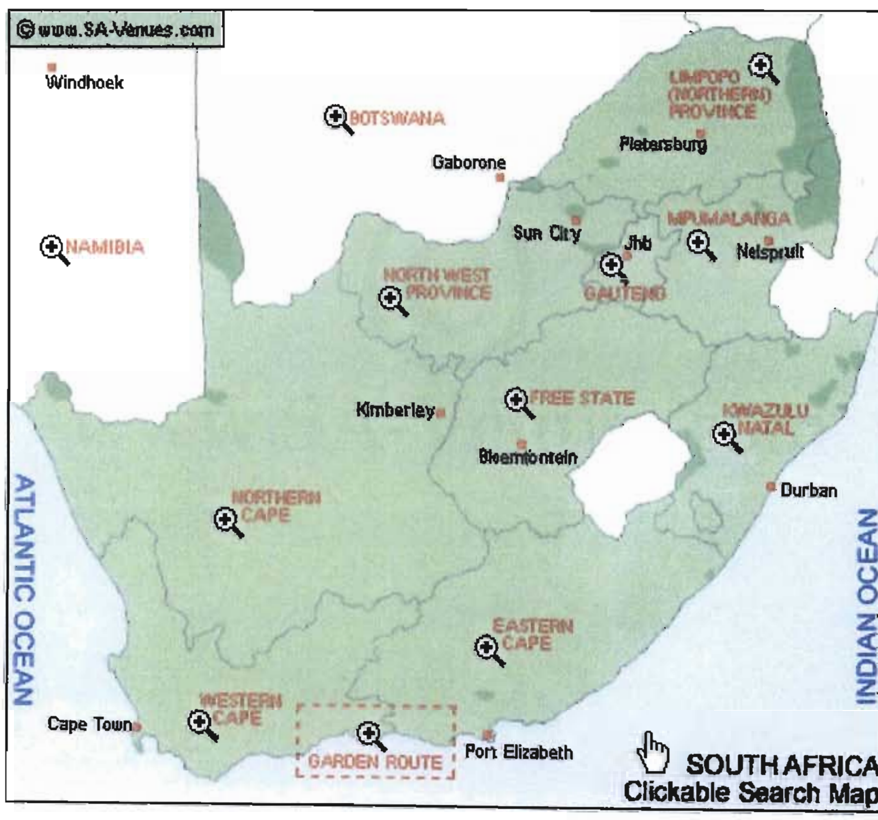

Figure 1: Map of South Africa [1]

The total area of South Africa is 1,219,090 km^2. The province with the largest area is the Northern Cape with an area of 361,830 km^2 and the province with smallest area is Gauteng with an area of 17,010 km^2. The table 1 below shows the distribution for all provinces.

	Gauteng	Mpum-alanga	Kwazulu-Natal	North-west	N-Province	W-Cape	Free State	E-Cape	N-Cape	National
Km^2	17,010	79,490	92,100	116,320	123,910	129,370	129,480	169,580	361,830	1,219 090
%	1,4	6,5	7,6	9,5	10,2	10,6	10,6	13,9	29,7	100

Table 1: Distribution of the land area of South Africa by provinces [2]

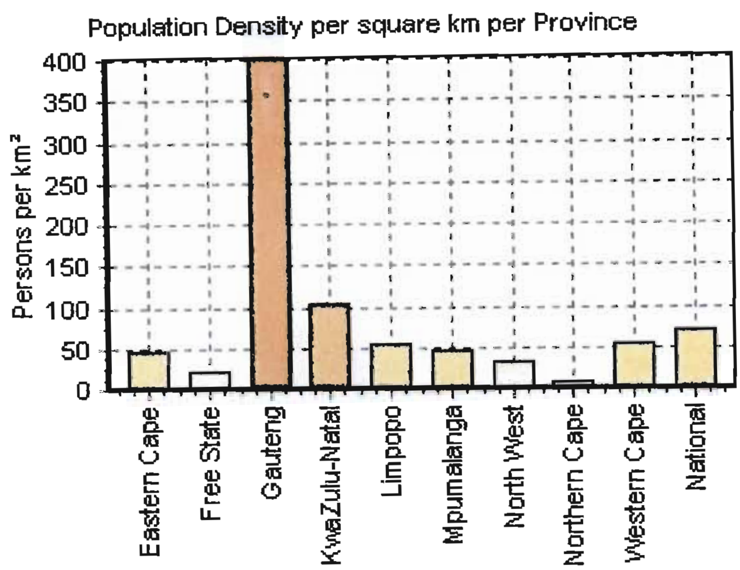

Figure 2: Population density per square km per province [4]

Figure 2 above shows that Gauteng is a province with the most number of people per square km. In Kwazulu-Natal, 57 % of the population resides in rural areas. Rural areas are defined as the sparsely populated areas in which people farm or depend on natural resources, including the villages and small towns that are dispersed through these areas. In addition, they include the large settlements in the former homelands, created by the apartheid removals, which depend for their survival on migratory labour and remittances.

Kwazulu-Natal is generally hilly or mountainous, especially along its western border, with land rising from the coast to more than 3 300 m along the Drakensberg Escarpment on the province's western border. The slope is not gradual. Various rocky outcrops render the terrain into steps of undulating land ascending from an elevation of 150 m along the coastal plain to areas of 600 and 1 200 m, respectively, in the centre of the province known as the Midlands.

Kwazulu-Natal's climate varies from subtropical to temperate. Rainfall decreases from more than 1 270 mm annually along the coast to 760 –1 020 mm inland. Temperatures decrease from the frost-free coastal area to frost area inland but still remain warm. In general, summers are hot with occasional rain, while winters are warm, dry, and sunny. The major components of the physical structure of a rural society are the patterns of settlement of rural people, the physical and other resources of the rural society, the type and spatial arrangement of houses, supplies and services, and the population characteristics.

1.3 PATTERNS OF RURAL SETTLEMENT

The patterns of settlement of rural people are of two fundamental types: the grouped or clustered dwelling forms, and the dispersed forms. There are a number of patterns of settlement that have been identified.

- **Isolated Farmsteads.** Here the individual lives on his farm with his farmland surrounding him. His neighbour may be a few miles from him depending on the size of their respective farms. Adjacent to his dwelling he keeps his livestock, barn, farm equipment, harvested produce and other such commodities. This pattern is found in South Africa, rural Africa, and other parts of India [42].

- **Villages.** This pattern of settlement consists of dwellings of rural people concentrated together with their farmland outlying their clustered dwellings or village. The number of dwellings will vary and will indicate the size of the village. The patterns of rural habitat that follow constitute variations of the two fundamental types referred above.

- **Line Villages.** Here houses are located along a road, a waterway or artery of transportation, each with adjoining strips of farmland oblong in shape extending away from the road. Residences are thus close and easily accessible to one another and at the same time are located on their respective farms.
- **Round Villages or Circular Patterns.** In a round village houses are arranged in a circle enclosing a central area with the house and a yard apex of a triangular plot. In this way, houses are closer together without creating a corresponding greater length in the tract of farmland.
- **Crossroads and Market Centre Settlements.** Common in various parts of the world and based on economic factors of location for supply and distribution of goods, these settlements provide needed products and commodities, such as prepared foodstuffs, refreshments, services such as petrol stations, repair shops, barber shops, etc. Merchants who handle agricultural products, bankers, shopkeepers and others, therefore, predominantly inhabit market centre settlements. Farmers usually do not reside in such centres unless their farmland is adjacent. Normally, these centres consist of shops that line the main road.

In South Africa we have isolated farmsteads and villages. In most instances villages are far away from trading centres. Rural populations are usually based in villages whereas farmers are found in isolated farmsteads. Villages in Kwazulu-Natal are between 2 – 5 Km apart and isolated farmsteads are 5 – 10 km apart.

Figure 3 below shows a typical rural settlement in Kwazulu-Natal. The households in this rural part are spatially distributed as shown in figure 3 below.

Figure 3: Plots showing a typical rural settlement

1.4 SIZE OF A RURAL COMMUNITY

The rural community is always smaller than the urban community. Agricultural occupations, by their very nature, call for higher land-to-man ratio than industry does, and consequently, rural areas have a low population per square kilometre. Farmland may vary in size depending on the type of farming practiced, but enough land must be available to raise crops and livestock. A rural community is hence a small community, much smaller than an urban community.

1.5 OCCUPATION

The major occupation in most rural areas of the world is farming. There are non-agricultural occupations in rural areas, but these are secondary in economic importance. In some areas farming is a business or an industry, but in others it operates largely as a way of life, a family occupation. Furthermore, in urban areas occupational pursuits tend to be specialized. A man may work in a factory at a lathe or at a stamping machine turning out hundreds of similar parts; he may develop the specialized skills of manager, foreman, or executive. A farmer, on the other hand, must usually be competent in a variety of skill. Farmers thus have a wide area of specialization as compared with urban workers.

1.5.1 AGRICULTURE IN KWAZULU-NATAL

Agricultural production in Kwazulu-Natal, together with its forward and backward linkages is an important contributor not only to household food security but also to the economy. South Africa is self-sufficient in most essential agricultural products and is part of the Cairns Group, a group of agricultural exporting countries whose objective is to strive for fair and free trade in global agricultural markets.

Due to the good reliable rainfall and fertile soils, the region's agricultural sector has become very productive and is known for its specialist capacity in several types of farming. The agricultural sector is focused mainly on the following [3]:

- Crops: sugar, maize, sorghum
- Horticulture: sub-tropical fruits, cashew nuts, potatoes, Vegetables
- Animal Husbandry: beef, mutton, poultry, wool
- Forestry: pine, saligna, wattle

Irrigation is used extensively, particularly for sugar, maize and animal pastures. The South African Sugar Association and the South African Forest Owners Association both support extensive small farmer development programmes, which are showing excellent results.

1.5.1.1 HORTICULTAURE

1.5.1.1.1 Sub-tropical Fruit

Measured in terms of the value of production, the subtropical fruit industry earned R966 million in 2002/03, an increase of 18, 2% on the 2001/2002 figures of R817 million.

The particular climatic requirements of some types of subtropical fruit make the cultivation thereof possible in only certain specific areas of the country. In general, subtropical fruit require warmer conditions and are sensitive to large fluctuations in temperature and frost.

The main production areas of subtropical fruit in South Africa are parts of the Limpopo, Mpumalanga and Kwazulu-Natal Provinces. Fruits such as granadillas and guavas are also grown in the Western Cape, while pineapples are grown in the Eastern Cape and Kwazulu-Natal. The total areas of production of avocados, banana, mangoes, litchis and pineapples during 2002/2003 are estimated at approximately 12 000, 12 035, 7 748, 3 000 and 13 581 ha, respectively.

Fruit Type	1998/1999	1999/2000	2000/2001	2001/2002	2002/2003
	Ton				
Avocados	79,9	68,9	69,5	66,5	78,2
Bananas	226,9	249,8	260,1	273,9	229,1
Pineapples	146,6	160,2	161,2	167,7	171,1
Mangoes	50,6	40,8	48,0	59,2	52,1
Papayas	23,2	23,6	20,3	22,1	16,1
Granadillas	1,1	0,9	1,2	1,4	1,5
Litchis	7,3	5,0	7,5	4,8	4,3
Guavas	18,1	21,9	23,9	26,6	27,7

Table 2: Production of Subtropical Fruit from 1998/1999 to 2002/2003

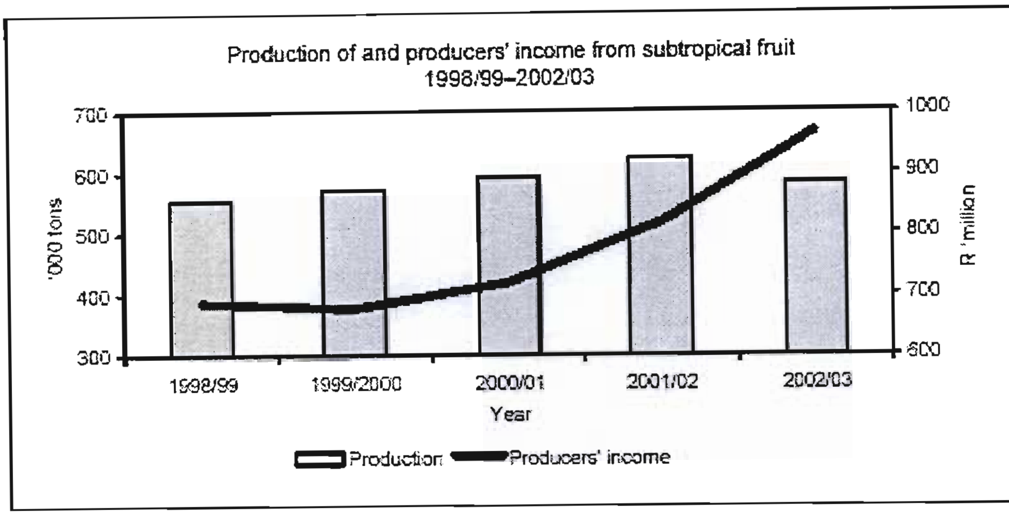

Figure 4: Production and producers' income from subtropical fruit

Figure 4 shows the production and producers' income from 1998/1999 to 2002/2003. It can be seen that from 1998/99 to 2002/03, total production of subtropical fruit increased on average by 2,8 % per annum. From 2001/02 to 2002/03, production of avocados increased by 17,6%, while the total production of papayas showed a decrease of 29,1 %. Bananas, pineapples and avocados respectively contributed 39,3, 29,4 and 13,4 % to the total production of subtropical fruit during 2002/03.

From 1998/99 to 2002/03, total exports of subtropical fruit increased by an average of 4,9 % per annum and export prices for all subtropical fruit increased on average by 9,3 % per annum. Figure 5 shows the quantity and the average price of subtropical fruit exported between 1998/1999 to 2002/2003.

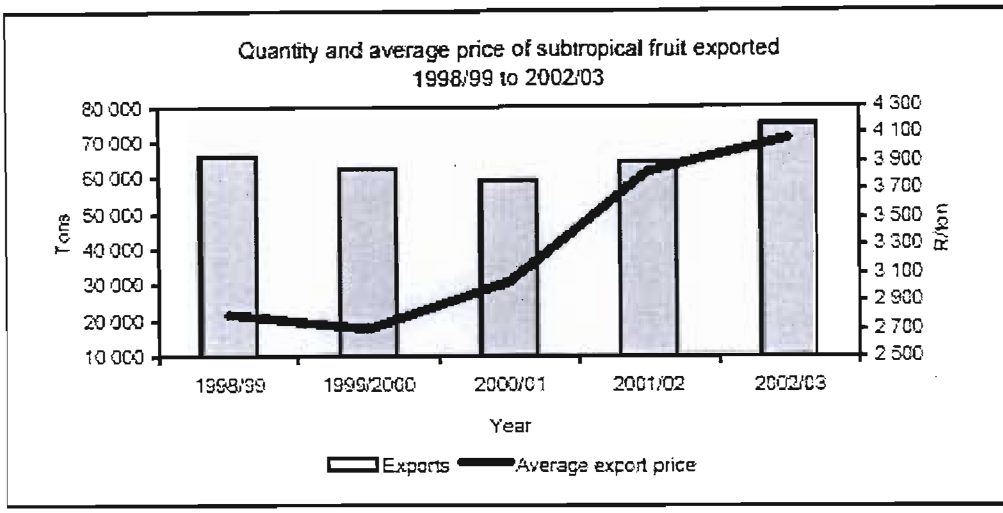

Figure 5: Quality and average price of subtropical fruit exported [44]

The main subtropical fruit type exported is avocados. During 2002/03, exports of avocados contributed 61,1 % to the total value of exports of subtropical fruit. Other subtropical fruit types that were exported are mangoes, pineapples and papayas. The largest contributors to sales of subtropical fruit on the 16 major fresh produce markets are bananas, pineapples, avocados, mangoes and papayas, contributing 73,2, 7,5, 7,4, 5,8 and 3,9 %, respectively. Except for granadillas, the quantities of all subtropical fruit types sold on the major fresh produce markets decreased during 2002/03.

Table 3 show total quantities of subtropical fruits sold on the 16 major fresh produce markets. It is very difficult to separate production of sub-tropical fruits according to provinces as a result the information used is for Limpopo, Mpumalanga and Kwazulu-Natal.

Fruit Type	1998/1999	1999/2000	2000/2001	2001/2002	2002/2003
	Tons				
Avocados	28 051	19536	26005	21996	21128
Bananas	212 790	227505	234 043	249 117	209845
Pineapples	18 116	25994	24827	23 864	21528
Mangoes	20 852	19875	20277	24513	16564
Papayas	17029	16831	14127	15279	11134
Granadillas	749	729	803	1008	1093
Litchis	3717	2312	4151	1807	2655
Guavas	3696	3240	2 960	3076	2852
Total	305 050	316 022	327 193	340660	286799

Table 3: Total quantities of subtropical fruit sold on the 16 major fresh produce markets

1.5.1.1.2 Citrus Fruits

In 2000 there were 3500 citrus fruit growers in South Africa, mainly in Western Cape, Eastern Cape, Limpopo, Mpumalanga and Kwazulu-Natal provinces. They collectively manage 16 million trees.

Oranges constitute about 67 % of the total production of citrus fruit in South Africa. On average, citrus fruit production increased by 7,4 % per annum from 1998/99 to 2002/03. However, with the exception of oranges, the production of other citrus fruit types levelled out or even decreased during 2003 as shown in table 4.

South Africa is one of the top five exporters of citrus fruit in the world. Exports increased from 811 432 tons during 1998/99 to 1 108 983 tons during 2002/03. During 2002/03, about 757 028 tons of oranges, almost 60% of the crop, were exported.

Fruit type	1998/1999	1999/2000	2000/2001	2001/2002	2002/2003
	Tons				
Oranges	963 589	1 156 359	1 117 964	1 262 527	1 265 247
Grapefruit	196 037	212 181	267 669	383 709	268 195
Lemons	103 283	101 669	120 121	169 688	189 256
Naartjies	90 123	136 901	108 432	147 688	109 783
Soft citrus	82 507	126 267	98 492	72 189	63 441
Total	1 435 539	1 733 377	1 712 678	2 036 112	1 895 924

Table 4: Citrus production for the past 5 production seasons.

1.5.2 TOURISM

The tourism industry is a key contributor to the Kwazulu-Natal economy. It is structured around four components [3]:

- The coastal holiday areas
- The wild life game parks
- The Drakensberg Mountains
- The historical battlefields. Two world heritage sites have been declared recently, i.e. the greater St Lucia Wetlands Park, and the Ukuhlamba /Drakensberg Mountain Reserve.

1.5.3 SPATIAL DEVELOPMENT INITIATIVES (SDI's)

One of South Africa's key industrial policies remains its commitment to fostering sustainable industrial development in areas where poverty and unemployment are at their highest. In Kwazulu-Natal, the following well-established SDI's are at varying stages of delivery, with further possible cross-border initiatives to be developed [3].

1.5.4 MANUFACTURING

Manufacturing, the largest sector, enjoys a comparative advantage in this province over elsewhere in South Africa in terms of access to basic production inputs such as water and coal, its excellent infrastructure and close access to South Africa's two most important ports. The regional advantages have contributed to this province attracting major industrial investment under past regional industrial incentive schemes. Only industries that empower rural areas are considered [3].

1.5.4.1 Wood Products

Because of its climate and soil types, Kwazulu-Natal is a home to extensively developed private forests. Apart from supplying the paper and pulp sector, the province is at the forefront of the country's manufacturing capabilities in areas such as sawn timber, particle board, furniture, kitchen cupboards and manufactured wood products for the building industry, such as panelled doors and windows. Exports from the wood product sector are growing rapidly.

1.5.4.2 Textile, Clothing and Footwear

There are traditional sectors with a number of established operations. Approximately 60% of footwear (by volume) manufactured in South Africa takes place in Kwazulu-Natal. The textile sector is well developed, especially in cotton and cotton/synthetic blended products. There are also fabric and garment knitters and the country's primary under-garment manufacturer is located in Kwazulu-Natal.

1.5.4.3 Food and Beverages

These two sectors are developed around a number of established companies, both domestic and international. They have a strong capability and have well-developed supply linkages from both domestic agriculture and international markets. The sugar industry, with its highly efficient base of coastal sugarcane production, is an important contributor to the local food industry.

1.6 INFRASTRUCTURE

1.6.1 TRANSPORT

Kwazulu-Natal offers established and advanced infrastructure and modes of transport to move people, goods and services between the main centres of the province, the country and globally. Categories of transport include rail, road and air.

1.6.1.1 Road

Kwazulu-Natal has two double carriageway highways running through the province. These are the N2, which runs along the coast from South to North, and the N3, which runs from Durban westwards and is the main road link to Johannesburg, Gauteng and other inland areas. The department of transport allocated R810 million in 2001 for the maintenance, upgrading and construction of the road infrastructure. The fact that there are cargos ports in Richards Bay and Durban means the road should be in good condition for the transportation of the goods for export.

The problem is within the rural areas, where there are gravel road which at times are difficult to drive through, especially during rainfalls. There are usually no bridges in the rural areas, and since Kwazulu-Natal has good rainfall in most parts of the province this hampers movement by road.

1.6.1.2 Richards Bay Port

Richards Bay is responsible for 50% of South African port cargo by volume and 14% of South African port cargo by value. The multi-purpose terminal is situated in the deep-water port of Richards Bay, on the east coast of South Africa, and is the product of the merging of two separate terminals, namely the Bulk Metal and Combi Terminals. The resultant integration of infrastructure and facilities has enhanced the terminal's ability to logistically manage a variety of cargo types, namely break bulk and containers.

The terminal serves the vibrant hinterlands of Kwazulu-Natal, Mpumalanga, Gauteng and even as far a field as Zimbabwe, with a strong emphasis on the export of raw and semi-processed materials. Adequate undercover storage is provided by two 10 000m^2 warehouse, including a canopy between the warehouse that provides an additional 8 000m^2 covered storage for sensitive cargo as well as a shed of 4 500m^2.

Open storage comprises 330 000m^2. In addition, a specialised Ferro-alloy handling facility of 75 000m^2 is available. The terminal currently operates out of seven berths in the port, six with a permissible draught of 13.5m and one of 17.5m, affording the terminal flexibility in handling import and export cargoes. Operations are active 24 hours a day and the terminal is open for 363 days a year. Annual throughput of cargo is 5.6 million tons.

By the early 1950's, in the wake of burgeoning South African industrial expansion, the need for new port facilities had become ever more pressing. The need for major expansion of export facility was further emphasised by the chamber of Mines that claimed there was a vast potential for South Africa's raw materials, provided adequate rail and port facilities capable of accommodation large vessels were available.

Prior to the mid 1970s the port complex of Richards Bay, situated on the east coast of South Africa, was a large natural lagoon, home to the exuberant wildlife of the coastal region of Northern Kwazulu-Natal. In April of 1976 the port was officially opened; a one-time lagoon converted into a thriving 19m deep man made port.

Now is the country's largest exporting port, handling more than half of all cargo passing through South African ports. The Dry Bulk Terminal is one of the original (initial) port operators, and in its first year, only managed to trade some 100 000 tons of cargo. Today, 26 years later, Dry Bulk Terminal handles some 12 million tons of cargo annually.

Ferro alloys	Granite
Steel	Pitch Coke
Scrap Steel	Forest Products
Pig Iron	Containers
Aluminium	Loose Bulk
Project Cargo	General

Table 5: Commodities handled at multi-purpose terminal.

The Dry Bulk Terminal is a unique terminal in that it handles multiple products over its conveyer system. This means to say that no conveyor is dedicated to any one specific commodity, and hence, to avoid contamination, belts, transfer points, rail trucks and vessel loaders/unloaders need thorough washing after each loading/unloading of a parcel, before commencing the next product handling. In general, commodity parcel sizes that can be handled are limited to 65mm maximum.

Export	**Import**
Andalusite	Alumina
Chrome	Coking Coal
Copper Concentrate	Fertilizer products
Ferro fines	Metallurgical Coke
Fertilizers	Petcoke
Rock Phosphate	Rock Phosphate
Rulite	Salt
Titanium Slag	Sulphur
Vanadium Slag	
Vermiculite	
Woodchips	
Zircon	

Table 6: The current range of commodities handled

1.7 COMMUNITY FACILITIES

1.7.1 HEALTH SERVICE

Kwazulu-Natal has 65 public hospitals, with 11 hospitals located in Durban district and the rest scattered throughout the province as shown in figure 6. There are about 418 public clinics in Kwazulu-natal, which do not include private clinics.

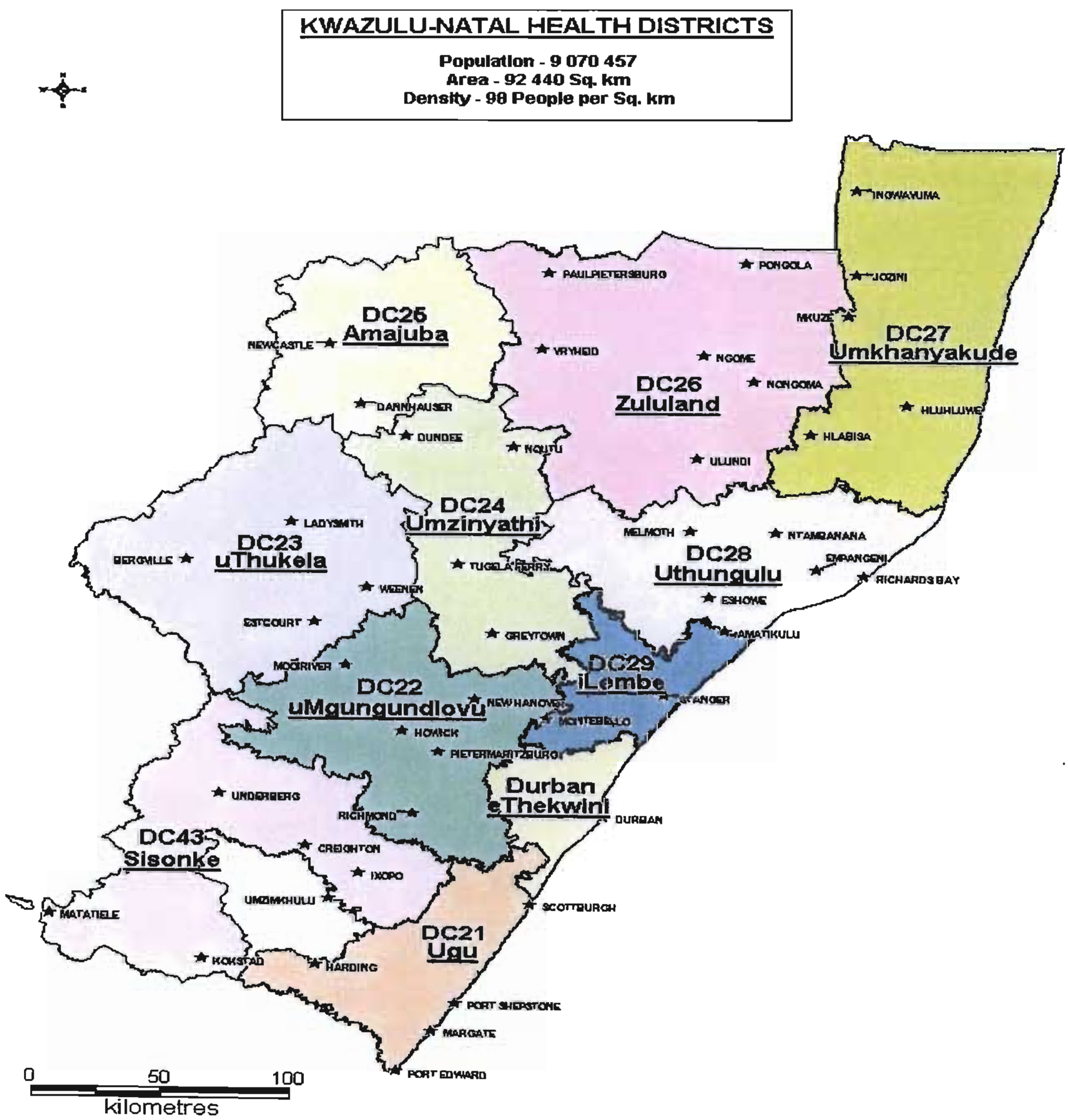

Figure 6: Map that shows the distribution of provincial hospitals within Kwazulu-Natal province.

DC 21 G.J. Crookes hospital Murchison hospital Port Shepstone hospital St. Andrews hospital	**DC 22** Appelsbosch hospital Edendale hospital Fort Napier hospital Grey's Hospital Montebello hospital Northdale hospital Townhill hospital Umgeni hospital	**DC 23** Emmaus hospital Estcourt Hospital Ladysmith hospital	**DC 24** Charles Johnson Church of Scotland Dundee hospital Greytown hospital
DC 25 Madadeni Hospital Newcastle Hospital Niemeyer Memorial	**DC 26** Benedictine Hospital Ceza Hospital Itshelejuba hospital Nkonjeni Hospital St. Francis Hospital Thulasizwe Hospital Vryheid Hospital	**DC 27** Bethesda hospital Hlabisa hospital Manguzi hospital Mosvold Hospital Mseleni Hospital	**DC 28** Catherine Booth hospital Ekombe Hospital Eshowe Hospital Lower Umfolozi War Memorial Mbongolwane hospital Ngwelezane hospital Nkandla Hospital KwaMagwaza hospital
DC 29 Stanger hospital Umphumulo hospital Untunjambili hospital	**DC 43** Christ the King hospital E.G & Usher Memorial hospital St. Apollinaris hospital Tayler Bequest	**Durban** Addington Hospital Clairwood hospital Hillcrest hospital Inkosi Albert Luthuli Central King Edward VIII hospital King George V hospital Mahatma Gandhi hospital Osindisweni hospital Prince Mshiyeni hospital R. K. Khan hospital St. Aidan's hospital Wentworth hospital	

Table 7: Table showing the distribution of hospitals within Kwazulu-Natal province

Department of health in Kwazulu-Natal has divided Kwazulu-Natal into health districts and this makes it difficult to show population density per hospital.

1.7.2 EDUCATIONAL INSTITUTIONS

In 1998, 2 725 371 pupils enrolled in schools in Kwazulu-Natal which was 22.6% of 12,071 355 of South Africa's total enrolment. These figures include both primary and secondary schools. The tertiary enrolments for the same year were as follows [5]:

- Universities - 30 684 students which is 8.7% of South Africa (352 739)
- Technikons - 25 403 students which is 13.0% of South Africa (195 194)

There are 6 universities in Kwazulu-Natal with only one being at a rural area and the rest are located within the Durban district.

1.8 IMPORTANCE OF TELECOMMUNICATION INFRASTRUCTURE IN RURAL AREAS

Telecommunication is a tool for the conveyance of information, and thus can be critical to the development process. By providing information links between urban and rural areas and among rural residents, telecommunication can overcome distance barriers that hamper rural development. Access to information is the key to many development activities, which include agriculture, industry, shipping, education, health and social services.

Rural telecommunication is an issue because statistics show that the majority of the population in developing countries live in rural, and often isolated areas therefore the majority of the population in these countries do not have a ready access to a telecommunication infrastructure. The rural population is excluded from the technology society and misses out on opportunity available to urban society.

In South Africa, telecommunication infrastructure will go a long way in assisting the Reconstruction and Development Programme (RDP). Access to communications facilities is not only necessary for the delivery of services in critical sectors such as education and health; it also serves to stimulate the creation of small business and offers a channel of communication to reinforce participation in the democratic processes at community, provincial and national levels.

It is the essential backbone for development and offers the only opportunity for leapfrogging its relatively slow sequential phases. The telecommunications sector is both a source of economic growth and an enabler of growth in other sectors. The sector itself offers opportunities for locally developed innovative products and services which, with appropriate transfers of skills and technologies, can contribute significantly to economic empowerment of previously disadvantaged communities.

The sector can make an important contribution to export and import substitution. In addition it forms part of the basic infrastructure needed for the stimulation of economic activity including the creation and development of business in all sector and therefore the growth of the economy as a whole [6].

In addition to fostering intra-regional trade, the use of information and communication technologies (ICTs) could also accelerate Africa's integration into the global economy.

In rural areas we have police stations, hospitals, schools and social places. These places need some sort of telecommunication infrastructure in order to function effectively. Telecommunication can be used to bridge the gap between urban and rural areas and thus can limit rural-to-urban migration.

Rural areas in South Africa are made of 2 different groups namely:

- Business people
- General citizens

In the case of schools, in an effort to meet skills manpower demand, the South African Ministry of Education is currently going through a process of making available relevant resources to all schools and communities. The curriculum 2005 that is currently being developed by the ministry of education can benefit greatly from the provision of such systems. The distance education system is expected to improve the situation by providing access to services of course materials offered by experts, virtual libraries which can be accessed all the time and to virtual laboratories with online experiments.

Distance learning is the most popular name for learning over the Internet. In its earliest form distance learning meant studying by correspondence. Technology developed and distance instruction was delivered through media such as videotapes, radio and television broadcasting and satellite transmission. The Internet and World Wide Web are giving a new shape to the current generation of distance learning.

Distance education is defined as the use of print or electronic communications media to deliver instructions when teachers and learners are separated in place and/or time. Perhaps more than any other media, the Internet and the web help overcome the barriers of time and space in teaching and learning. Due to the above fact, rural communities, which are connected to the Internet, can explore the on-line interaction with the instructors and offline videotapes for class discussions.

The first model with which distance education can be imparted to rural population is called the curriculum-sharing model. In this model schools are linked so that courses available at one school can be taught to students at another school or location.

The advantages of distance learning on the Internet are:

- There is flexibility in the time and place of learning.
- The Internet has a potential to reach the global audience.
- There is no concern about compatibility of computer equipment and operating systems.
- It involves less time in development and delivering as compared to videos and CD-ROMs.
- It is very easy to update the contents.

In hospitals, medical doctor are currently in need of Internet to help them improve the quality of service they provide. The telecommunication infrastructures in general are used in two different ways for support of health care delivery:

- For consultation to rural health workers or directly to isolated patients.
- For training of health care workers.

Health care services for remote rural areas are broadly known as telemedicine, tele-health or e-health use communication equipments to link health care practitioners and patients in different locations. In clinical settings, the Internet enables health workers to gain rapid access to information that can aid in the diagnosis of health conditions or development of suitable treatment plans. It can make patients' records, test results and practice guidelines accessible from the examination room.

The Internet supports a shift towards a more patient-centred care, enabling patients to gather health related information by themselves, to communicate with health workers electronically, and even to receive care at their home. Sighting the rural environment, where medical cost and shortage of health workers is an escalating problem, telemedicine is seen as a justified alternative for resolving issues like transportation costs, hotel expenses, lost days of work.

The access to information and communication technologies (ICTs) implies access to channels and modes of communication that are not bound by language, culture, or distance. ICTs application in rural areas can generally be summarized as shown below in figure 7.

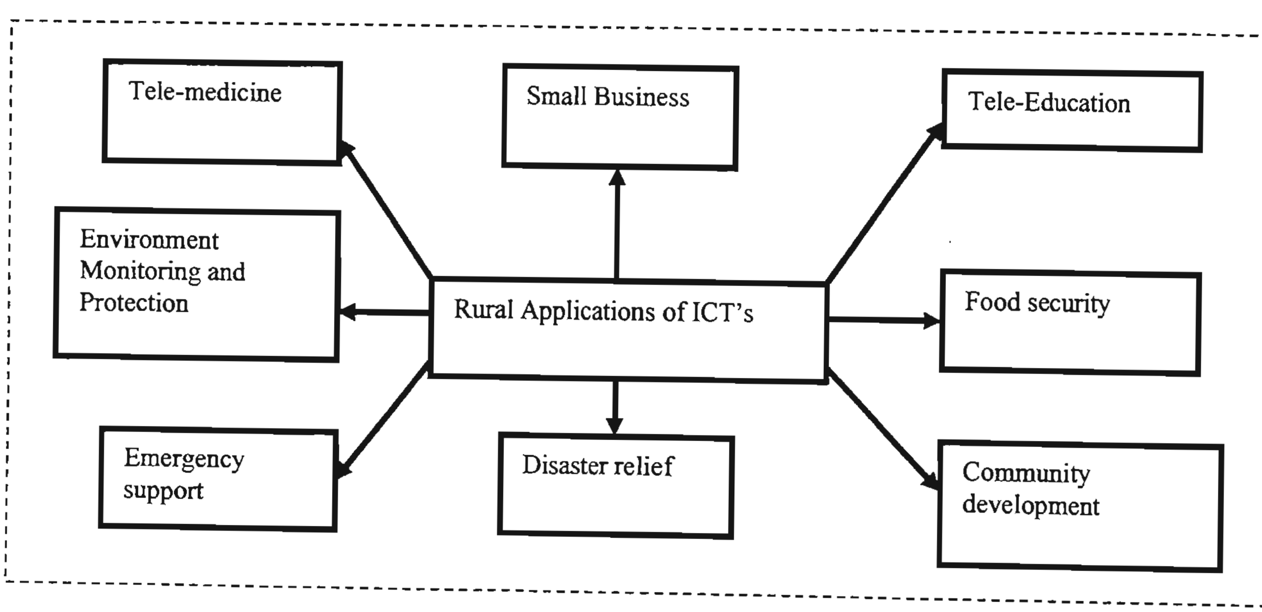

Figure 7: Information and Communication technologies (ICT)

1.9 TELECOMMUNICATIO INFRASTRUCTURE IN KWAZULU-NATAL

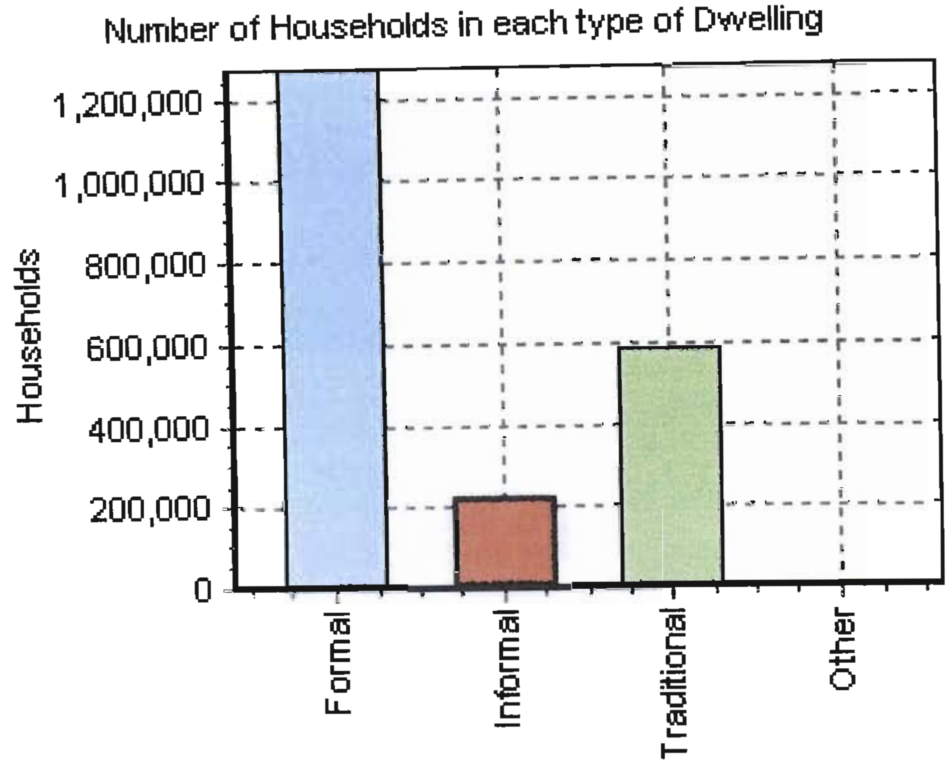

Figure 8: Number of households in Kwazulu-Natal [6]

Figure 8 above shows that the total number of households in Kwazulu-Natal is approximately 2 million. 1,2 million (61%) being formal, 225 825 (11%) informal, 581 036 (28%) traditional and 7595 households not accounted for in terms of being formal, informal or traditional. The combination of informal, traditional and others is 814 456 households, which is about 40% of the total household in the province [6].

The dwelling types are classified as Formal, Informal and Traditional households. Traditional households are households that are made of mud. Informal households are shack houses. Formal households are houses that are made of bricks and cement.

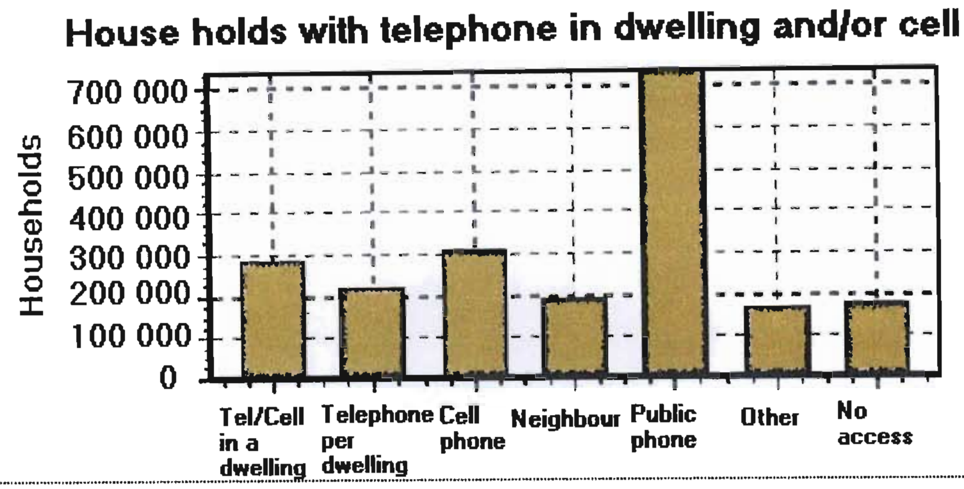

Figure 9: Households with telephone and/or cell phone

Figure 9, shows that about 800 000 households have access to telecommunication infrastructure. This is in a form of telephone, cell phone or both. Another significant point is that about 700 000 households have access to public phones [6].

The number of households with public phones at another location, not nearby are 104 163 households and 174483 households without telephones. The combination of these two groups gives about 280 000 households without *access*. This figure is pretty big and need not be ignored. The word neighbour means a household that is less than a kilometre away. Another location nearby means a location that is between 2 – 5 km away and another location that is not nearby means any distance above 5 kilometres. There is a definite market for more telephone deployment in rural areas [6].

1.10 TELEPHONE TRAFFIC IN RURAL AREAS

The traffic pattern study was undertaken in Kwazulu-Natal. Phoenix exchange was considered as an urban environment and Empangeni exchange was taken as a rural environment. The study showed that traffic patterns between urban and rural areas are similar except for the volume of traffic. The only difference detected was the rise in traffic in the rural area at 20h00 at night, which did not appear in the urban traffic patterns. This may be due to the fact that the urban exchange used consists of predominantly business subscribers [7].

The traffic measurement was done within Telkom SA network system. Electronic Switching Exchange was changed to accommodate daily traffic measurements. The data obtained is transferred from the exchange on a daily basis to the Unix system. The graphs shows the following:

- Traffic volume of the exchange (TV_EXCH)
- Traffic volume internal to exchange (TV_INT)
- Traffic volume outgoing from exchange (TV_OUT)
- Traffic volume terminating in exchange (TV_TER)
- Traffic volume transit traffic in exchange (TV_TRANS)

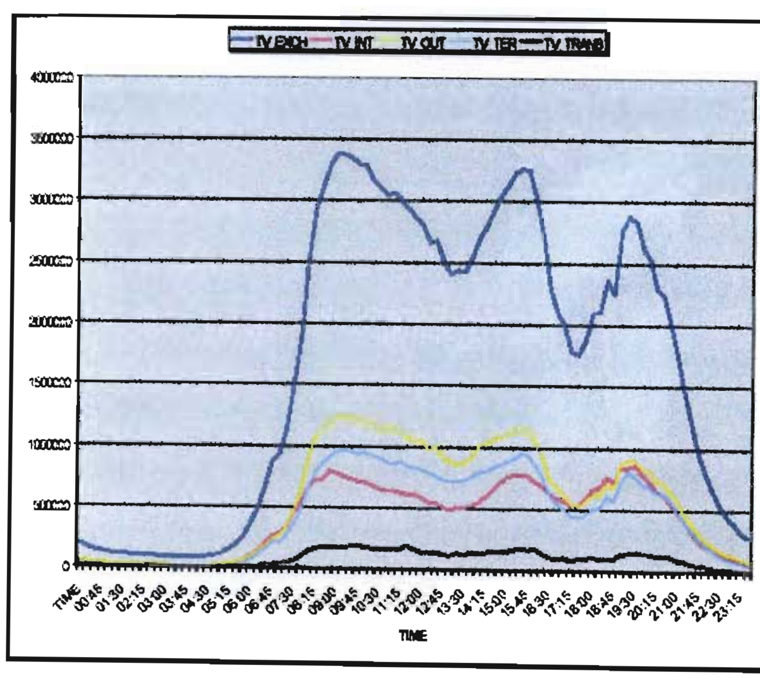

Figure 10a: Urban (Business and Residential) for Wednesday [7]

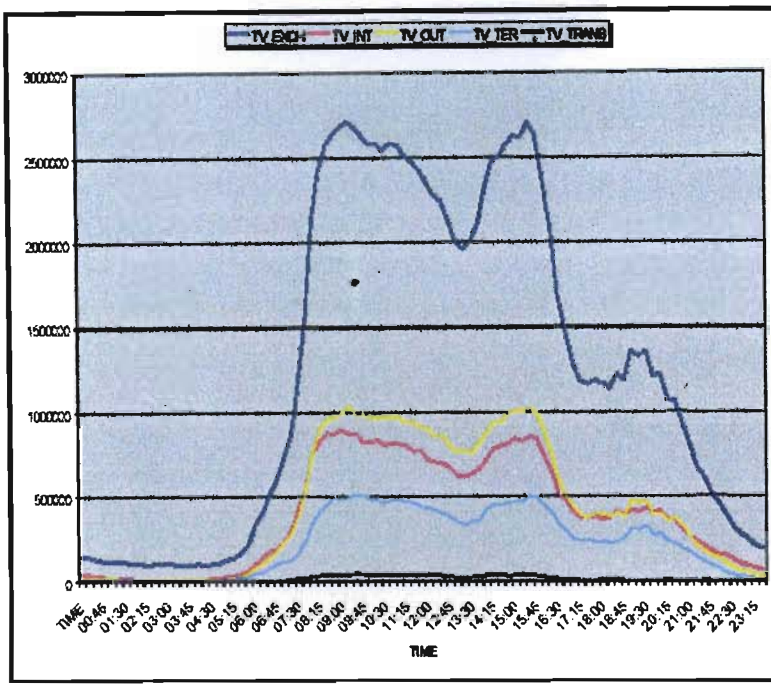

Figure 10b: Rural (business and residential) for Wednesday [7]

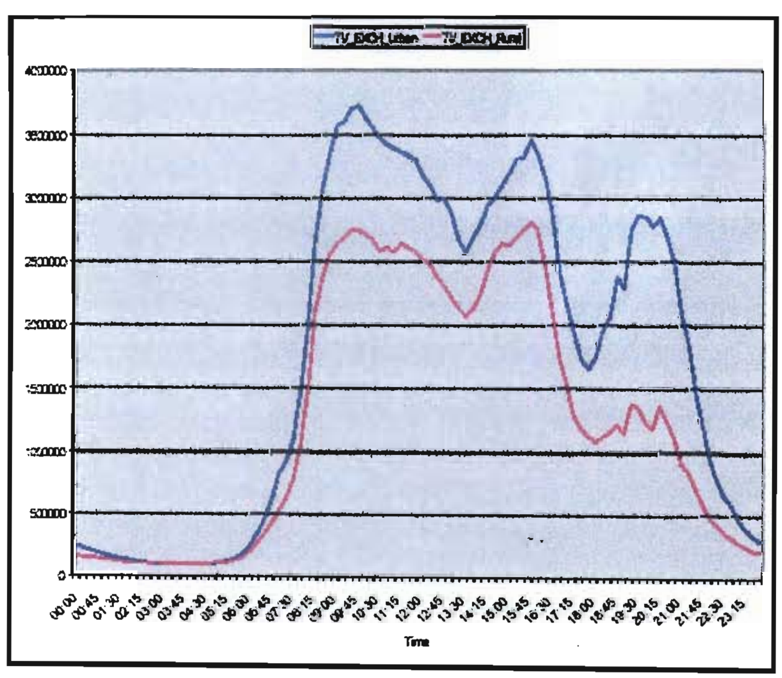

Figure 10c: Rural and Urban Traffic for Wednesday (Residential) [7]

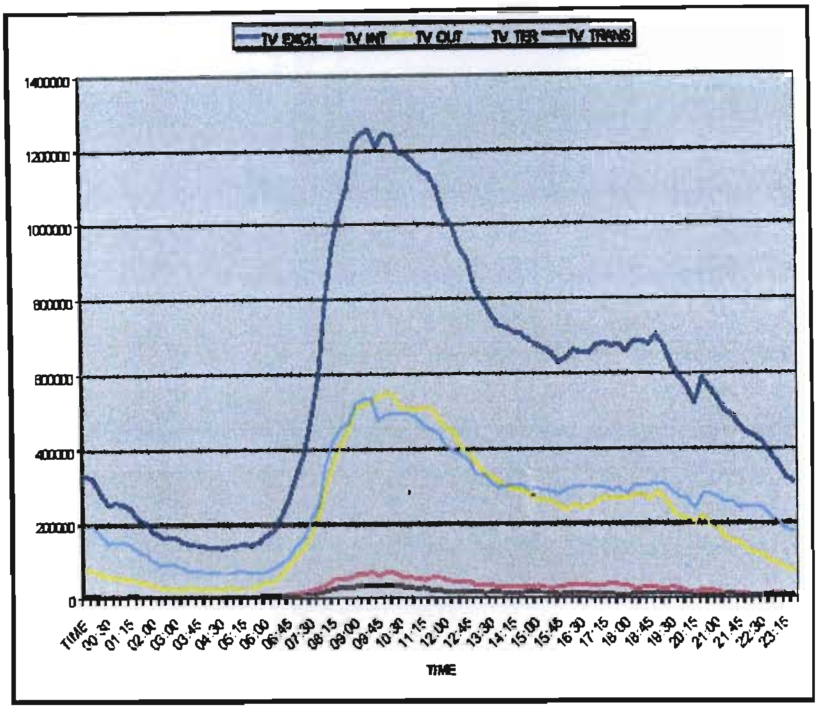

Figure 10d: Urban (business and residential) for Saturday [7]

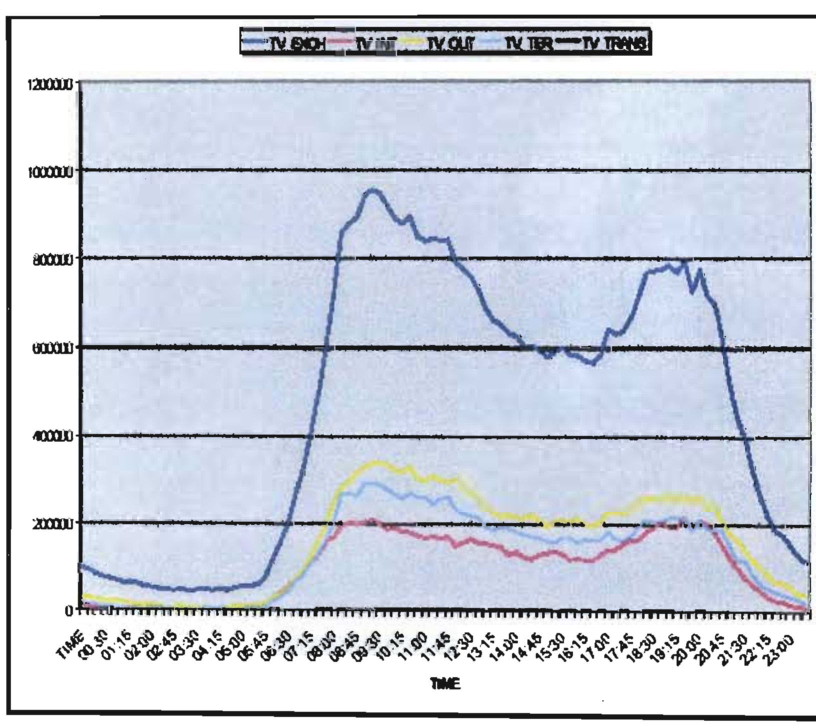

Figure 10e: Rural (business plus residential) for Saturday [7]

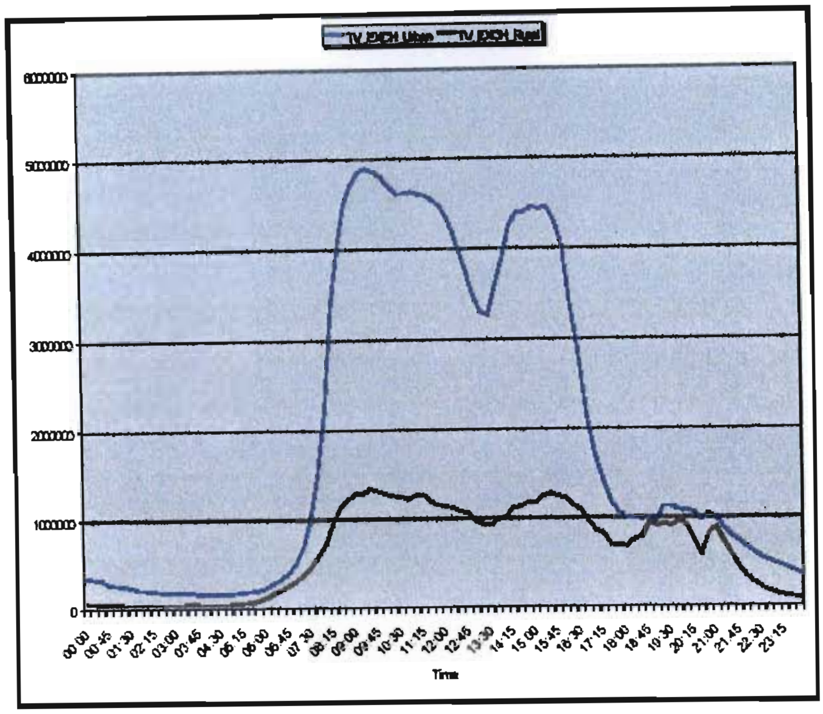

Figure 10f: Urban and Rural (residential plus business) for Wednesday [7]

Figure 10a shows the traffic generated in an urban area for both business and residential area. The traffic starts in the morning at about 06h00 and drops just before 24h00. The traffic drops slightly at about 13h00 when people goes for lunch. It picks up again after 14h00. The traffic then drops sharply at 17h30, after which it picks up again up until 20h00. This last phase is a contribution from calls generating from residential area.

The traffic generated in a rural exchange starts earlier as compared to urban traffic. This might be due to the fact that in rural areas there are a lot of residential dwelling. In Phoenix, there are a lot of industries and most traffic starts after 7h00 in the morning whilst in rural areas traffic starts at about 5h15. Traffic in Figure 10a decreases sharply after 17h00, but for rural areas the traffic continues up until 22h30.

Figure 10c shows that the traffic pattern for rural and urban areas are similar on Wednesday with the difference being the number of calls made in rural areas. Rural area traffic is low; this is due to spatiality of population.

Figure 10d, show the traffic generated in an urban area for both business and residential areas on Saturday. The traffic is very high during office hours and drops after 15h00. The assumption is that the traffic after 15h00 is generated from residential area.

Figure 10e shows the traffic generated in a rural area for both business and residential areas on Saturday. The traffic is high during office hours and drops, and picks up again in the early evening. In this case, the traffic during office hours is generated from business and drops. Between 17h00 and 22h00 might be the traffic generated in the residential area. In residential areas call are usually made during early evening.

The main difference between Figure 11d and Figure 10e is that the traffic in Figure 10d is high as compared to Figure 10e. There are businesses next to residential areas in urban areas and the population in urban area is usually high as compared to rural areas this is why traffic generated in urban areas is high compared to rural areas.

Figure 10f shows the traffic generated in an urban and rural areas. Urban traffic is represented in blue colour. The traffic that is generated in urban areas picks up in the morning around 06h00 and drops around 13h00 for lunch. The traffic drops around 17h00 as employees leave the business area. The traffic generated in a rural area picks up early in the morning, and then it remains constant until late in the evening.

1.11 PURPOSE OF RESEARCH

The objective of this research is to evaluate the performance of CDMA system in a rural area. Different types of systems that can be used in a rural area are compared and the best suited system for a rural area is chosen and evaluated. There is a lot of telecommunications development in urban areas, but the same cannot be said about rural areas. There is a perception that there is no telecommunications demand in rural areas and rural people are poor and cannot afford telecommunication. P. Wolthers [7] shows that the traffic patterns between urban and rural areas are the same, with urban traffic larger than rural traffic. Wireless systems behave differently in different path loss exponents. A. Neskovic [21] presents modern approaches in modelling of mobile radio systems propagation environment. Models that are reviewed in this article [21] were carried out in Europe, whilst P.J. Chitamu [24] reviews propagation models in rural Africa. This information is helpful in our simulation. The system that is designed should be able to give proper results in rural areas.

Rake receiver is the receiver for multipath channels. P.J. Chitamu [45] proposes a Rake receiver structure for asynchronous CDMA system. Matlab program is used for the simulation of our system in a rural area.

1.11.1 OUTLINE OF THESIS

The remainder of this thesis is organized as follows. Chapter 2 discusses the market structure in telecommunications, Market liberalization, Universal service obligation and the Universal Service Agency. Period of exclusivity for Telkom and competition are discussed. Major Service providers are presented and their share structures are highlighted. Functions of ICASA and Universal Service Agency are discussed.

Chapter 3 is a review of alternative systems that can be used in rural areas. These systems include Terrestrial microwave links, Microwave video distribution system, very small aperture terminal, Optical fibre and Multiple Access techniques. The ITU model is reviewed. The major advantages of these systems are highlighted. Frequency Division Multiple Access and Code Division Multiple Access are discussed. These systems are discussed in the order of importance.

Chapter 4 reviews the model of code division multiple access system in depth. The CDMA transmitter and Receiver structures are discussed. The receiver structures are presented. The Rake receiver is mathematically analysed because its suites our rural scenario. Asynchronous CDMA model is analysed and mathematically modelled. The intention of this thesis is to move from GSM system to CDMA system, thus the cost and performance comparison of GSM and CDMA are presented.

Chapter 5 investigates the performance of a CDMA system in a rural environment. Population density of rural Kwazulu-Natal is used to predict the estimated traffic for rural areas. Simulations are also covered in this chapter. Base stations and mobile users are generated in a given area and simulations of Minimum Mean Square Error and Conventional power algorithms are compared to show the best algorithm in a given rural area. Simulations results that measure Bit Error Rate (BER) are also performed. We demonstrate BER at AWGN channel, multirate traffic, multipath environment and at different processing gains. System implementation is discussed for Mtubatuba municipality. Chapter 6 gives the conclusions of the thesis.

CHAPTER 2

MARKET STRUCTURE IN THE TELECOMMUNICATIONS SECTOR

2.1 INTRODUCTION

The Communications Ministry of South African believes a new market structure is necessary for the telecommunications sector, one which orientates the sector towards accelerated development and which also takes into account technological and international trends. In general, the new market structure entails a period of exclusivity for Telkom SA, after which various telecommunications market segments are to be liberalised in a phased process put into motion and overseen by an independent Regulator. The new market structure is largely contingent on the assumption that Telkom will be able to access sufficient capital. If Telkom is not able to access capital because of non-resolution of the ownership question, the scenario below will be seriously compromised and will have to be reformulated. Telkom managed to sort out the issue of ownership in March 2003 when they listed in New York stock Exchange. This means there is no need to reformulate the market structure. Three interrelated issues that must be acknowledged are [5]:

- Because of the inherent flexibility of telecommunication technologies it has become increasingly difficult to define particular market segment or services and establish viable boundaries around them. Due to this reality, there will be to some degree an inevitable arbitrariness to such definitions. The key point is that with this legislation, it is the Regulator, not Telkom, who is now charged with settling upon such definitions and enforcing the rules around them.

- There are forces at work in the international arena pushing for liberalization which, when combined with the technological flexibility discussed above, have great salience when formulating a coherent and enforceable domestic telecommunications policy. International accounting rates are now under review and their resolution will undoubtedly affect domestic tariffs and Telkom's rebalancing. World Trade Organization (WTO) regulations, which treat telecommunications as a trade-related sector, have begun to be applied in the international arena. South Africa is a signatory to the WTO protocols and has indicated its intention to liberalise trade in basic telecommunications services. Satellite operators such as PamAMSat now permit direct access by users, thus technically allowing the bypass of the domestic telecommunications network by large users. International call-back services are, at this time, unregulatable, and they are growing. Advances in digital voice compression make voice telephony by the Internet and other means of high likelihood. These global forces cannot be ignored, and this policy must be realistic in accommodating them. Furthermore, this policy must be consonant with South Africa's general trade policy and its specific obligation as a signatory to the WTO.

- It is widely acknowledged that in the near future broadcasting and telecommunications will undergo convergence. This White Paper does not undertake policy prescriptions in this area, but alerts the Minister to convergence and empowers her/him to study the issue and generate a policy framework around it.

2.2 THE PERIOD OF EXCLUSIVITY

In order to best promote the goals for the sector, which includes: the expansion of the telecommunications infrastructure and attainment of universal service, the promotion of growth within the sector and as an enabling infrastructure for economic growth in other areas, the adoption of a strong customer focus, and the enhancement of South Africa's telecommunications capacity internationally, Telkom SA should has been granted a period of exclusivity to provide basic public switched telecommunications services.

During the period of exclusivity, the central goal is building out of the basic network as quickly and as extensively as possible. Following the period of exclusivity, various market segments will be opened to various degree of competition. There must be fixed dates for the transition to a liberalised environment, so that potential competitors are able to plan their entrance and investments accordingly. The Regulator is empowered to grant prospective licenses to would-be competitors, so that they can plan and invest and be ready to enter the market.

The Regulator was established in 1997. Telkom is given 6 year to offer value added network services (VANS), switching networks, international services and national long distance service without competition. Three years into this exclusivity period, the regulator will review the gradual introduction of competition.

During the period of exclusivity, Telkom has the primary role in universal service provision. All regulatory functions that were taken by Telkom in the past are now removed from Telkom's authority and are vested in the Regulator. Telkom will function as the primary provider of the local loop, exchanges, transmission, and international services during the period of exclusivity.

Telkom will be licensed to operate the public switched telephone networks (PSTN) and the public switched data networks (PSDN) for a period of exclusivity with clear-cut contractual obligations and performance criteria, as determined by the Regulator. The aim is to install 20 telephones per 100 population by the year 2008, recognizing that this in part depends on demands, which itself depends in part on affordability.

In September 2003, the Minister of Communications was expected to announce the licensee for the Second National Operator. This did not happen because all applicants did not meet the criterion. The Second National Operator currently consists of Eskom and Transnet they both share 30% stake and the empowerment group Nexus which owns 19%. The process of looking for a company that will own 51% stake in the Second National Operator is delaying the licensing.

2.3 MARKET LIBERALISATION

2.3.1 TELKOM SOUTH AFRICA

Telkom is currently the only holder of Public Switched Telecommunication Services licence in South Africa. It was awarded the licence in 1997. The licence has a 25-year validity period. Among others it grants Telkom the right to provide:

1. National Long-distance telecommunication services
2. International telecommunication Services
3. Local Access Telecommunication Services
4. All telecommunication facilities used for the provision of Value Added Network Services
5. All telecommunication facilities comprising fixed lines used by operators for the provision of Mobile Telecommunication Services
6. All telecommunication facilities used for provision of Private Telecommunication Networks except those situated on a single piece of land, contiguous pieces of land or those belonging to Eskom or Transnet.

Telkom's right to provide the above services on an exclusive basis ended on 7 May 2002, in terms of its licence terms and conditions. Telkom is owned 67% by government, 30% Thintana (SBC and Malaysia Telecom) and 3% empowerment.

In 2001 Government announced plans for the privatisation and listing of Telkom although the date of its Initial Public Offering (IPO) has not yet been announced. In preparation for the IPO and entry into the market of the Second Network Operator ICASA has begun making regulations on such issues as Carrier-pre-selection, facilities leasing guidelines and universal service fund contributions.

ICASA regulates tariffs that Telkom levies on customers for services. The Authority performs this function in terms of section 45 of the Telecommunications Act of 1996. In November 2001 ICASA prescribed new regulations (GG 22870 Regulation Gazette

7214 of 26 Nov 2001) for the control of Telkom's tariffs and fees. The new rate regime replaced the Ministerial Determination on fees and charges that was promulgated in 1997.

Telkom submits its accounting record to ICASA for scrutiny on a yearly basis. The operator is required to do so in terms of section 46 of the Telecommunications Act of 1996. ICASA is in the process of prescribing regulations that will determine the manner in which Telkom and other operators will present accounting records for regulatory control. The regulator has chosen Chart of Accounts and Cost of Allocation Manual (COA/CAM) as the preferred framework for this purpose and is embarking on a public consultation process to finalize the intended regulations.

Volume 1 of the proposed regulations set out guidelines on regulatory accounting and will apply to all operators, Volume 2 details requirements for mobile cellular telecommunications services licensees while Volume 3 which affects Telkom gives the detailed requirements for presentation of records by public switched telecommunication services licensees.

In May 2001 ICASA granted Telkom permission to commence implementation of a 10 digit dialling system to run parallel to the current 7 digit dialling system until 8 May 2002 when the 7 digit dialling would be completely phased out. After consultation however the Authority acceded to the public request for an extension (link to media release of 4 April 2002) of the parallel run period to enable industry players to adapt their systems. The 10 digit dialling will become mandatory 6 months after promulgation of the new numbering plan regulations by the Minister of Communication. ICASA has also granted Telkom permission to commence technical preparations for introduction of a 010 code in Gauteng Central.

2.3.2 Cell C

Cell C is the latest addition to the mobile network operators in South Africa. It was awarded the licence to provide national cellular telecommunications services in 2001. The Company launched its service in November 2001 and announced that it had registered more than 20 000 subscribers on the first day of operation.

Cell C operates a Global System for Mobile (GSM) communication in the 1800 and 900 MHz bands. It has the exclusive use of the full number range in the access code 084.

Cell C is 100% owned by 3C Telecommunications, which in turn is 60% owned by Oger Telecom South Africa, a division of Saudi Oger and 40% by CellSAF. CellSAF represents 33 black empowerment groups of which 10 are business groups, 11 regional investment and technology companies and 12 social empowerment groups

Cell C is required to install 52 000 community telephone service phones over a period of six years.

2.3.3 MOBILE TELECOMMUNICATION NETWORK (MTN)

License awarded 1993. MTN is a South African cellular network operator and is listed on the Johannesburg Stock Exchange under the umbrella of the M-Cell Group. Launched in 1994, MTN now has close on five million subscribers. MTN's GSM network is one of the largest in the world. It has approximately 4000 sites covering 19 200km of road, 900 000km2 of land and providing access to 94.5% of South Africa's population. MTN owns service provider M-Tel and has interests in I-Talk Cellular, Leaf Wireless and New Bucks Holdings.

Towards the end of 2004, MTN moved towards 3G when it switched from mainly GSM circuit switched to packets switched General Packet Radio Service (GPRS) system. This is one path from 2G to 3G. We would not say they support CDMA, but they are on route to CDMA.

2.3.4 VODACOM

License issued in late 1993 and launched GPRS and MMS in late 2002. Vodacom has 10 million subscribers in South Africa (5/2005). Vodacom is continuing to consolidate its network coverage by extending it to yet uncovered areas and to increase capacity and quality. It has built up in excess of 5000 base stations countrywide providing coverage to more than 95% of the population. Vodacom has also deployed 25 000 active community service telephones in underdeveloped areas run by 1800 entrepreneurs that record 80-million call minutes a month. Vodacom as main competitor with MTN, moved toward 3G in mid 2004.

They also moved to General Packet Radio Service (GPRS), which bring high switching speeds and is more efficient that GSM. Of course GRPS can be used on GSM or TDMA network with the addition of two core modules, the Gateway GPRS Service Node (GGSN) and Serving GPRS Service Node (SGNS). We can safely say Vodacom is also moving towards CDMA system. It is not very clear whether Vodacom support CDMA system, but they are on route towards CDMA system.

Vodafone AirTouch Plc is mobile telecommunications company which owes 31,5% of VODACOM and is headquartered in Newbury in the United Kingdom. The company was formed in June 1999 following a merger between Vodafone Group Plc and AirTouch communications, Inc and has interests in mobile telephone networks in 23 countries on four continents. The Vodafone AirTouch proportionate customer base at the end of June 1999 stood at almost 28 million users, excluding paging customers. Vodafone Airtouch Plc owns 31.5% of Vodacom Group (Pty) Ltd.

Telkom SA Ltd is presently South Africa's sole fixed-line telecommunications operator and it owns 50% of VODACOM. In May 1997 the South African Government sold a 30% stake in Telkom to SBC Communications and Telekom Malaysia for R5.54 billion. The telecommunications utility was granted a five-year exclusivity period during which no competition would be allowed on fixed-line telephony. In return Telkom and its equity partners have agreed to deliver 2,8-million new lines and meet service, quality and upgrading targets.

Hosken Consolidated Investments (Sold to Venfin 11/2002 for SAR1.2billion) Hosken Consolidated Investments (HCI) is a trade union investment vehicle and is controlled by the SA Clothing and Textile Workers' Union (Sactwu) and the National Union of Mineworkers (NUM).

HCI's market capitalization has grown from about R400 million at the time the Mineworker's Investment Company (MIC) and Sactwu took control to R2.7 billion at present. It has a net asset value of R3.5 billion. Recently it unbundled about R1.5

billion worth of investments to shareholders, half of this going to trade union backers. Hosken Consolidated Investments own 5% of Vodacom Group (Pty) Ltd.

Rembrandt is an investment holding company based in Stellenbosch and deriving its income mainly from dividends from investments in tobacco products, banking and financial services, printing and packaging, engineering and motor components, adhesives, life assurance, medical services, mining, petrochemical products, portfolio investments, pulp and paper, cellular communications and food. Rembrandt Group Limited owns 13.5% of Vodacom Group (Pty) Ltd. It covers almost 13 000 km's of national roads, about 80% of the country's population and 52% of the total land surface.

2.4 UNIVERSAL SERVICE OBLIGATION

The state recognizes the central importance of access to telecommunications to the achievement of its economic and social goals. Affordable communications for all, citizens and business alike, throughout South Africa, is at the core of its vision and is the goal of its policy. The challenge is to articulate a vision that balances the provision of basic universal service to disadvantaged rural and urban communities with the delivery of high-level services capable of meeting the needs of a growing South African economy [5].

The vision must therefore reconcile these two seeming opposites within an integrating framework, which also allows for a dynamic definition of universal service and facilitates the co-ordination of all available infrastructures behind its goal. An integrated high-quality network providing value-added services and access to the international information highway is required to support the needs of South Africa's internationally competitive industries and links its economy into the global system. Improved communication with the African region will reinforce South Africa's presence by facilitating exchanges among institutions in the public and private sectors and providing opportunities for technology exports.

The Ministry of Posts, Telecommunications and Broadcasting will establish a universal service agency to promote universal service in telecommunications in South Africa, while Independent Communications Authority of South Africa (ICASA) is the telecommunications regulator.

The Regulator and the universal service agency do not compete; they are part of the same team focused on the same overall objective of promoting universal service in telecommunications in South Africa but with responsibility for different but closely linked activities. One set of activities is rules-based: it involves the firm and transparent application and enforcement of the regulations, which embody the principles of telecommunications policy.

The Regulator has sole power of enforcement. The other set of activities is concerned with development where clearly defined rules, which would apply within the regulatory complex, simply do not now exist. The Agency has no enforcement power but should identify more creative and innovative methods to promote universal service within the broad framework of development planning. The Agency and the Regulator will require different modes of operation, as well as different sets of skills, knowledge and experience.

The Agency and the Regulator share common administrative and financial systems and information infrastructure. They both report to the same Minister. The precise functions of the two agencies are clearly defined to ensure minimum overlap and maximum synergy with the view to ensuring concentration of resources on achieving their linked objectives and reducing potential opportunities for bureaucratic infighting. The Agency will clearly need to operate within the legal and regulatory framework administered by the Regulator and will be accountable to the Regulator in that sense [5].

2.4.1 THE REGULATOR - ICASA

The Independent Communications Authority of South Africa (ICASA) is the regulator of telecommunications and the broadcasting sectors. It was established in July 2000 in terms of the Independent Communications Authority of South Africa Act No.13 of

2000. It took over the functions of two previous regulators, the South African Telecommunications Regulatory Authority (SATRA) and the Independent Broadcasting Authority (IBA).

The two bodies were merged into ICASA to facilitate effective and seamless regulation of telecommunications and broadcasting and to accommodate the convergence of technologies [8]. ICASA derives its mandate from four statutes. These are the ICASA Act of 2000, The Independent Broadcasting Act of 1993, the Broadcasting Act of 1999 and the Telecommunications Authority Act No. 103 of 1996 [9].

SATRA was established by law to be capable in law of instituting, defending or opposing legal proceedings of whatever nature, of purchasing or otherwise acquiring, holding and alienating or otherwise disposing of movable or immovable property or any other real right or other right or interest, of entering into contracts and concluding agreements and generally, of performing such other acts and doing such other things as juristic persons may by law perform and do, subject to the provisions of this Act. The functions of SATRA were not clearly defined in respect to Universal Service Obligation. SATRA gives the Minister the powers to invite interested persons to lodge written presentations in relation to the direction of the policy. This means that SATRA had to wait for the direction before they could act, which was not enough to fast track the development of telecommunications in rural and under developed areas.

To make new provision for the regulation of telecommunication activities other than broadcasting, and for the control of the radio frequency spectrum; and for that purpose to establish an independent South African Telecommunications Regulatory Authority and a Universal Service Agency; to repeal the Radio Act, 1952, and the Radio Amendment Acts of 1957, 1962, 1963, 1969 and 1974 and to amend the General Law Amendment Acts of 1957 and 1975, the Post Office Act, 1958, the Post Office Service Act, 1974, the Broadcasting Act, 1976, the Legal Succession to the South African Transport Services Act, 1989, and the Independent Broadcasting Authority Act, 1993; and to provide for matters connected therewith. (English text signed by the President.) (Assented to 12 November 1996.)

2.4.2 FUNCTIONS OF ICASA

The Authority regulates the telecommunications and broadcasting industries in the public interest. Its key functions are to [9]:

- Make regulations and policies that govern broadcasting and telecommunications
- Issue licenses to providers of telecommunication services and broadcasters
- Monitor the environment and enforce compliance with rules, regulations and policies
- Hear and decide on disputes and complaints brought by industry or members of the public against licensees
- Plan, control and manage the frequency spectrum and
- Protect consumers from unfair business practices, poor quality services and harmful or inferior products.

2.4.3 UNIVERSAL SERVICE AND ACCESS

It is the policy of the Government of South Africa that all people should have access to basic telecommunications services at affordable prices. The role of ICASA as a regulator is central to achieving this goal. The Authority promotes the attainment of universal service and access by imposing requirements in operator's licenses to roll out services in under-serviced areas and ensuring that licensees contribute to the Universal Service Fund. ICASA does not however administer the Universal Service Fund, but merely receives monies on behalf of the Universal Service Agency (USA) [8].

The Authority is also responsible for ensuring that relevant and appropriate broadcasting services are extended to all citizens.

2.4.4 EMPOWERMENT OF PREVIOUSLY DISADVANTAGED GROUPS

ICASA has a mandate in terms of its enabling statutes, to promote and encourage the ownership and control of telecommunication and broadcasting services by people from historically disadvantaged groups.

ICASA has a responsibility to ensure level playing fields where rules apply equally to all industry players. This is why the Authority has a strong belief in open and transparent processes. There are many ways in which ICASA ensures regulatory fairness. These include developing regulations and policies, engaging consultative processes in developing rules, regulations and policies. ICASA also ensures fairness through its adjudication functions [9].

The administration of regulatory justice and fairness is important for the creation of regulatory certainty. It is crucial for competition, for building confidence in the market and for attracting investment into the communications market.

2.4.5 MEMBERSHIP TO REGIONAL AND INTERNATIONAL BODIES

In regulating the industry ICASA aligns its actions, policies and regulations with the framework set by international and regional bodies to which it is affiliated. These include the Telecommunication Regulatory Association of Southern Africa (TRASA), the International Telecommunications Union (ITU), the International Institute of Communication s (IIC) and Reseau Des Instances Africaines De Regulation De la Communication (RIARC).

2.5 UNIVERSAL SERVICE AGENCY

The objective of the universal service agency shall be [8]:

- To maintain universal service at the heart of telecommunications policy and of the public debate surrounding it, and

- To ensure telecommunications components are introduced into development projects whenever their objectives can be reinforced by information flows and communication.

The Agency will work with the reconstruction and development programme, operators and with community and development organizations in the following areas:

- Building national consensus on the meaning of affordable and accessible universal service:
  - Definition of universal service in terms of the current South Africa reality;
  - Promoting national consensus on the definition and its evolution;
  - Monitoring, from a development perspective, technology, applications, use of services and public expectations in order to adjust the definition as and when required.
- Establishing goals, objectives, timetables, indicators and monitoring mechanisms:
  - Establishing agreement on the parameters that would govern universal service priority setting: for example degrees of deprivation, geography, and availability of applications, institutional base, local government capacity, and so on;
  - Recommending to the Minister the universal service goals (and intermediate objectives), country-wide, but differentiated by region or community;
  - Identifying indicators for measurement of progress towards those goals;
  - Identifying indicators of the impact to access on telecommunications services in terms of creation of small businesses and employment opportunities, economic empowerment of disadvantaged groups;

- Advising the Regulator on the establishment of universal service monitoring mechanism.

- Advising the Regulator on universal service obligations in licenses to be granted by the Regulator, and on the means to monitor their implementation;

  - Proposing to the Minister and Regulator methods to redress imbalances in the telecommunications sector and thereby promote the achievement of universal service goals;

  - Working with the service providers to develop linkages to communities that will help them design mechanism to improve implementation of universal service obligation.

- Regular reporting to the Minister

  - Drawing on the information base of the Regulator, supplemented as necessary by community information sources, to maintain and disseminate a South African map of access and services which would indicate the degree of achievement of universal service goals and obligations;

  - Highlighting gaps and opportunities for the extension of infrastructure and services, including applications in prime development sectors;

  - Proposing adjustments to policy, law and regulation to meet universal service goals.

- Catalytic functions:

  - Interacting and consulting with the Reconstruction and Development Programme (RDP), health, education and other ministries, and with operators, with regard to the progressive connection of schools and clinics and the identification of projects to maximize the development impact of the telecommunications infrastructure;

  - Working with communities to identify telecommunication needs;

- Promoting research on model applications of telecommunication and information technology;

- Managing the universal service funds;

- Disseminating information on universal service

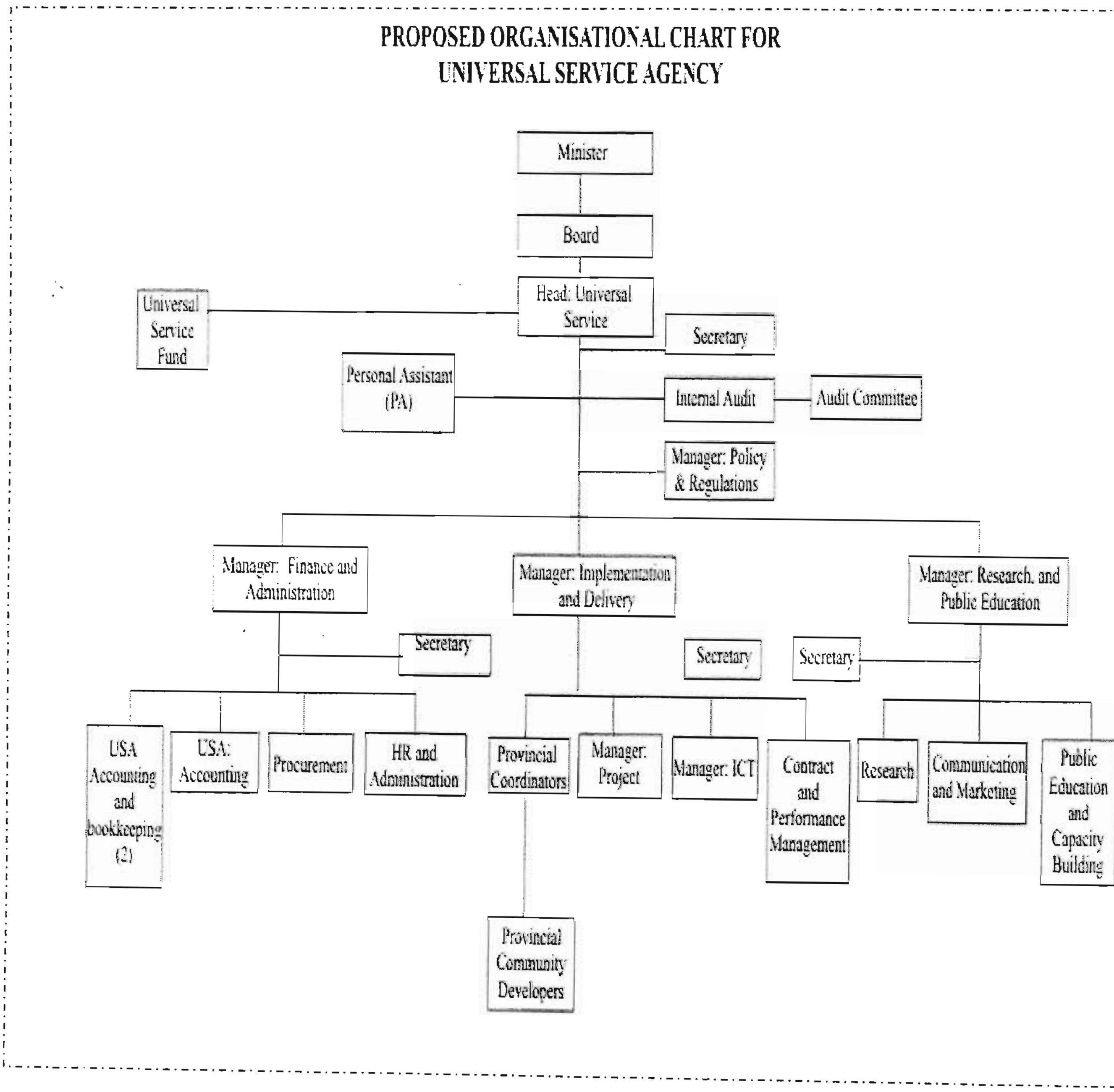

Figure 11: Organizational structure of the Universal Service Agency [8]

The Agency will manage the universal service fund generated through universal service obligations defined by the legislation and implemented by the Regulator. The Regulator will monitor Agency usage of funds. Operational costs of the agency will be funded through a telecommunication fund, which is administered by the Department of Posts and telecommunications.

- Finances of the Universal Service Agency
  - The Agency's budget will be prepared by the department in consultation with the Agency for approval by Parliament.
  - The operating and capital costs of the Agency shall be financed from money appropriated by Parliament from time to time for that purpose.

The ongoing need for the universal service agency to reviewed by the Minister in consultation with all stakeholders after five years and, if appropriate, its functions will be transferred to the Regulator. Figure 11 shows the proposed organisational structure of the Universal Service Agency.

2.6 CHAPTER SUMMARY

This chapter looks at the market structure in the telecommunication sector in South Africa (S.A). This includes the intervention by the government through the Universal Service Agency to provide service in the under-serviced areas and oversee the operation of the service providers to make sure that there is fairness in their operation. Different service providers are presented and the share structure of these service providers is highlighted. The roles and functions of the Independent Communications Authority of South Africa as the regulator are presented. The South African government decided to introduce Telkom exclusivity and gradually introduce competition.

CHAPTER 3

ALTERNATIVE SYSTEM FOR RURAL AREAS

3.1 INTRODUCTION

In Kwazulu-Natal, 57% of the population resides in rural areas [2]. Rural communities in Kwazulu-Natal are relatively poor and cannot afford telecommunication services. The need to provide telecommunication services to rural areas is faced with a difficult of cost efficiency and time for the implementation. In South Africa we have an additional problem with wire-line installations in that copper cables are being stolen faster than providers can install new cables. The installation of cables is also labour intensive, especially in remote areas.

Service providers are forced to look at wireless systems due to the tendencies in the large world markets such as Europe, USA and the Far East. There is also an important fact that needs to be considered before the provision of such services, the type of system that will meet the demand and should be in line with the 3G developments. Future wireless communication systems beyond 3G will be characterized by an integration of different access technologies such as cellular, cordless, WLAN type systems, short-range connectivity, broadcast systems and wired systems [3].

The main purpose for the provision of telecommunication infrastructure maybe for the telephones but the need might change in few years time; this means we should provide a system that can accommodate multiple services. The other reason is the fact that rural communities in Kwazulu-Natal depends mainly on agriculture for living and thus cannot afford telecommunication services, this implies that the provision of such services should be cheap and affordable.

This chapter looks alternative telecommunication systems that can be considered for rural areas of South Africa. Advantages and disadvantages of these systems are presented and the best option is chosen.

3.2 TERRESTRIAL MICROWAVE LINKS

3.2.1 LOCAL MULTIPOINT DISTRIBUTION SYSTEM

Local Multipoint Distribution Services (LMDS) is a fixed broadband wireless access system using a range of frequencies around 28-31 GHz. This service allows for two-way digital communication for voice, video and high-speed data communication. There are two blocks of spectrum, **A** and **B** blocks, which differ by the amount and location of spectrum. The **A** block spectrum is a total of 1150 MHz as compared to the **B** block at 150 MHz. Local Multipoint Distribution Service is a broadband wireless point-to-multipoint communication system as shown in Figure 12.

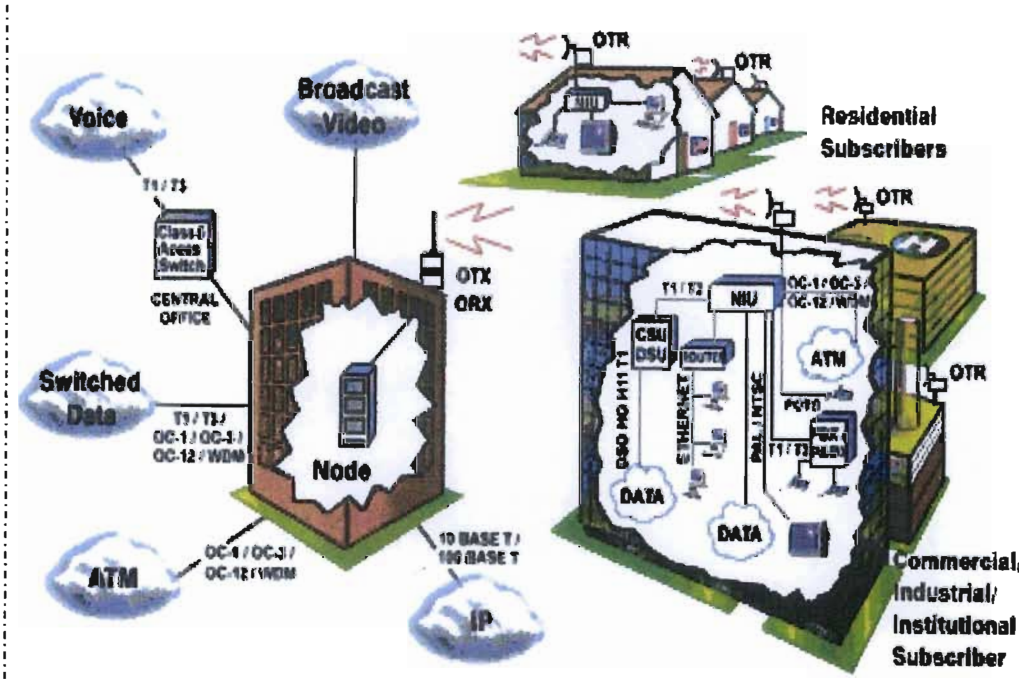

Figure 12: Local Multipoint Distribution System [10]

Point-to-point (PTP), point-to-multipoint (PMP) and TV distribution can be provided within the LMDS system. The acronym LMDS is derived from the following [16]:

- L (local) – denotes that propagation characteristics of signals in this frequency range limit the potential coverage to a single cell site; ongoing field trials conducted in metropolitan centres place the range of an LMDS transmitter at up to 9 kilometres
- M (multipoint) – indicates that signals are transmitted in a point-to-multipoint or broadcast method; the wireless return path, from the subscriber to the base station, is a point-to-point transmission
- D (distribution) – refers to the distribution of signals, which may consists of simultaneous voice, data, Internet, and video traffic
- S (service) – implies the subscriber nature of the relationship between the operator and the customer; the services offered through an LMDS network are entirely dependent on the operator's choice of business

Local Multipoint Distribution Systems (LMDS) have enormous potential to deliver cost-effective point-to-point and point-to-multipoint services to residential and business users. This system may be particularly attractive to users that do not anticipate the availability of high-speed wired connectivity. LMDS does have a number of challenges. It requires line of sight between a transmitter and receiver. That is, there must be no obstructions between hub and remote. This requires careful planning and may demand a repeater to retransmit the signal over a building, hilltop, or other obstacle.

LMDS signal strength is greatly reduced by the presence of moisture. In very heavy rainfalls (several inches per hour), the signal may even drop altogether. Though these outages are uncommon and typically brief, they can make the service inappropriate for some critical applications.

3.2.2 MULTI CHANNEL MULTIPOINT DISTRIBUTION SRVICE (MMDS)

Multi-channel Multipoint Distribution Service (MMDS) is broadcasting and communications service that operates in the ultra-high-frequency (UHF) portion of the radio spectrum between 2.1 and 2.7 GHz. MMDS is also known as wireless cable. It was conceived as a substitute for conventional cable television (TV). However, it also has applications in telephone/fax and data communications.

In MMDS, a *medium-power* transmitter is located with an omindirectional broadcast antenna at or near the highest topographical point in the intended coverage area. The workable radius can reach up to 110 kilometres in flat terrain (significantly less in hilly or mountainous areas). Each subscriber is equipped with a small antenna, along with a converter that can be placed next to, or on top of, a conventional TV set.

The MMDS frequency band has room for several dozen analogue or digital video channels, along with narrowband channels that can be used by subscribers to transmit signals to the network. The narrowband channels were originally intended for use in an educational setting (so-called wireless classrooms). The educational application has enjoyed some success, but conventional TV viewers prefer satellite TV services, which have more channels.

Because of recent deregulation that allows cable TV companies to provide telephone and Internet services, along with the development of digital technologies that make efficient use of available bandwidth, MMDS has considerable future potential. An MMDS network can provide high-speed Internet access, telephone/fax, and TV together, without the constraints of cable connections. MMDS service is ideal for home users because the data rate and the cost of using the system are well matched to a home user's requirements [11].

3.2.3 MICROWAVE VIDEO DISTRIBUTION SYSTEM (MVDS)

Microwave Video Distribution System is a local point-to-multipoint radio system, delivering broadcast services from a central transmitter (hub) to individual houses or blocks of apartments within its cell size. MVDS offers rapid infrastructure deployment. It can be significantly cheaper to install than cable systems since only homes requesting the MVDS services are provided with receivers. MVDS operates in the 40.5 – 42.5 GHz range. This is a one-way broadcasting distributions system. It has the potential for providing expanded TV services like pay per view and to become a low-cost integrated medium for providing voice and data services [12]. MVDS has low range capabilities and offers voice services of reasonable quality. MVDS is still in the development stages and the MVDS equipment, especially with interactive paths, is still in the prototype stages.

3.3 VERY SMALL APERTURE TERMINAL (VSAT)

Low cost business terminals with very small antennas (less than 2 meters in diameter) are often termed Very Small Aperture Terminals (VSATs). VSAT is a one-way or two-way terminal used in a star, mesh or point-to-point network as shown in figure 13. Antenna size is restricted to being less than or equal to 3.8 m at Ku band and 7.8 m at C band. Many populations of Africa are without a basic telephone. VSAT-based solutions are flexible enough to grow as requirements increase and a combination of VSAT and terrestrial technologies, such as wireless local loop, accommodates a wide range of population densities.

There are various solution available with VSAT technology and these includes:

- VSAT connected to subscriber lines to serve scattered population (< 20 lines)
- VSAT connected to wired or wireless/cordless local loop to serve clustered populations (20 – 300 lines)
- VSAT connected to macro cellular networks to serve medium density populations (> 300).

VSAT stations are connected to pay phones or small number of lines to serve scattered populations with a dispersed subscriber base as in figure15 above. It can be located at an individual home or co-located with a public phone. The public phone network can be composed of individual pay phones connected to a phone shop where multiple community lines (phones and fax) are connected to a single VSAT station.

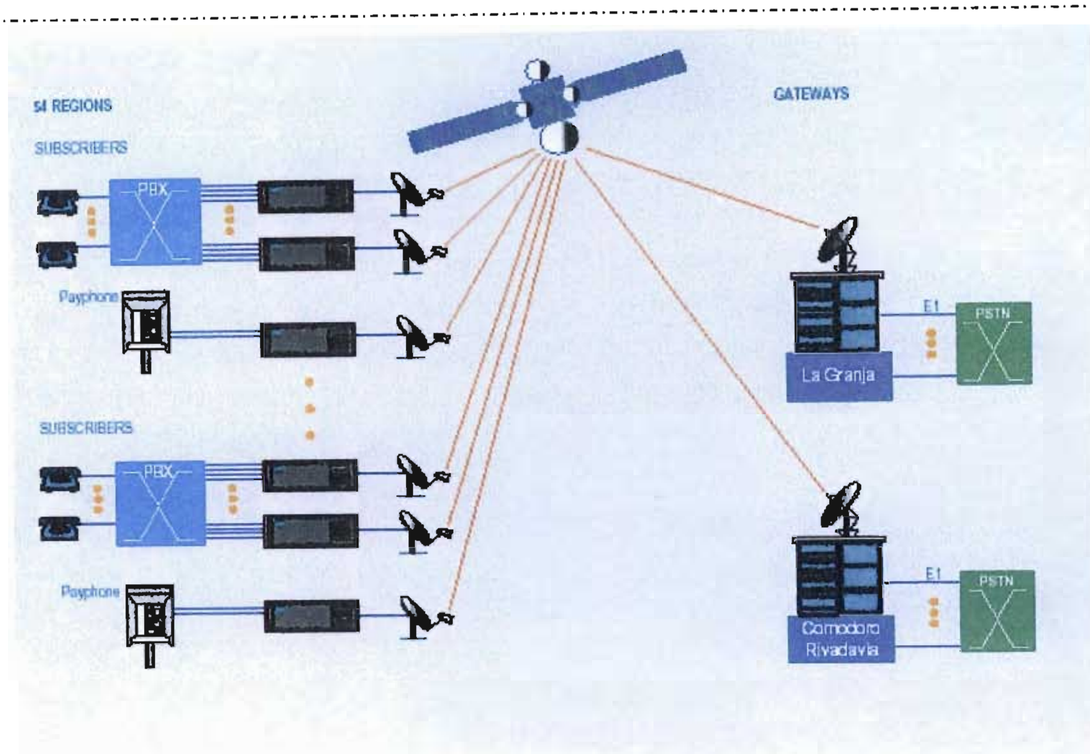

Figure 13: VSAT network diagram that is implemented in Argentina [17]

In this case a small antenna of 1.8m for C-band or 1.2m for Ku-band can be used to serve the population.

The second point refers to clustered populations in rural areas. This solution is well suited to serve concentrated populations in rural areas, especially clusters of populations located within a 5 Km range. VSAT networks connected to a local switch may provide high data rate transmission for local traffic. All users are wire-connected to a local switch and the switch is connected to a VSAT station. Since the data rate for this condition is higher compared to a single line, the antenna is bigger in size, 2.4m for C-band or 1.8m for Ku-band.

The third point refers to VSAT used with wireless local loop (WLL) technology. WLL provide communication solutions for subscriber densities greater than 20 lines. In this configuration, VSAT are used for long distance communication, while cordless WLL are used for local communication.

3.3.1 FEATURES OF VSAT

- Ability to target small-dish audiences from space and meet specialized service requirements
- High powered, fully steerable Ku-band spot beams
- Applications include banking, LAN/WAN networking, Internet/intranet, video conferencing, remote site networking
- End users with a 90 cm to 120 cm dish can download Internet data 20 times faster than PSTN
- Large in-orbit capacity makes VSAT platforms cost-effective
- Star, multi-star, mesh wideband and remote solutions are realizable
- Solutions using all the most widely used VSAT equipment

3.3.2 ADVANTAGES OF VSAT

- Rapid installation, as quickly as 2 days per site and low cost of operation and maintenance
- VSAT hub facilities can be shared among multiple users and application
- Provision of high quality narrow and wideband communications (voice, fax, Internet, etc)
- Alternative power supply such as solar energy (35 to 60 watts per channel)
- A cost-effective solution for implementing high quality and reliable communications in locations that terrestrial facility cannot economically accommodate.

3.4 OPTICAL FIBRE LINKS

Optical fibre can be defined as the branch of optics that deals with communication by transmission of light through ultra pure fibres of glass or plastic. Optical fibre systems operate in the range of about 10^{14} to 10^{15}Hz. The fibre optic system has three major parts performing this communication task: a light source, an optical fibre, and a light detector or receiver. The light source can be either a light-emitting diode (LED) or a semiconductor laser diode (LD).

The optical fibre can be a strand as short as 1m or as long as 7 km. The detector can be either an avalanche photodiode (APD) or a positive-intrinsic-negative (PIN) diode. Basically, fibre-optic system simply converts an electrical signal to an infrared light signal, launches or transmits this light signal onto an optical fibre, and then captures the signal on the other end, where it reconverts it to an electrical signal.

3.4.1 OPTICAL TRANSMITTERS

The role of an optical transmitter is to convert the electrical signal into optical form and launch the resulting optical signal into the optical fibre. An optical transmitter consists of an optical source, a modulator, and a channel coupler. Semiconductor lasers or light emitting diodes are used as optical sources because of their compatibility with the optical fibre communication channel. Modulating the optical carrier wave generates the optical signal. Although an external modulator is used in certain cases, it can be dispersed with in most cases, since the output of semiconductor optical source can be modulated directly by varying the injection current. The input signal is then applied to the driver of the optical source. The coupler is typically a micro lens that focuses the optical signal onto the entrance plane of an optical fibre with maximum possible efficiency.

3.4.2 OPTICAL FIBRE AS A COMMUNICATION CHANNEL

The role of the communication channel is to transport the optical signal from the transmitter to the receiver without distorting it. Most light wave systems use optical fibres as the communication channel because fibres can transmit light with relatively small amount of power loss.

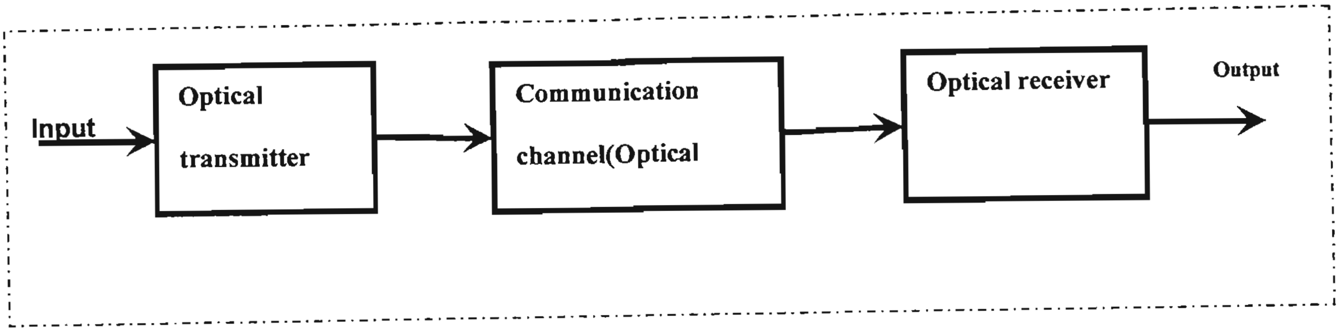

Figure 14: Optical transmission system

Long-haul fibre transmission is becoming increasing common in the telecommunication network. Long-haul routes average about 1450 km in length and offer high capacity (typically 20,000 to 60,000 voice channels).

3.4.3 OPTICAL RECEIVERS

An optical receiver converts the optical signal received at the output end of the optical fibre back into the original electrical signal. Optical receiver consists of a coupler, a photo detector, and a demodulator. The coupler focuses the received optical signal onto the photo detector. Semiconductor photodiodes are used as photo detectors because of their compatibility with the whole system. The design of the demodulator depends on the modulation format used by the light wave. The most popular modulation schemes used are Frequency Shift Key (FSK) and Phase Shift Key (PSK) [13].

3.4.4 ADVANTAGES OF OPTICAL FIBRE

- It is virtually immune to electromagnetic Interference (EMI) and humidity, which are of paramount important especially in the confines of a ship or aircraft. As dielectrics, rather than metal, optical fibres do not act as antennas to pick up radio-frequency interference. The result is noise-free transmission.
- It is not very susceptible to interference from lightning. Carrying light rather than electrical signals, fibre optic cables ignore electrical disturbances such as interferences caused by lightning, nearby electric motors and relays.

- It is a relatively secure transmission media. Greater security through total immunity to wiretapping is a matter of much greater importance to military services, banks, and computer networks than it is to the average citizen who is calling a relative.

- Extremely wide bandwidth. Greater volume of information can be carried over a particular circuit. Fibre optic has been placed on the market with bandwidth up to 40 GHz. Data rates of 2Gbps over tens of kilometres have been demonstrated

- Smaller-diameter, lighter-weight cables. The size reduction makes fibre-optic cables the ideal transmission system for ships, aircraft, and high-rise buildings, where bulky copper cables take up too much space. Together with reduction in size goes an enormous reduction in weight.

- Lack of cross talk between parallel fibres. In conventional communication circuits, signals often stray from one circuit to another, resulting in other calls being heard in the background.

- Low transmission loss. Attenuation is significantly lower for optical fibre than for coaxial cable or twisted pair and is constant over a wide range.

- Longer life span compared to conventional cable. Predicted life span for fibre optics is 20 – 30 years, compared to 12 - 15 years for the conventional cable. Glass, after all, does not corrode as metal does.

- Greater repeater spacing. Fewer repeaters mean lower cost and fewer sources of error. The performance of optical fibre systems from this point of view has been steadily improving.

3.5 MULTIPLE ACCESS TECHNIQUES

3.5.1 PROPAGATION CHARACTERISTICS OF RADIO CHANNELS

A radio channel is generally hostile medium in nature. It is rather difficult to predict its behaviour. Traditionally, radio channels are modelled in a statistical way using real propagation measurement data [20]. In general, the signal fading in a radio environment can be decomposed into large-scale path loss component together with a medium-scale slow varying component having a log-normal distribution, and a small-scale fast varying component with a Rayleigh distribution, depending on the presence or absence of line-of-sight (LOS) situation between the transmitter and the receiver [20].

The phenomenon of decreasing received power with distance due to reflections, diffraction around structures, and refraction within them is known as path loss. The propagation models have been developed to determine the path loss and are known as large-scale propagation models because they characterize the received signal strength by averaging the power level over large transmitter-receiver separation distances, in the range of hundreds or thousands of meters. Both shadow margin and Rayleigh margin can degrade the signal by about 20 dB each. This is why we need to pay more attention to the propagation models.

3.5.2 THE ITU MODEL (previously CCIR)

The ITU-R method is based on the statistical analysis of a considerable amount of experimental data obtained by measurements in many countries. The curves for the field strength prediction refer to the kind of rolling terrain found in many parts of the world [16]. There are a number of propagation models around. Okumura model is a widely used model. Hata model is based on Okumura graphs. Hata developed empirical formulae for the Okumura graphs [14].

N	**Terrain, environment**	**Path loss (dB)**
4.2	Flat terrain with light vegetation	$P_L = 42\log_{10}d + 88$
5.3	Undulating landscape, with moderate vegetation	$P_L = 53\log_{10}d + 93$
7.2	Hilly and heavily forested	$P_L = 72\log_{10}d + 67$

Table 8: Path loss exponent

Hata model is based on extensive measurements carried out in Tokyo, Japan. Ibrahim and Parsons Model is based on measurements in the city of London. Chitamu model is based on propagation measurements in rural Tanzania. The path loss exponent for the Chitamu model is based on 3 different terrains [18] as seen in Table 8:

- Flat terrain with light vegetation
- Undulating landscape, with moderate vegetation
- Hilly and heavily forested

Due to the fact that chitamu's model was modelled in rural Africa, Tanzania, it is chosen for this project. Other models are modelled in European cities and the Asia which might not be accurate for rural Africa. There are similarities between rural Tanzania and rural Kwazulu-Natal and the level of accuracy is better compared to other models. Path loss exponent of $\boldsymbol{n} = \boldsymbol{5.3}$, is proposed for this thesis because the rural Kwazulu-Natal is flat, with light vegetation [18]. The path loss exponent of $n = 4$ is usually used for urban areas. There is no sense in using path loss that has been developed in the city for a rural area.

Medium-scale propagation model determines the gradual changes in the local-mean power if the receiving antenna is moved over distances larger than a few tens or hundreds of meters. The medium-scale variation of the received signal power is called shadowing, and it is caused by obstructions, tree and foliage. Small-scale propagation model characterize the fast variation of the signal strength over a short distance on the order of a few wavelength or over short time durations on the order of seconds.

Small-scale fast fading, also known as short-term fading or multipath fading, is due to multipath reflections of a transmitted wave by local scatterers such as buildings surrounding a mobile unit. In an ideal channel, the received signal would only consist of a single direct path signal, which would be a perfect reconstruction of the transmitted signal. In real channel this is not the case, the signal is modified during transmission in the channel because of free space attenuation, reflection, refraction and diffracted replicas of the transmitted signal. In addition to the attenuation, reflection, refraction and diffraction the channel adds noise to the signal.

3.5.3 MULTIPATH

Multipath propagation is a characteristic of the mobile radio and one of its effects is that delayed signal combine to give a composite signal at the receiver antenna whose amplitude and phase undergo wide and rapid fluctuations.

The effect can be understood when two signals travel to one antenna, one arrives first and the other later. Depending on the length of the second path the delayed signal may arrive late enough to cause serious inter-symbol interference thus limiting the maximum usable bit rate.

i. In the presence of a multipath, the signal travels through separate paths to the receiver. Such effects could occur in mountains or in urban regions through reflection. The received signal is the sum of a number of components whose amplitudes and phase may differ. This reduces the performance of a receiver.

ii. The adaptive filter is used to estimate the overall multipath response and to compensate for its effects.

3.5.4 INTER-SYMBOL INTERFERENCE

When a waveform is transmitted over a communication channel, the frequency response of the channel will, in general, introduce linear distortion. Linear distortion means that the shape of the waveform undergoes a change, but no new frequency components are generated in the spectrum. However, the linear distortion can take the form of ringing, in which a pulse, for example, may have a tail added, as illustrated in figure 15.

The tail is as a result of the natural build-up and decay of energy in the inductive and capacitive elements in the transmission path, rather in the same way that a resonant circuit behaves. The problem this creates with digital waveform transmission, for example, with a polar binary waveform, is that many of the tails can combine at some later time to produce a polarity inversion in the waveform.

If the inversion coincides with the time that the waveform is sampled to determine if a 0 or 1 is present, a bit error will occur. The interference caused by the tails is referred to as inter-symbol interference (ISI). The purpose of the equalizer is to remove the deleterious effects of the ISI on the symbol detection.

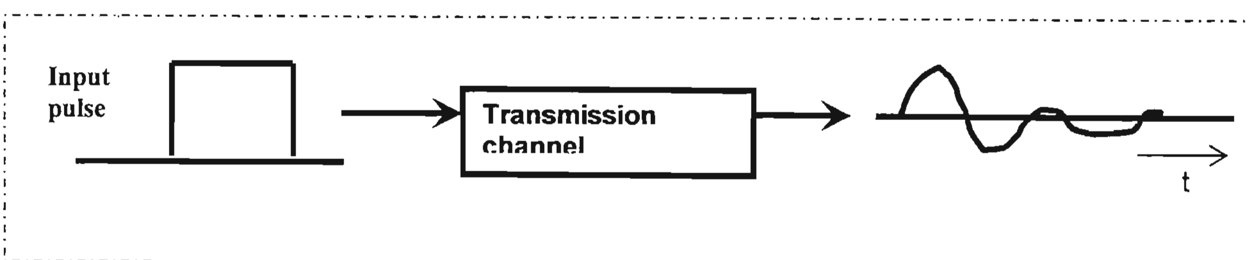

Figure 15: Linear distortion of a pulse that produces ringing

3.5.5 REFLECTION

Reflection occurs when a radio wave propagating in one medium impinges upon another medium having different electrical properties. The wave is partially reflected and partially transmitted [14]. If the plane wave is incident on a perfect dielectric, part of the energy is transmitted into the second medium and part of the energy is reflected back into the first medium, and there is not loss of energy in absorption.

If the second medium is a perfect conductor, then all incident energy is reflected back into the first medium without loss of energy. The electric field intensity of the reflected and transmitted waves maybe related to the incident wave in the medium of the origin through the Fresnel reflection coefficient (Γ). The reflection coefficient is a function of the material properties, and generally depends on the wave polarization, angle of incidence, and the frequency of the propagating wave. Reflection coefficient is divided into two: the vertical and horizontal polarization [14].

$$\Gamma_{11} = \frac{-\varepsilon_r \sin\theta_i + \sqrt{\varepsilon_r - \cos^2\theta_i}}{\varepsilon_r \sin\theta_i + \sqrt{\varepsilon_r - \cos^2\theta_i}} \tag{3.1}$$

and

$$\Gamma_{\perp} = \frac{\sin\theta_i - \sqrt{\varepsilon_r - \cos^2\theta_i}}{\sin\theta_i + \sqrt{\varepsilon_r - \cos^2\theta_i}} \tag{3.2}$$

where ε_r is the relative permeability and θ_i is the incident angle.

3.5.6 DIFFRACTION

Diffraction is a phenomenon where the radio signals are transmitted to the receiver where the line-of-sight (LOS) is block by the opaque obstacle. Diffraction occurs at the edges of the obstacle, where the radio wave signals are scattered. The diffraction mechanism allows the reception of radio signals when line-of-sight condition is not satisfied. This is called non-line-of-sight NLOS case.

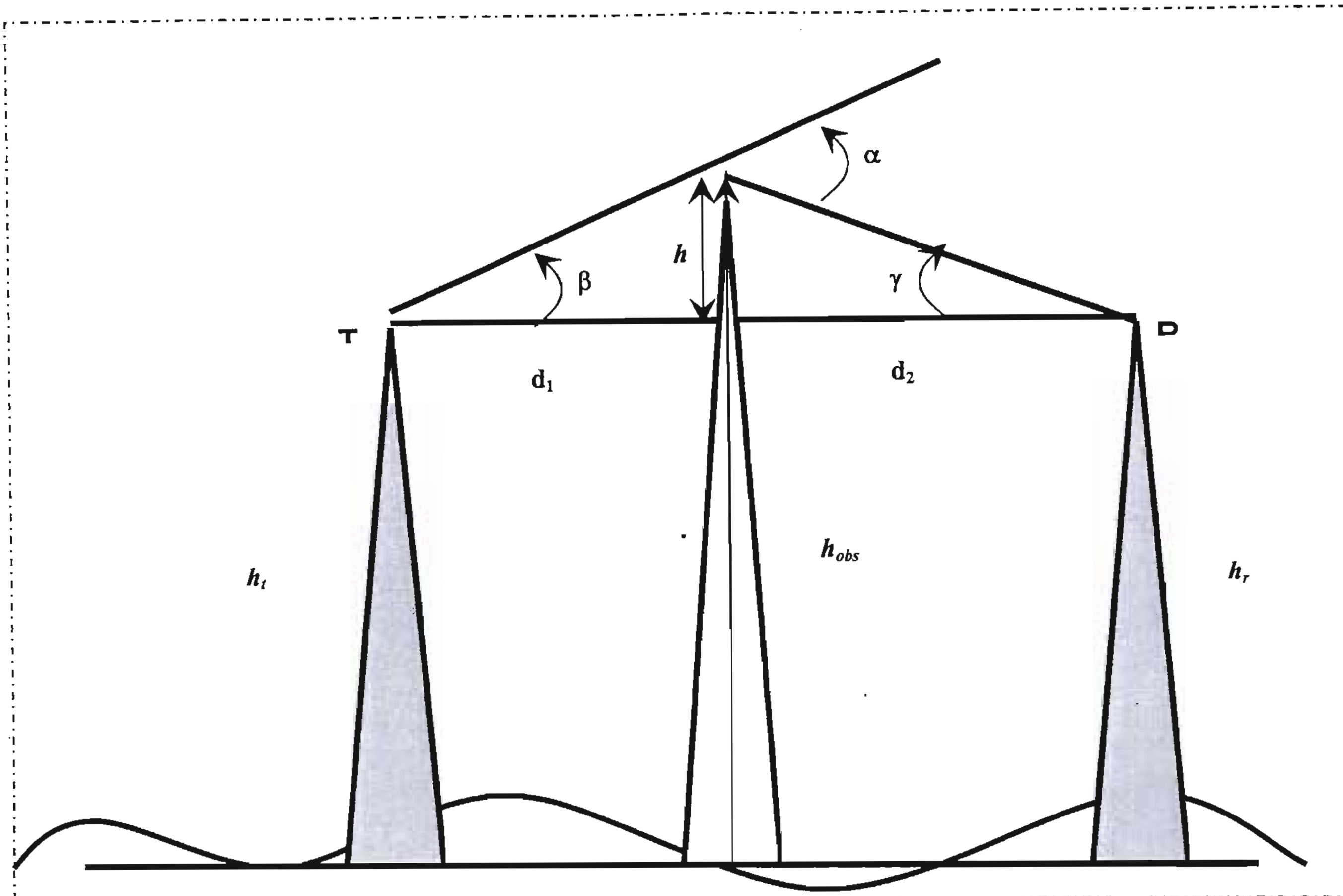

Figure 16: Knife-edge diffraction geometry

The difference between the direct path and the diffracted path, called the excess path length (Δ), can be obtained as follows:

$$\Delta \approx \frac{h^2(d_1 + d_2)}{2d_1 d_2} \tag{3.3}$$

The corresponding phase difference is given by

$$\phi = \frac{2\pi\Delta}{\lambda} \tag{3.4}$$

where $\lambda = \dfrac{c}{f}$ and c=speed of light, f= frequency and

$$\alpha \approx h(\frac{d_1 + d_2}{d_1 d_2}) \tag{3.5}$$

Then the *Fresnel -Kirchoff* diffraction parameter v is given by:

$$v = \alpha\sqrt{\frac{2d_1 d_2}{\lambda(d_1 + d_2)}} \tag{3.6}$$

v is used to find the diffraction loss.

3.5.7 ATTENUATION

Attenuation is the drop in the signal power when transmitting from one point to another. Attenuation can be caused by the transmission path length, obstruction in the signal path, and multi-path effects. Any objects that obstruct the line of sight signal from the transmitter to the receiver can cause attenuation. Shadowing of the signal can occur whenever there is an obstruction between the transmitter and receiver. It is generally caused by building and hills, and is the most important environmental attenuation factor.

3.5.8 REFRACTION

Refraction is very important in macro cell radio system design. Due to the variable refractive index of the atmosphere, the radio waves do not propagate along a straight line, but rather along a curved one. Therefore, the coverage area of an actual transmitter is actually larger [16].

3.5.9 NEAR-FAR-EFFECT

Radio multiple access techniques are based on contention within a channel. When used with spread spectrum modulation, it is possible for the strongest user to successfully capture the intended receiver, even when many other users are also transmitting. Often, the closest transmitter is able to capture a receiver because of the small propagation *path loss*. The capture effect offers both advantages and disadvantages in practical systems. This problem is solved by power control at the base station.

3.5.10 POWER CONTROL

A signal received on the reverse link by the base station differs in path loss due to the following:

1. Differing distances between each user and the base station
2. Statistical variations in radio propagation paths.

Hence, if all mobiles transmit at the same power, their signals will arrive at the base station with vastly different power levels. If a particular signal received at the base station is too weak, it will be overshadowed by other stronger signals. On the other hand, if it has too high power, its performance will be satisfactory but it will introduce interference to other users in the same cell and degrade their performance.

The capacity of a conventional CDMA system is maximized if each mobile-transmitted power is controlled so that at the base station the same power level is received from each mobile [28]. Power control is used on the reverse link to combat the *near far problem* and thus minimize the effect of interference on system capacity.

One way of controlling the mobile transmitter power is by applying automatic gain control (AGC) measurements in the mobile receiver. Before any transmission, the mobile monitors the total power received by the base station. The measured power provides an indication of the propagation loss to each user. The mobile adjusts its transmitter power so that it is inversely proportional to the total signal power it receives. This is called open-loop power control. The more effective power control scheme is the closed-loop power control. It requires that the base station provide continuous feedback to each mobile so that the mobile varies its power accordingly. The base station estimates the user signal power on the reverse link and compares it with the desired nominal threshold.

In chapter 3, different type of technologies that can be deployed in rural areas are highlighted. There are factors that influence our decision on which system to deploy in rural areas, and these factors are trends, time of deployment, costs of deployment and maintenance, rural traffic and regulations.

Currently the world is moving into third generation networks (3G) that are characterized by digital voice, video transmission, data and more data transmission. It has been shown that with the increase in popularity of the Internet comes at a price, which is the need for more bandwidth. The Internet is undisputedly the largest multimedia source available and is becoming increasing more popular for the home user.

We need to deploy a system that will be able to cater for rural communities. Rural communities are spatially distributed and the traffic generated in rural areas is similar to the traffic generated in urban areas with the difference being the number of calls made. Fewer calls are made in rural areas compared to urban areas [7]. Most of South African communities in rural areas have never placed or received a call and we cannot just deploy broadband system for telephony only. This simply means we do not need a broadband system in South African rural areas at this point in time.

Rural areas are far apart and the amount of cable needed to join these places together is high which directly impact on the cost. In South Africa we have problem of cable theft, so when we deploy a cable it is better if the cable is underground and this increases the cost of deployment even further. The time of deployment for a cable system is more compared to wireless system especially in difficult conditions. Clearly it is not advisable to deploy a wire line system in rural areas.

The legislation also pushes us to work very fast in solving the problem of deployment of telephone infrastructure in rural areas. In 1993, Vodacom and MTN were given licenses and targets of deploying telecommunication infrastructure in under-developed areas. They managed to deploy the required number of telephone lines but the legislation had loopholes because it did not state clearly that rural areas were a priority. As a result rural areas were overlooked in the deployment phase.

Clearly our aim is to deploy a system that is in line with 3G systems and should be narrowband because we are only catering for telephones. LMDS and MVDS are broadband services which if deployed will be idling for the better part of the day. GSM and CDMA are compared in terms of cost. This is done because currently companies are moving from the current 2G (GSM) to 3G (WCDMA).

3.5.11 FREQUENCY DIVISION DUPLEX (FDD)

In FDD, a pair of simplex channels with a fixed and known frequency separation is used to define a specific radio channels in the system. The channel used to convey traffic to the mobile user from a base station is called the *forward channel*, while the channel used to carry traffic from the mobile user to a base station is called the *reverse channel*

3.5.12 TIME DIVISION DUPLEX (TDD)

Time division duplex (TDD) uses the fact that it is possible to share a single radio channel in time, so that a portion of the time is used to transmit from the base station to the mobile, and the remaining time is used to transmit from the mobile to the base station. If the data transmission rate in the channel is much greater than the end-user's data rate, it is possible to store information bursts and provide the appearance of full duplex operation to a user, even though there are not two simultaneous radio transmissions at any instant of time. TDD is only possible with digital transmission formats and digital modulation, and very sensitive to timing. Full duplex means communication is possible in both directions.
Half duplex means communication is possible in only one direction.

3.6 FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)

In a personal communications system, the access technology makes it possible for a receiver to separate the desired signal from interfering signals. As in broadcast radio and television, the original approach to media access in cellular and cordless systems is frequency division multiple access (FDMA), in which each signal occupies its own band of frequencies as shown in figure 18.

Two different signals, simultaneously occupy the frequency-time plane. In an FDMA system, a physical channel corresponds to a band of frequencies. The frequency at the centre of the band is the carrier. Therefore in Figure 17, each vertical strip represents one carrier capable of transmitting one signal. The total number of signals that can be transmitted is equal to the number of carriers. The modulation technique determines the required carrier spacing. Figure 17 represents a system with 6 physical channels. There are 2 types of FDMA systems, the analogue cellular system, advanced mobile phone system (AMPS) and the digital cordless telephone system, CT2. AMPS contain 832 carriers, with adjacent carriers separated by 30 kHz. CT2 contains 40 carriers, with adjacent carriers separated by 100 kHz [14].

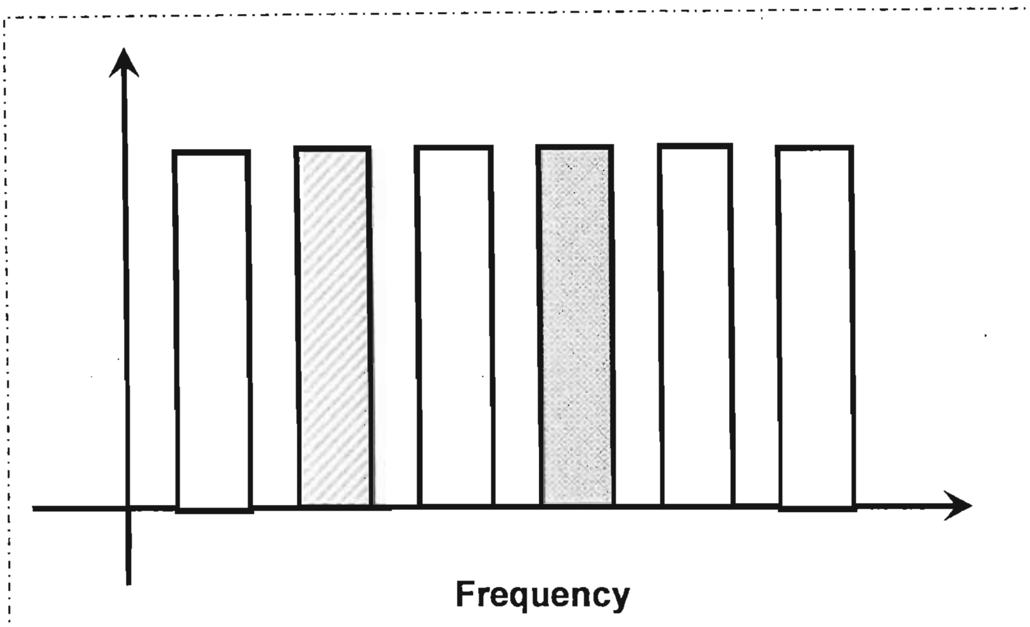

Figure 17: FDMA where channels are assigned different frequency bands.

These channels are assigned on demand to users who request service. During the period of the call, no other user can share the same frequency band. Some of the features of FDMA are:

- The FDMA channel carries only one phone circuit at a time.
- If a channel is not in use, then it sits idle and cannot be used by other users to increase or share capacity. It is a wasted resource.
- After the assignment of a voice channel, the base station and the mobile transmit simultaneously and continuously.
- The bandwidths of FDMA channels are relatively narrow (30kHz) as each channel supports only one circuit per carrier. That is, FDMA is usually implemented in narrow band systems.
- The symbol time is large as compared to the average delay spread. This implies that the amount of inter-symbol interference is low and, thus little or no equalization is required in FDMA narrowband systems.

- FDMA is a continuous transmission scheme and fewer bits are needed for overhead purposes.
- The FDMA mobile unit uses duplexers since both the transmitter and the receiver operate at the same time. This results in an increase in the cost of FDMA subscriber units and base stations.
- FDMA requires tight RF filtering to minimize adjacent channel interference.

Inter-symbol interference (ISI) is caused by multi-path in band-limited time depressive channels; ISI distorts the transmitted signals, causing bit errors at the receiver. ISI has been recognized as the major obstacle to high-speed data transmission over mobile radio channels. Equalization is a technique used to combat inter-symbol interference. In a FDMA system, many channels share the same antenna at the base station. The power amplifiers or the power combiners, when operated at or near saturation for maximum power efficiency, are non-linear.

The non-linear ties cause signal spreading in the frequency domain and generate Intermodulation (IM) frequencies. Intermodulation is undesired RF radiation, which can interfere with other channels in the FDMA systems. Spreading of the spectrum results in adjacent-channel interference. Intermodulation is the generation of undesirable harmonics. Harmonics generated outside the mobile radio band cause interference to adjacent services, while those present inside the band cause interference to other users in the mobile system.

3.7 DIGITAL ENHANCED CORDLESS TELECOMMUNICATION SYSTEM

Digital Enhanced Cordless Telecommunications (DECT) is a digital radio standard for cordless telephony in home and working environments. DECT has been a standard in the EU countries since 1993, and it has also been adopted in several countries outside of Europe. Today DECT is used in more than 30 countries around the world.

The DECT standard is mainly used for multiple-user wireless communications in offices, factories and other working environments. Such a business cordless system, which is also called cordless PBX (Private Branch Exchange), is a system consisting of a number of radio base stations which are connected to a central exchange. Users can make and receive calls when in range of a base station. Like in a cellular mobile telephony system (e.g. GSM), the radio connection is handed over from one base station to another when a user is moving within the area covered by the system.

The main feature of DECT cordless systems is that very high densities of users are permitted. However, unlike cellular mobile telephone systems, DECT telephones generally cannot be used outside of the working environment. DECT is based on the TDMA (Time Division Multiple Access) technology, which means that each of the radio channels (RF carriers) is divided into 24 time slots (12 duplex time slots). One user is allocated two time slots, one for transmission and one for reception. Consequently, each radio channel can be used for 12 simultaneous calls. The total time of 24 slots is 10 milliseconds, which means that a DECT telephone transmits with a time slot repetition rate of 100 Hz.

DECT uses 10 radio channels in a 20 MHz frequency band between 1880 and 1900 MHz. The telephones and the base stations have a peak output power of 250 mW. Since the handsets only use 1 time slot out of 24 for transmission, the average output power is 10 mW.

3.7.1 DECT SYSTEM DATA

For the DECT system, the current characteristics are as follows:

(a) Peak power/mean power:

- Handset: 250 mW/ 10 mW
- Base station: 250 mW/ max 125 mW (depending on number of Channels used)

(b) Frequency band 1.88 - 1.90 GHz

© Multiple access method: TDMA (Time Division Multiple Access)

(d) Duplexing method: TDD (Time Division Duplex)

(e) Time slots per channel: 24 (12 duplex slots)

(f) Time slot duration: 0.417 ms

(g) Time slot repetition rate: 100 Hz

3.8 TIME DIVISION MULTIPLE ACCESS (TDMA)

In time division multiple access (TDMA) each signal uses the entire frequency band of the system for a fraction of the time. To perform TDMA, a transmitter stores the source information that arrives in a time interval referred to as TDMA frame. A TDMA system transmits each signal for a fraction of the frame. The time interval occupied by one signal is a slot.

When its time slot begins, a transmitter sends the stored information at an accelerated speed, so that all the information recorded in one frame is transmitted in a slot. The transmitted signal occupies a wider band of frequencies than the source signal. The receiver records the signal arriving in its slot and plays it back at the original slower rate. The playback interval is one frame and the received information, restored to the lower rate, emerges in a continuous stream with no gaps [14].

Figure 18 shows the TDMA, where channels occupy a cyclically repeating time slot. In principle, time division techniques can be used for analogue communications. In practice however, they appear only in digital systems, where it is a simple matter to store binary signal arriving at the source rate, and then release them at the faster channel rate.

The number of physical channels in a time division system is the number of slots per frame. It is a basic principle of communications that two regions in the time-frequency with equal areas can carry same amount of information regardless of its shape. This is common in fixed telephone networks. The enabling technology in radio systems is speech encoding and data compression, which removes redundancy and decrease the time it takes to represent any period of speech. A pure TDMA radio system would have only one physical operating frequency, which is not particularly useful.

In modern digital cellular systems, TDMA implies the use of digital voice compression techniques, which allows multiple users to share a common channel on a schedule. Modern voice encoding greatly shortens the time it takes to transmit voice messages by removing most of the redundancy and silent periods in speech communications. Users share a physical channel in TDMA system, where they are assigned time slot. All the users sharing the physical resource have their own assigned, repeating time slot within a group of time slots called frame.

TDMA systems transmit data in a buffer-and-burst method, thus the transmission for any user is non-continuous. This implies digital data and digital modulation must be used with TDMA. In TDMA/TDD, half of the time slots in the frame information message would be used for the forward link channel and half would be for reverse link channels. In TDMA/FDD systems, an identical of similar frame structure would be used solely for either forward or reverse transmission, but the carrier frequencies would be different for the forward and reverse links. Figure 19 shows the TDMA frame structure.

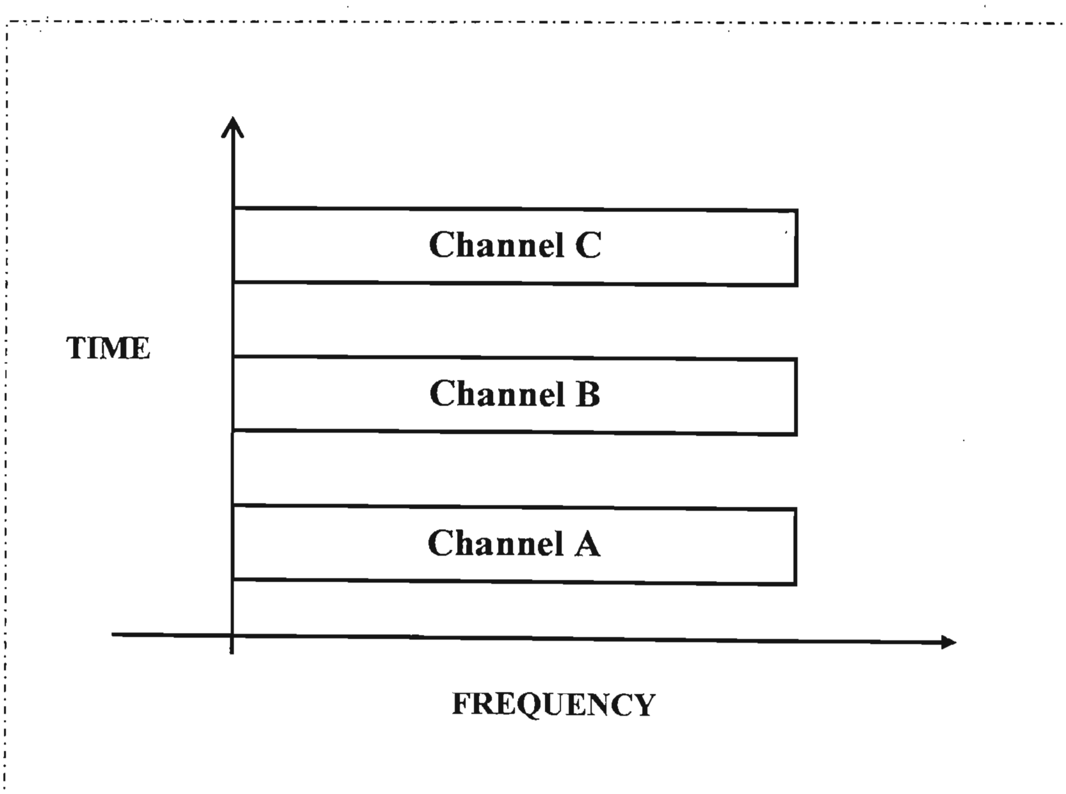

Figure 18: TDMA where each channel occupies a cyclically repeating time slot.

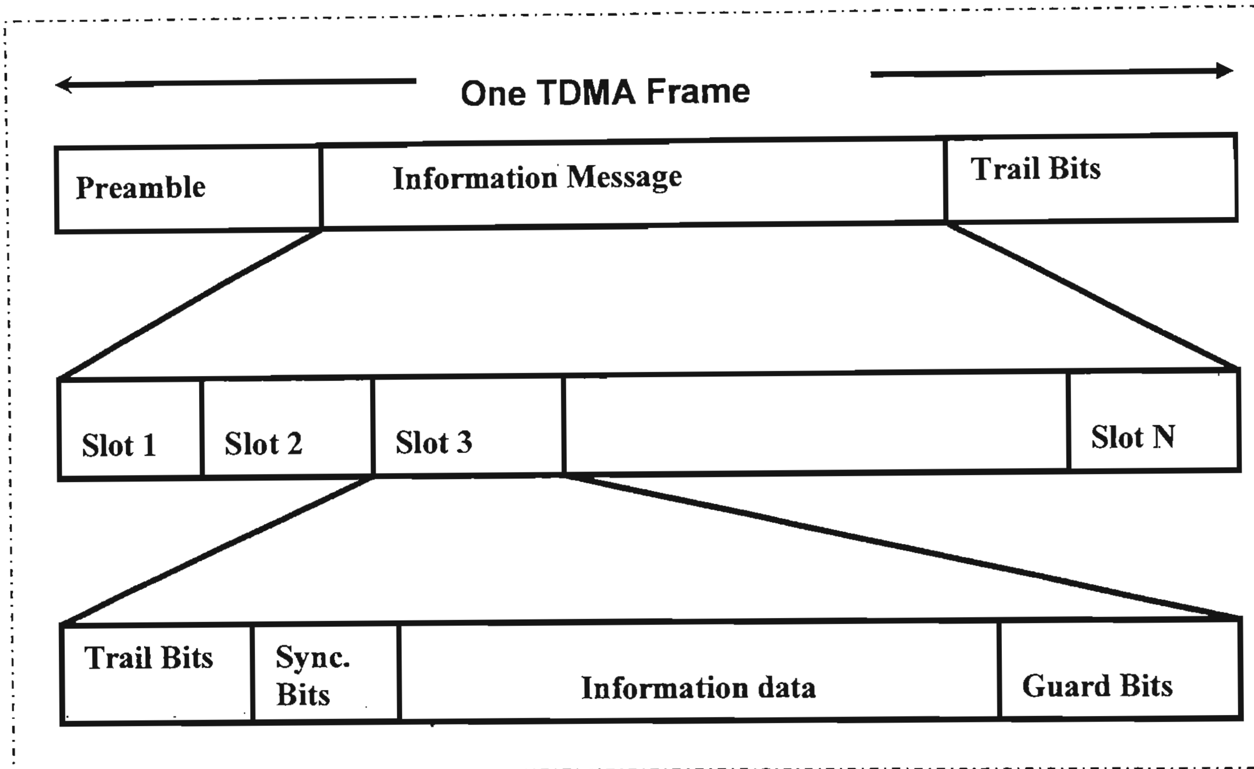

Figure 19: TDMA Frame structure

In a TDMA frame, the preamble contains the address and synchronization information that both the base station and the subscribers use to identify each other. Guard times are utilized to allow synchronization of the receivers between different slots and frames. The features of TDMA include the following [14]:

- TDMA shares a single carrier frequency with several users, where each user makes use of non-overlapping time slots. The number of time slots per frame depends on several factors, such as modulation technique, available bandwidth and others.
- Data transmission for users of a TDMA system is not continuous, but occurs in bursts. This results in low battery consumption, since the subscriber transmitter can be turned off when not in use.
- Because of discontinuous transmissions in TDMA, the handoff process is much simpler for a subscriber unit, since it is able to listen to other base stations during idle time slots.
- TDMA uses different time slots for transmission and reception, thus duplexers are not required. Even if FDD is used, a switch rather than duplexer

inside the subscriber unit is all that is required to switch between transmitter and receiver using TDMA.

- Adaptive equalization is usually necessary in TDMA systems, since the transmission rates are generally very high.
- In TDMA guard times are minimized. This will help minimize interference.
- TDMA has an advantage in that it is possible to allocate different numbers of time slots per frame to different users. Thus bandwidth can be supplied on demand to different users by reassigning time slots based on priority.

The efficiency of a TDMA system is a measure of the percentage of transmitted data that contains information as opposed to providing overhead for the access scheme. The frame efficiency, η_f, is the percentage of bits per frame which contain transmitted data. Note that the transmitted data may include source and channel coding bits, so the raw end-user efficiency of a system is generally less than η_f. The frame efficiency η_f is given as

$$\eta_f = \left(1 - \frac{b_{oH}}{b_T}\right) \times 100\% \qquad (3.9)$$

where $b_T = T_f R$, where T_f is the frame duration, R is the channel bit rate and b_T is the total number of bits per frame and b_{OH} is the number of overhead bits per frame which is given as [14]:

$$b_{OH} = N_r b_r + N_t b_p + N_t b_g + N_r b_g \qquad (3.10)$$

where, N_r is the number of reference bursts per frame, N_t is the number of traffic bursts per frame, b_r is the number of overhead bits per reference bursts, b_p is the number of overhead bits per preamble in each slot, and b_g is the number of equivalent bits in each guard time interval. The total number of bits per frame, b_T, is

$$b_T = T_f R \qquad (3.11)$$

The number of TDMA channel slots N that can be provided in a TDMA system is found by multiplying the number of TDMA slots per channel by the number of channels available and is given by

$$N = \frac{m(B_{tot} - 2B_{guard})}{B_c} \tag{3.12}$$

where B_{tot} is the total bandwidth, B_{guard} is the guard bandwidth, B_c is the channel bandwidth and m is the maximum number of TDMA users supported on each radio channel. There are two guard bands, one at the low end of the allocated frequency band and one at a high end. These are required to ensure that users at the edge of the band do not "bleed over" into an adjacent radio service.

3.9 CODE DIVISION MULTIPLE ACCESS (CDMA)

In CDMA, many signals simultaneously occupy the same wide band of frequencies. The cellular CDMA system employs direct sequence spread spectrum modulation. With this technique, a physical channel corresponds to a binary code. Each physical channel has its own binary code, which is a sequence of binary symbols referred to as chips. To transmit one information bit, a CDMA system transmits its entire code if the bit is a 1. For a 0, it transmits the complement of its code. CDMA differs from TDMA and FDMA in the mutual effects that different signals produce when they arrive at the same receiver. TDMA and FDMA are similar in that a receiver can completely separate the signals arriving on different physical channels.

This is not the case in CDMA. Owing to the nature of the physical channels, the output of a receiver contains small components of all input signals. Provided that the number of simultaneous transmissions is not too high or more than the maximum possible number, each receiver, with high probability, accurately detects the transmitted information signal. As the number of simultaneous transmissions increases, the interference increases, causing receivers to make an increased number of digital errors.

The channel capacity definition for CDMA is different from the TDMA and FDMA. In TDMA and FDMA, capacity corresponds to the number of physical channels. CDMA capacity is the highest number of simultaneous transmissions consistent with an error-rate objective established for a system.

In code division multiple access system, the narrowband message signal is multiplied by a very large bandwidth signal called the spreading signal. The spreading signal is a pseudo-noise code sequence that has a chip rate, which is orders of magnitudes greater than the data rate of the message. All users in a CDMA system use the same carrier frequency and may transmit simultaneously.

Each user has its own pseudorandom codeword, which is orthogonal to all other code words. The receiver performs a time correlation operation to detect only specific desired codeword. All other codeword appear as noise due to de-correlation. For detection of the message signal, the receiver needs to know the codeword used by the transmitter. Each user operates independently with no knowledge of the other users. Figure 20 shows a CDMA with 3 channels sharing the same frequency band.

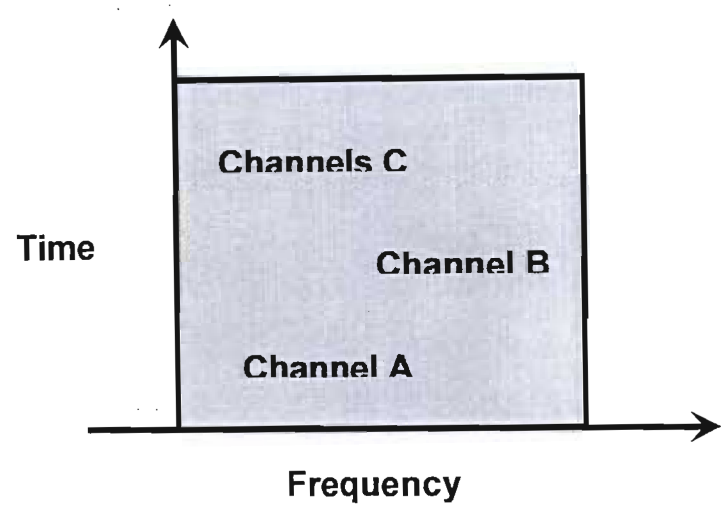

Figure 20: CDMA in which each channel is assigned a unique PN code, which is orthogonal to PN codes used by other users. Users share frequency and time.

In CDMA, the power of multiple users at a receiver determines the noise floor after de-correlation. If the power of each user within a cell is not controlled such that they do not appear equal at the base station receiver, then the near-far end problem occurs. The near-far problem occurs when many mobile users share the same channel. In general, the strongest received mobile signal will capture the demodulator at a base station. In CDMA, stronger received signal levels raise the noise floor at the base station demodulators for the weaker signals, thereby decreasing the probability that weaker signal will be received. To combat the near-far problem, power control is used in most CDMA implementations.

Power control is provided by each base station in a cellular system and assures that each mobile within the base station coverage area provides the same signal level to the base station receiver. This solves the problem of a nearby subscriber overpowering the base station receiver and drowning out the signals of far away subscribers. Power control is implemented at the base station by rapidly sampling the radio signal strength indicator (RSSI) levels of each mobile station and then sending a power change command over the forward radio link. Despite the use of power control within each cell, out-of-cell mobiles provide interference, which is not under the control of the receiving station. The features of CDMA including the following [14]:

- Many users of a CDMA system share the same frequency. Either TDD or FDD may be used.
- Unlike TDMA or FDMA, CDMA has a soft capacity limit. Increasing the number of users in a CDMA system raises the noise floor in a linear manner. Thus, there is no absolute limit on the number of users in CDMA. The performance only degrades with the increase in the number of users.
- Multi-path fading may be substantially reduced because the signal is spread over a large spectrum. If the spread spectrum bandwidth is greater than the coherence bandwidth of the channel, the inherent frequency diversity will mitigate the effects of small-scale fading.
- The near-far problem occurs at a CDMA receiver if an undesired user has a high-detected power as compared to the desired user.

3.10 CHAPTER SUMMARY

In this chapter, different types of systems are discussed. This includes terrestrial microwave links, very small aperture terminal, optic fibre link and multiple access techniques. In Terrestrial microwave links both telephone and broadcasting share the same licence but in South Africa telecommunications licence and broadcasting licence are separated. Optical Fibre links offer extremely wide bandwidth up to 40 GHz but rural areas are spatially distributed, as a result there are low traffic generated. Very

Small Aperture Terminal system is being tested in rural areas of Senegal and Argentina, as a result it is not considered for our rural of Kwazulu-Natal. CDMA is the best option for rural telecommunication system. It can be implemented quicker and it can be upgraded to accommodate more users at a later stage.

Chapter 4 will discuss the CDMA model and different receiver structure that can be used for CDMA.

3.11 CHAPTER CONCLUSION

Many rural people desperately need telecommunications service, as a result we need to provide cost effective service in a very short space of time. This means wire line systems including Optical fibre are not considered because they take a long time to implement. Terrestrial microwave links they provide fixed broadband wireless access for both telecommunication and broadcasting. Telecommunication licence in South Africa is separate from broadcasting licence; thus High-capacity terrestrial microwave links are not considered for South African rural areas. While Very Small Aperture Terminal (VSAT) and Code Division Multiple Access (CDMA) are suitable for rural areas, VSAT still going through rigorous research in rural parts of Africa and South America.

CHAPTER 4

CODE DIVISION MULTIPLE ACCESS

4.0 INTRODUCTION

In rural areas, the path loss exponent exceeds 4.2 and varies from 5.3 to 7.2. Therefore, for this environment a comparison of CDMA and GSM networks is undertaken to determine the better technology. This comparison is done after introducing CDMA principles.

4.1 CDMA BLOCK DIAGRAM

The transmitter consists of data source and modulation block. This is where spreading operation takes place, where a narrow band signal is spread into a wideband signal and transmitted to the receiver. In the channel the wideband signal is combined with other wideband signals and noise. The receiver part is where the de-spreading operation and demodulation takes place. The transmitter block diagram shown in figure 24 consists of data modulator, which modulates the binary data signal with a RF carrier. The modulated carrier is then modulated by the code signal. This code signal consists of a number of code bits called chips that can be either +1 or –1.

To obtain the desired spreading of the signal, the chip rate of the code signal must be much higher than the chip rate of the information signal. There are various spreading modulation techniques that can be used, but usually phase shift keying (PSK)'s are employed. These are binary shift keying (BPSK), differential binary phase shift keying (D-BPSK), Quadrature phase keying (QPSK) and the minimum shift keying (MSK).

4.2 CDMA TRANSMITTER

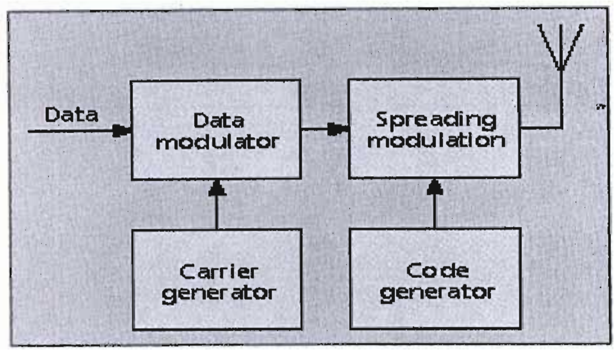

Figure 21: CDMA transmitter block diagram [19]

4.2.1 DATA MODULATOR

Detailed discussion of data modulator is obtained in [36], which is summarized below. The simple form of direct sequence communication system employs binary phase-shift keying (BPSK) for both the data modulation and the spreading modulation. But the most common form uses BPSK for data modulation and Quadrature phase-shift keying (QPSK) for the spreading modulation.
The **BPSK signal** is given by

$$x(t) = c(t)s(t) = c(t)d(t)\sqrt{2P}\cos\omega_c t \tag{4.1}$$

where $s(t) = d(t)\sqrt{2P}\cos\omega_c t$

$d(t)$ = the base band signal at the transmitter input and receiver output

$c(t)$ = the spreading signal

P = the signal power

ω_c = the carrier frequency

The signal at the receiver is given as

$$r(t) = x(t) + I(t) + n(t) \tag{4.2}$$

The receiver multiplies this by the PN waveform to obtain the signal Coherent Detection

$$r(t) = c(t)[x(t) + I(t) + n(t)] = c(t)[c(t)s(t)] + c(t)I(t) + c(t)n(t) = s(t) + c(t)[I(t) + n(t)] \tag{4.3}$$

since $c(t)^2 = 1$, $c(t)[I(t)+n(t)]$ is the noise waveform due to interference and AWGN.

The BPSK detector output is given as

$$r = d\sqrt{E_b} + n(t) \tag{4.4}$$

where d = the data bit for the T second interval

E_b=the bit energy

$n(t)$ = the equivalent noise component

$I(t)$ = interference from other users.

The spreading-despreading operation does not affect the signal and does not affect the spectral and probability density function of the noise. For this reason, the bit error probability P_b associated with the coherent BPSK Spread Spectrum signal is the same as with the BPSK signal given as

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \tag{4.5}$$

For QPSK modulation, we denote the in-phase and Quadrature data waveforms as $d_c(t)$ and $d_s(t)$, respectively, and the corresponding pseudo-random noise (PN) binary waveform as $c_c(t)$ and $c_s(t)$. The QPSK signal is represented as follows:

$$x(t) = c_c(t)d_c(t)\sqrt{P}\cos\omega_c t + c_s(t)d_s(t)\sqrt{P}\sin\omega_s t \tag{4.6}$$

where each QPSK pulse is of duration $T_s = 2T$.

The in-phase output component is

$$r = d_c\sqrt{E_b} + n_c \tag{4.7}$$

$$\text{where } n_c = \sqrt{\frac{2}{T_s}} \int_0^{T_c} c_c(t) I(t) \cos \omega_c t dt$$

and the Quadrature component is

$$r_s = d_s \sqrt{E_b} + n_s \qquad (4.8)$$

$$\text{where } n_s = \sqrt{\frac{2}{T_s}} \int_0^{T_c} c_s(t) I(t) \sin \omega_c t dt$$

QPSK modulation can be viewed as two independent BPSK modulations. Thus the net data rate is double. For this case, the in-phase and Quadrature components take forms

$$r_c = d \sqrt{\frac{E_b}{2}} + n_c \qquad (4.9)$$

and

$$r_s = d \sqrt{\frac{E_b}{2}} + n_s \qquad (4.10)$$

where n_c and n_s are zero mean independent with conditional variances.

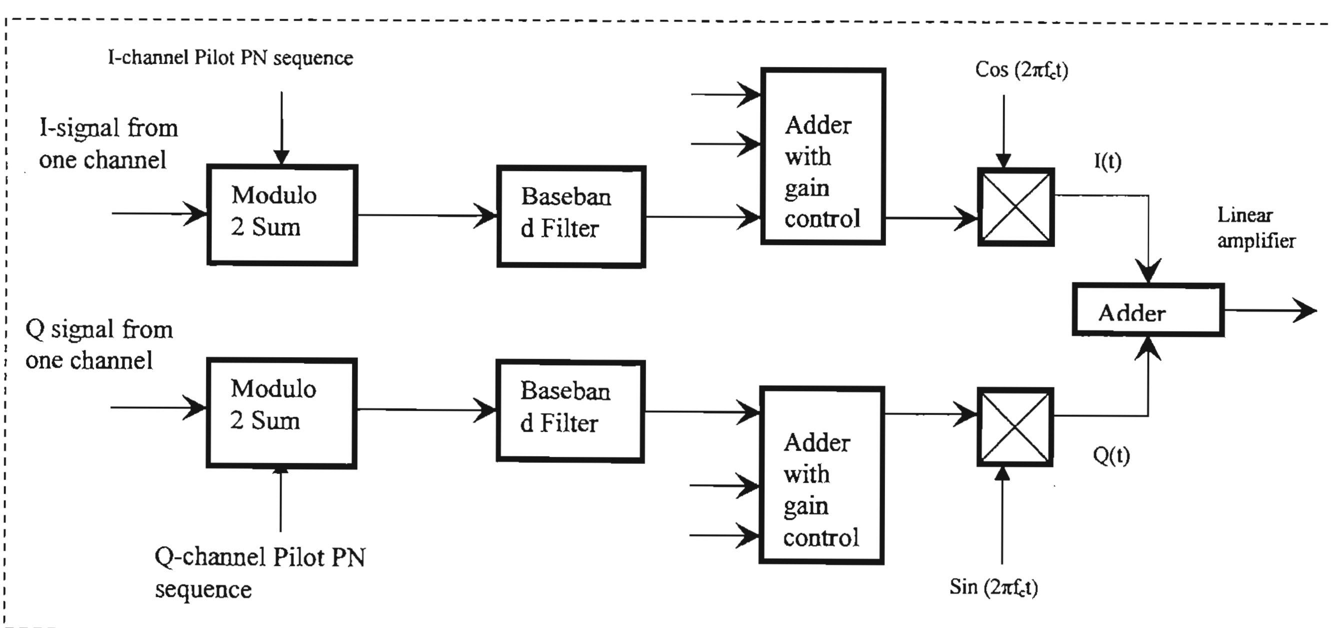

Figure 22: CDMA modulator

The I and Q base band signals are modulated by the I and Q carrier signals, combined together, amplified, and sent to the antenna as shown in figure 22.

4.2.2 CODE GENERATOR

In CDMA, pseudorandom noise (PN) sequences are used to perform the following task:

- Spread the bandwidth of the modulated signal to the larger transmission bandwidth.

The PN sequences are not random; they are *deterministic*, *periodic* sequences. A signal that can be uniquely determined by a well-defined process such as a mathematical expression or rule is called a deterministic signal.

The generation of pseudo-random (PN) sequences for spread spectrum applications is very important and thus received considerable attention in technical literature. By far the most widely known binary PN sequences are the maximal-length shift-register sequences.

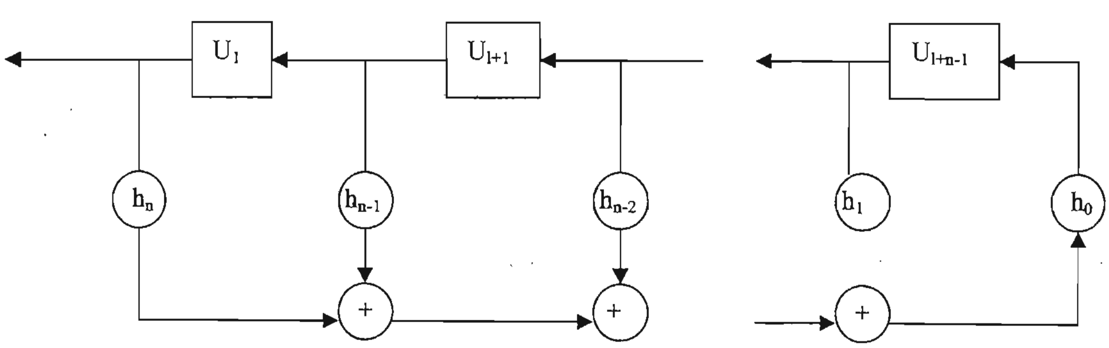

Figure 23: Binary Shift Register

Each user will be assigned a code generated from binary shift-registers according to Galois Field characteristic polynomials. Linear feedback shift registers are used to generate long binary spreading sequences. Binary sequence $u = \{u_l\}$ generated by the n-stage shift register and tap weights $h_0, h_1, h_2 ....h_n$ take on values from set {0, 1}. To obtain the bipolar BPSK spreading sequence x from the binary sequence u, we define a map χ from the space of binary sequences to the space of bipolar sequences by

$$x_l = \chi(u_l) = (-1)^{u_l} \tag{4.11}$$

This means '0' is mapped to '+1' and '1' is mapped to '-1'. Note that h_0 has to be 1, otherwise the output u will be identically zero after n-shifts. Similarly h_n has to be 1, otherwise we can simply remove the leftmost stage to get a shorter register without affecting the output sequence. It can be seen that the output sequence satisfies

$$u_{n+l} = h_n u_l \oplus h_{n-1} u_{l+1} \oplus \ldots\ldots \oplus h_l u_{l+n-1} \tag{4.12}$$

where $\oplus$ denotes addition modulo 2, that is the XOR operation. Tap weights $h_0, h_1, h_2 \ldots\ldots\ldots h_n$ of the shift register are usually represented as

$$h(x) = h_0 x^n + h_1 x^{n-1} + h_2 x^{n-2} + \ldots + h_{n-1} x + h_n \tag{4.13}$$

A shift register can generate different sequences depending on initial contents of the storing elements. If initial values are zero, the output will be all-zero which is not helpful.

If more sequences are needed we can use Gold codes. Gold codes are generated by the combination of 2 binary shift registers as in the Figure 24 below.

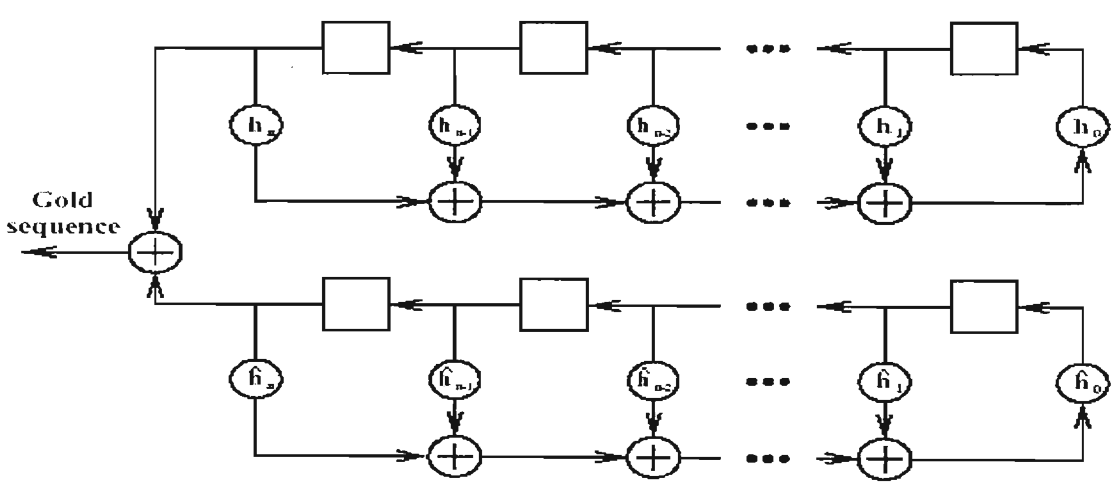

Figure 24: Gold sequence generator

There are $N+2$ 2 sequences in the set of Gold sequences and the peak cross-correlation magnitude is the same as that of a maximal connected set of m-sequences.

4.3 CDMA RECEIVER

The receiver shown in figure 25 below is used to de-spread the spectrum spreads signal using a locally generated code sequence. To be able to perform the de-spreading operation, the receiver must not only know the code sequence used to spread the signal, but the codes of the received signal and the locally generated code must also be synchronized. This synchronization must be accomplished at the beginning of the reception and maintained until the whole signal has been received. The code synchronization/tracking block performs this operation. After de-spreading, a data modulated signal results, and after demodulation, the original data can be recovered.

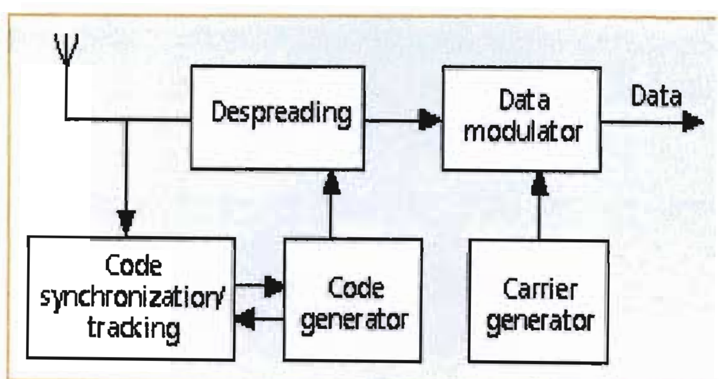

Figure 25: CDMA receiver block diagram

The interference in the downlink from the base station (BS) originates from a single point and the parallel code channels can be synchronized. When using orthogonal spreading codes in the ideal case, the intracell interference could be avoided; but after the multipath channel, part of the orthogonality is lost and intracell interference exist also in the downlink [14]. The estimate of the achievable degree of orthogonality can be determined by finding the derivation of the orthogonality factor.

4.3.1 REVERSE TRAFFIC CHANNEL

For the CDMA system, the primary traffic channel and signalling channel are multiplexed together and processed by the same Convolutional encoder, symbol repetition, interleaver, and 64-ary orthogonal modulator. The modulator output is then randomised to eliminate repetitive 0s and 1s patterns) by blocks of 14 bits taken from the long code. Figure 26 shows a reverse CDMA traffic channel.

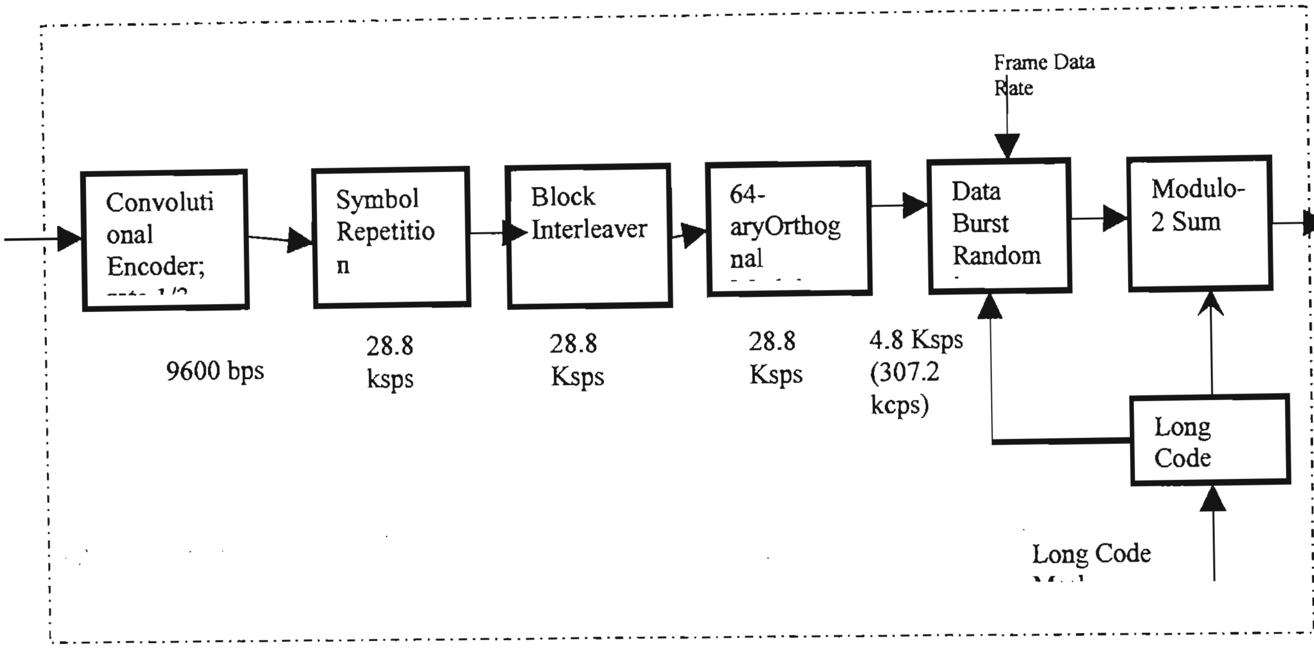

Figure 26: Reverse (Uplink) CDMA traffic channel

4.3.2 FORWARD TRAFFIC CHANNEL (Downlink)

Figure 27 shows the forward CDMA traffic channel. The traffic channel is transmitted by the base station to the mobile station (MS) to carry voice or data traffic. The mobile station in this case means end users who might be fixed user or mobile users. The traffic channel is multiplexed and can carry voice or data, power control bits, and signalling channel data.

The CDMA system multiplexes the voice, data, and signalling before the Convolutional encoder. For CDMA, the data bits can be voice, data, or signalling and are multiplexed together according to the capabilities described in the Table 9 below. Signalling can be sent only by reducing the number of bits used for voice or data.

Transmit Rate Bits/sec	Primary Traffic (voice or data), bits/frame	Signalling Traffic, bits/frame
9600	171	0
9600	80	88
9600	40	128
9600	16	152
4800	80	0
2400	0	0
1200	0	0

Table 9: Multiplexing Options for Forward CDMA Traffic Channel [36]

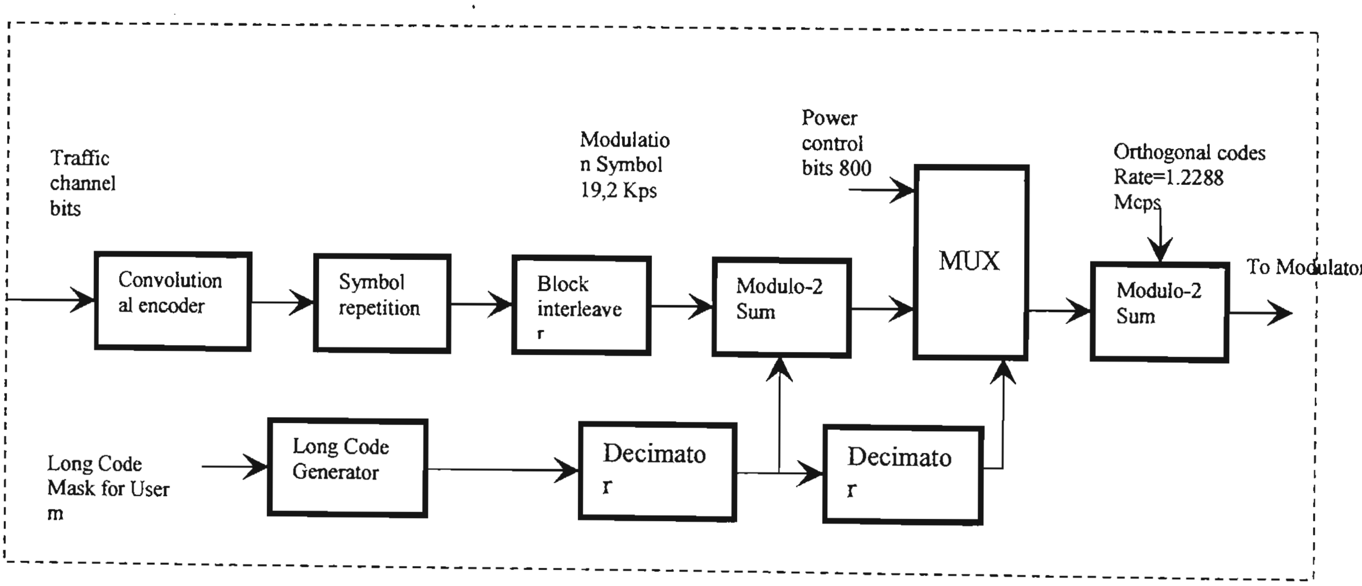

Figure 27: Forward CDMA traffic channel

4.3.3 BLOCK PARAMETERS

4.3.3.1 Block Interleaving

Communications over radio channel are characterised by deep fades that can cause large numbers of consecutive errors. By interleaving the data, no two adjacent bits are transmitted near each other, and data errors are randomised. For CDMA, the interleaver spans a 20 ms frame. If the data rate is 9.6 kbps, the resultant signal transmits with 100 percent duty cycle. If the data rate is lower, the interleaver and the randomiser delete the redundant bits and transmit with a lower duty cycle.

4.3.3.2 Randomising

For the CDMA system only, and only on the reverse traffic channel, a data randomiser processes the output of the interleaver. The randomiser removes redundant data blocks generated by the code repetition. It uses a masking pattern determined by the data rate and the last 14 bits of the long code.

4.3.3.3 Convolutional Encoder

Passing the information sequence through a linear finite-state shift register generates a Convolutional code. In general, the shift register consists of K (k-bit) stages and n linear algebraic function generators. The input data to the encoder, which is assumed to be binary, is shifted into and along the shift register k bits at a time. The number of output bits for each k-bit input sequence is n bits. Consequently, the code rate is defined as

$R_c = k/n$, consistent with the definition of the code rate for a block code. The parameter k is called the constraint length of the Convolutional code. The Convolutional encoder that is used in CDMA is shown below in Figure 28.

4.3.3.4 Bit Repetition

The nominal data rate on the forward and reverse CDMA channels is 9600 bps. If data being transmitted at a lower rate (4800, 2400, or 1200 bps), then the data bits are repeated n times to increase the rate to 9600 bps.

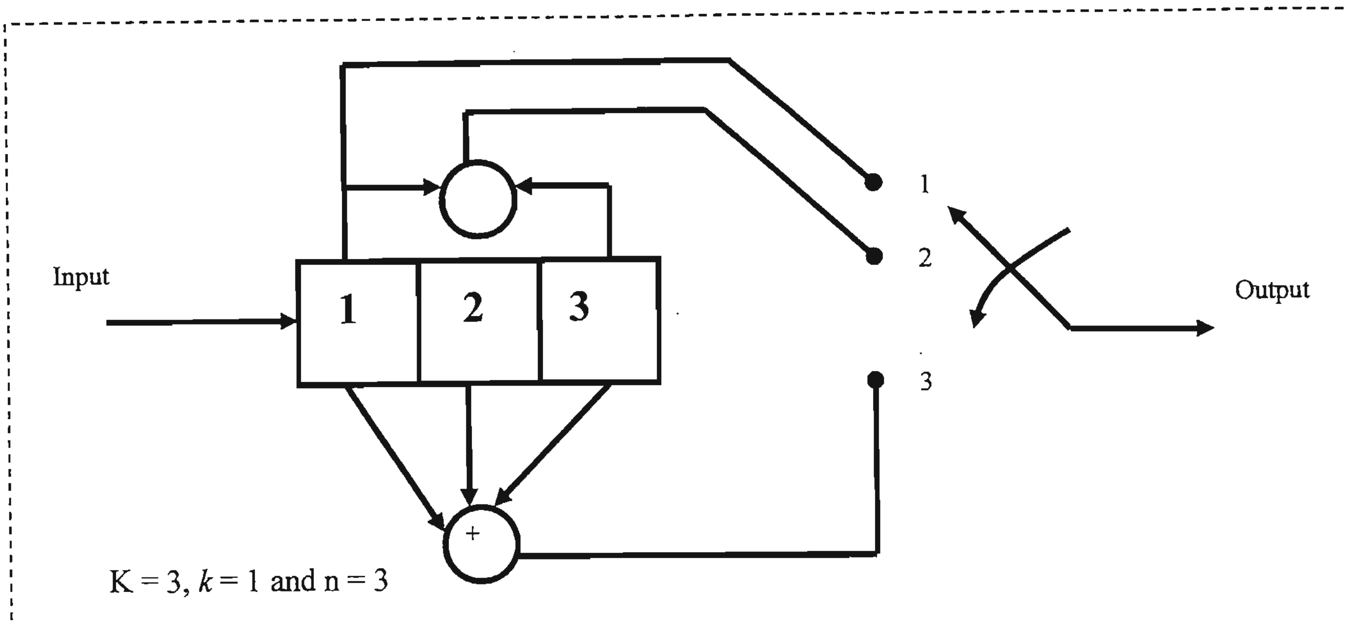

Figure 28: Convolutional encoder

4.3.3.5 64-ary Orthogonal Modulation

In the CDMA system only and only on the reverse channel, a 64-ary orthogonal modulator modulates the data stream. Every six code symbols select one of 64 possible orthogonal modulation symbols. The modulation symbols are generated using Walsh functions. The 64 modulation symbols are numbered 0 through 63. For each six input symbols to the modulator, one output Walsh function is generated. The output Walsh function is defined by

$$W_i = c_0 + 2c_1 + 4c_2 + 8c_3 + 16c_4 + 32c_5 \qquad (4.14)$$

where c_5 is the most recent and c_0 the oldest of the 6 bits to be transmitted and W_i is chosen from 1 to 64 orthogonal Walsh functions.

4.3.3.6 Base band Filtering

After the PN modulation, a base band filter filters the signal. The filter should have the following parameters:

Pass band ripple	3 dB
Upper pass band frequency	590 kHz
Minimum stop band attenuation	40 dB
Lower stop band frequency	740 kHz

Table 10: Parameters of the base band filter

4.3.3.7 Synchronization of CDMA Signals

CDMA system time is the same as the global positioning system (GPS). All base stations in a CDMA system are synchronized to the GPS. Each base station transmits a set of orthogonal cods that are synchronized to CDMA time and are time-shifted from the codes at other base stations in the system.

4.4 RECEIVER STRUCTURE FOR CDMA

4.4.1 CORRELATION RECEIVER

The following receiver shown in figure 29 is a correlation receiver at the base station of a CDMA cellular system. At the base station, there is a separate receiver for each user, and all receivers are presented with the same incoming signal *r(t),* which is the sum of the signals of all users and the noise(AWGN).

Each receiver correlates the incoming signal with a synchronized copy of the desired PN code to generate a decision statistic, which is used to estimate the transmitted data stream. Thus, conventional correlation detectors operate by enhancing the desired user, and treat the MAI, which is inherent in CDMA as additive noise. This would work well if the MAI were truly uncorrelated with the desired signal.

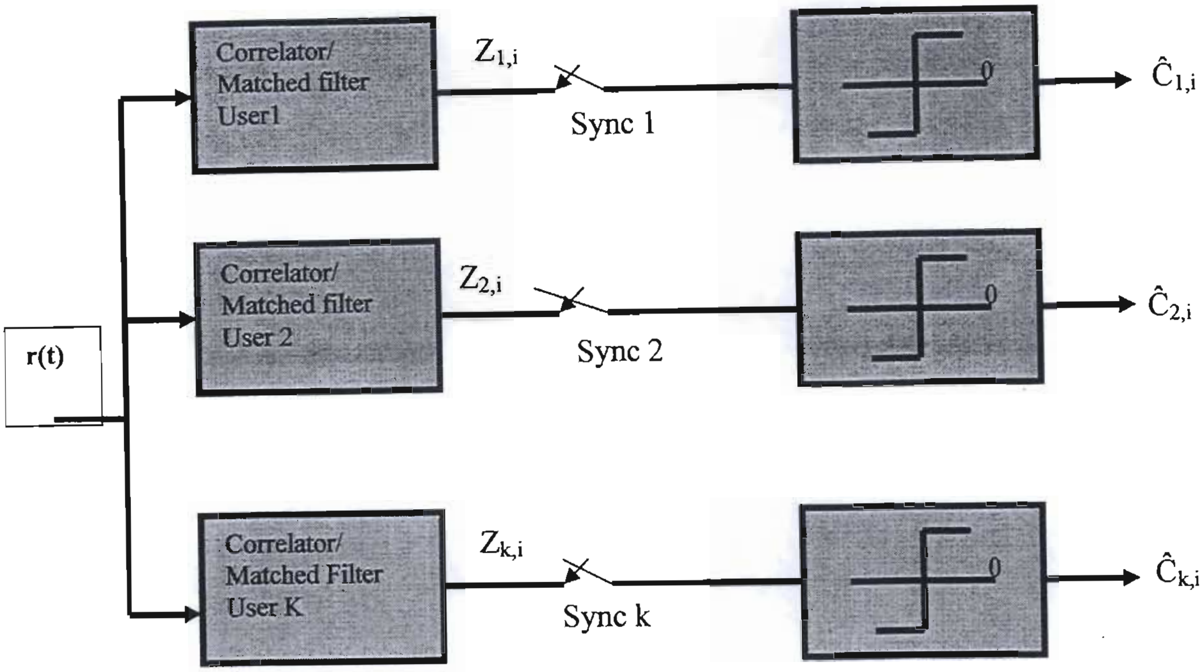

Figure 29: Correlation Receiver.

Unfortunately, some correlation between the codes cannot be avoided, and this cause significant degradation. As a result, capacities for single cell CDMA systems employing a correlation receiver can be significantly lower than those for FDMA or TDMA systems, which are truly orthogonal. Moreover, if an interferer is significantly stronger than the desired user it will dominate performance due to the near-far effect. This would limit the utility of the CDMA system to applications where each user's received power is approximately the same.

4.4.2 RAKE RECEIVER

A Rake receiver allows DS/SS to exploit multi-path. Each "finger" of Rake receiver is a correlation receiver synchronized to a different multi-path component.

When a signal travels through a practical channel, it undergoes reflection and scattering off objects in its path. The multi-path components could interfere either constructively or destructively, depending on their relative phases. This causes inter-symbol interference, which limits the data rate of un-equalized narrow-band systems (because delays are much smaller than the bit period). In wide band signalling, however, the duration of the transmitted symbols is small compared to the multi-path delay introduced by the channel. This provides inherent time diversity in case of wide band signals.

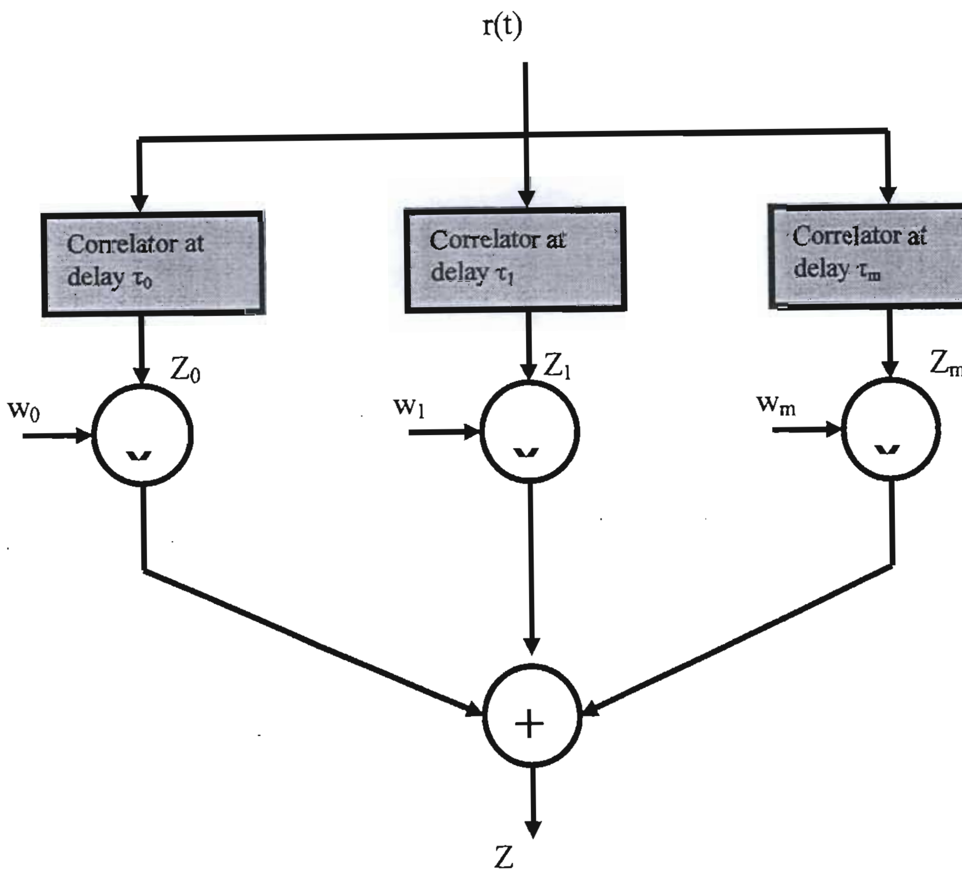

Figure 30: Structure of a RAKE receiver

Multi-path can be used to advantage in CDMA by using a RAKE receiver. The RAKE receiver exploits the time diversity by using information in multi-path components in the decision process. A RAKE receiver utilizes multiple correlators to separately detect the *M* strongest multi-path components. The outputs of each correlator are weighted to provide a better estimate of the transmitted signal than is provided by a single component. Demodulation and bit decisions are then based on the weighted outputs of the *M* correlators if we assume *M* correlators are used in a CDMA receiver to capture the *M* strongest multi-path components.

A weighting network is used to provide a linear combination of the correlator output for bit detection. Correlator 1 is synchronized to the strongest multi-path m_1. Multi-path component m_2 arrives τ_1 later than component m_1. The second correlator is synchronized to m_2. It correlates strongly with m_2 but has low correlation with m_1. But it should be noted that, if only a single correlator is used in the receiver, once fading corrupts the output of a single correlator, the receiver cannot correct the value. Bit decisions based on only a single correlation may produce a large bit error rate.

In a RAKE receiver, if fading corrupts the output from one correlator, the others may not be, and the corrupted signal may be discounted from the weighting process. Decisions based on the combination of the M separate decision statistics offered by the RAKE receiver provide a form of diversity, which can overcome fading and thereby improve CDMA reception. The M decision statistics are weighted to form an overall decision statistic as shown in Figure 30. Z_1, Z_2 and Z_m denote the output of the M correlators. They are weighted by w_1, w_2 ... and w_m, respectively.

The weighted coefficients are based on the power or the SNR from each correlator output. If the power or SNR is small out of a particular correlator, it will be assigned a small weighting factor. The overall signal Z is given by

$$Z = \sum_{m=1}^{M} \alpha_m Z_m \qquad (4.15)$$

The weighting coefficients, α_m, are normalized to the output signal power of the correlator in such a way that the coefficients sum to unity as shown below

$$\alpha_m = \frac{Z_m^2}{\sum_{m=1}^{M} Z_m^2} \qquad (4.16)$$

There are many ways to generate the weighting coefficients. However, due to multiple access interference (MAI), the RAKE finger with strong multi-path amplitudes will not necessarily provide strong output after correlation. Choosing weighting coefficients based on the actual outputs of the correlators yields RAKE performance.

When the transmission bandwidth, W, exceeds the coherence bandwidth of the channel, the signal experiences frequency selective fading and multiple transmission paths exist. For a slow fading channel, the received signal $r(t)$ is given by

$$r(t) = \sum_{l=1}^{L} \beta_l s(t - \tau_l) + n(t) \qquad (4.17)$$

where s(t) is the transmitted signal and n(t) is AWGN with power spectral density $N_0/2$. The incremental differences between excess delays $\tau_1, \tau_2, \tau_3, ..., \tau_L$ should have magnitudes at least of the order of 1/W because of the frequency selective fading assumption. In this case, we can utilize Multipath diversity. First, let us assume that a single BPSK symbol is sent, i.e. $s(t) = b_0 p_T(t)$. Given all the fading coefficients, the maximum likelihood receiver is the one that gives the following decision statistic [25]:

$$z = \sum_{l=1}^{L} \beta_l^* \int_{-\infty}^{\infty} r(t) p_T(t - \tau_l) dt \qquad (4.18)$$

$$= \sum \beta_l^* \int_{\tau_l}^{\tau_L + T} r(t - (\tau_L - \tau_l)) dt$$

Assuming $\tau_L > \tau_{L-1} > ...... > \tau_1$

The corresponding receiver, shown in Figure 30, is the so-called *Rake receiver*. It can be shown easily that the conditional symbol error probability given $\beta_1, ..., \beta_L$ and $\tau_1, ..., \tau_L$ is

$$P_s = Q\left(\sqrt{\frac{2\varepsilon}{N_0} \sum_{k=1}^{L} |\beta_k|^2}\right) \qquad (4.19)$$

Provided $\tau_k - \tau_{k-1} \geq T$, for $k = 2, ..., L$, which is our frequency selective fading assumption. For independent Rayleigh fading with a uniform Multipath intensity profile, i.e, $|\beta_k|$ are iid Rayleigh random variables with $\frac{\varepsilon}{N_0} E\left[|\beta_k|^2\right] = \bar{\gamma}$ for $k = 1, ..., l$

the average symbol error probability is given by P_s. Where $P_s = \int_0^{\infty} Q\left(\sqrt{2r}\right) p_T(\gamma) d\gamma$

$$P_S = \left[\frac{1}{2}\left(1-\sqrt{\frac{\bar{\gamma}}{(1+\bar{\gamma})}}\right)\right]^L \sum_{k=0}^{L-1}\left(\frac{L-1+k}{k}\right)\left[\frac{1}{2}\left(1+\sqrt{\frac{\bar{\gamma}}{1+\bar{\gamma}}}\right)\right]^k \qquad (4.20)$$

where γ is chi-square distribution [25]

This means that the performance gain of multipath diversity using the Rake receiver is the same as that of the maximal ratio combining with L independent channels. For other types of multipath intensity profiles, the performance gains will be different. In practice, we send a train of symbols instead of a single one. Unless consecutive symbols are separated by a guard interval, which is larger than the delay spread of the channel, they will interfere with each other.

However, the insertion of guard intervals greatly reduces the spectral efficiency (number of symbols transmitted per second per unit frequency). To avoid unnecessary waste of bandwidth, we usually pack data symbols tightly together in practice. This means that the Rake receiver in Figure 30 cannot be applied directly when a train of symbols is sent.

Employing DS-SS modulation can solve this problem. The transmitted bandwidth of the DS-SS system is determined by the chip duration, which is usually much smaller than the symbol duration. Thus we can still resolve multipaths and employ multipath diversity using the Rake receiver. Intersymbol interference is not a severe problem in DS-SS as long as the delay spread is smaller than the period of the spreading sequence, which is designed to have a small out-of-phase autocorrelation magnitude. The Rake receiver structure in Figure 30 can be easily modified to accommodate DS-SS signalling.

With the use of DS-SS, the transmission bandwidth increases to the order of $\frac{1}{T_c}$, where T_c, is the chip duration. Therefore we are able to resolve multipaths separated by incremental delays larger than T_c. Since the symbol duration $T = NT_c$ and N is usually large, the conditions $\tau_k - \tau_{k-1} \geq T$ assumed in equation (4.19) do not hold anymore. Thus one may not be able to use equation (4.19) to obtain the conditional symbol error probability. Let us consider a simple case where the delay spread T_m is much smaller than T^3 and the period of the spreading sequence is N (i.e., a short sequence). If the sequence is properly chosen, intersymbol interference is not a big concern and we can simply assume that one symbol is sent, i.e., $s(t) = b_0 a(t) p_T(t)$, where $a(t)$ is the BPSK spreading signal. The Rake receiver is still optimal in this case and the decision statistic z is

$$z = \sum_{l=1}^{L} \beta_l^* \int_{-\infty}^{\infty} r(t) a(t-\tau_l) p_T(t-\tau_l) dt \tag{4.21}$$

$$= b_o \sum_{l=1}^{L} \sum_{k=1}^{L} \beta_l^* \beta_k \int a(t-\tau_k) a(t-\tau_l) p_T(t-\tau_k) dt + \sum_{l=1}^{L} \beta_l^* \int_{-\infty}^{\infty} n(t) a(t-\tau_l) p_T(t-\tau_l) dt$$

In summary, we can employ DS-SS to enhance the multipath resolution and combine the powers from different paths in an optimal manner. The advantage of DS-SS is two-fold: DS-SS alleviates the detrimental effect of intersymbol interference on the Rake receiver and enhances the multipath resolution. Therefore, multipath diversity and Rake receiver usually come along with DS-SS signalling.

4.4.3 MULTI-USER RECEIVERS

Multi-user receivers for CDMA exploit the fact that the base station receives signals from all users simultaneously and could potentially share information to make better decisions on the received data. Since such receivers work on the principle of simultaneous reception of signals from multiple users, they are suited for the base station of a cellular radio system. The optimal multi-user receiver consists of a bank of matched filters followed by a Viterbi decision algorithm for maximum likelihood sequence estimation. The complexity of the Viterbi algorithm is exponential in the number of users (on the order of 2^K). This makes the optimum multi-user receiver to complex too implement in practice.

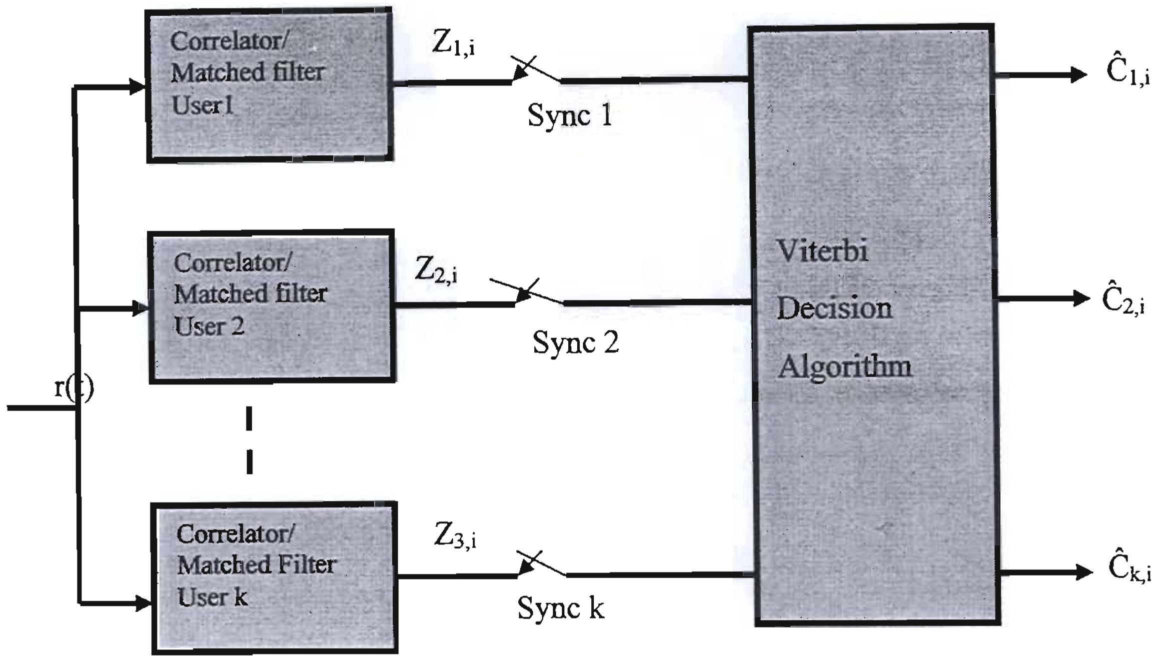

Figure 31: Optimal Multi user Receiver.

4.4.4 SUB-OPTIMAL RECEIVER

Due to the complexity of the optimum multi-user receiver, research has focused on sub-optimal receivers, which achieve significant performance improvement with reasonable complexity. In sub-optimal receiver, detector consists of a bank of K matched filters followed by a bank of K M-stage processors. The first stage is a conventional CDMA detector and provides a decision statistics for each user from the received signal. Then, M stages of processing are performed on the decision statistic, where each stage processes the decision statistic obtained from the previous stage. Such a receiver exhibits significant performance improvement over the conventional receiver, and approaches the performance and near far resistance of an optimum receiver [25].

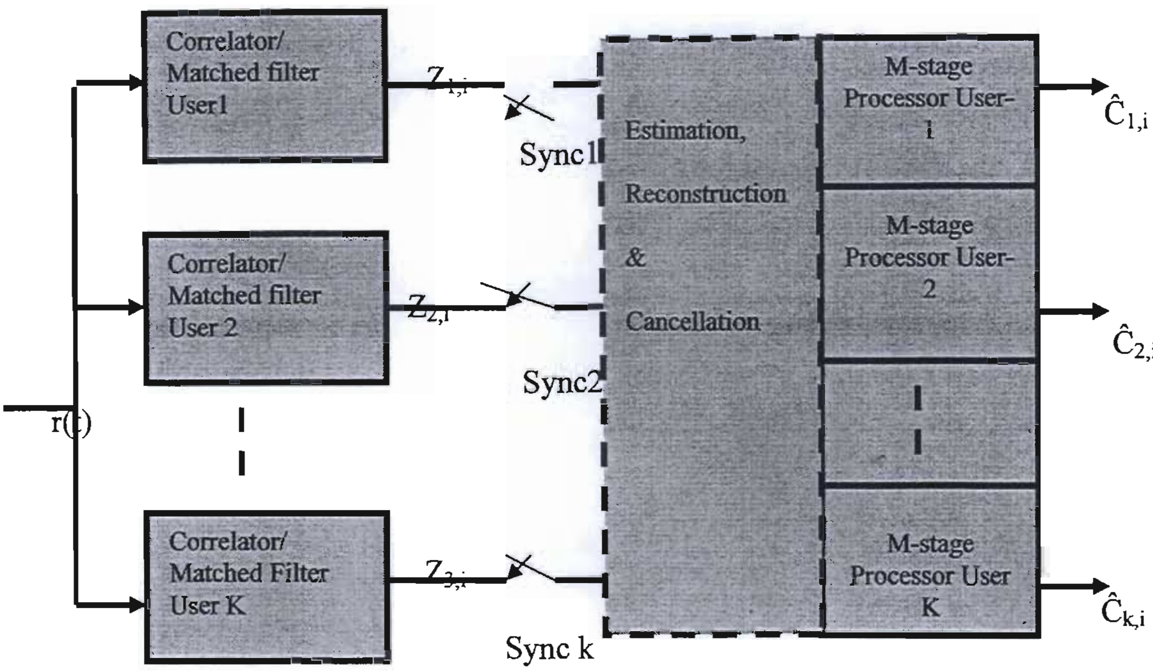

Figure 32: Multistage receiver (A sub-optimum multistage receiver)

4.5 ASYNCHRONOUS CDMA

Asynchronous CDMA is an operation where users are not transmitting simultaneously. This is an operation from the user to the base station.

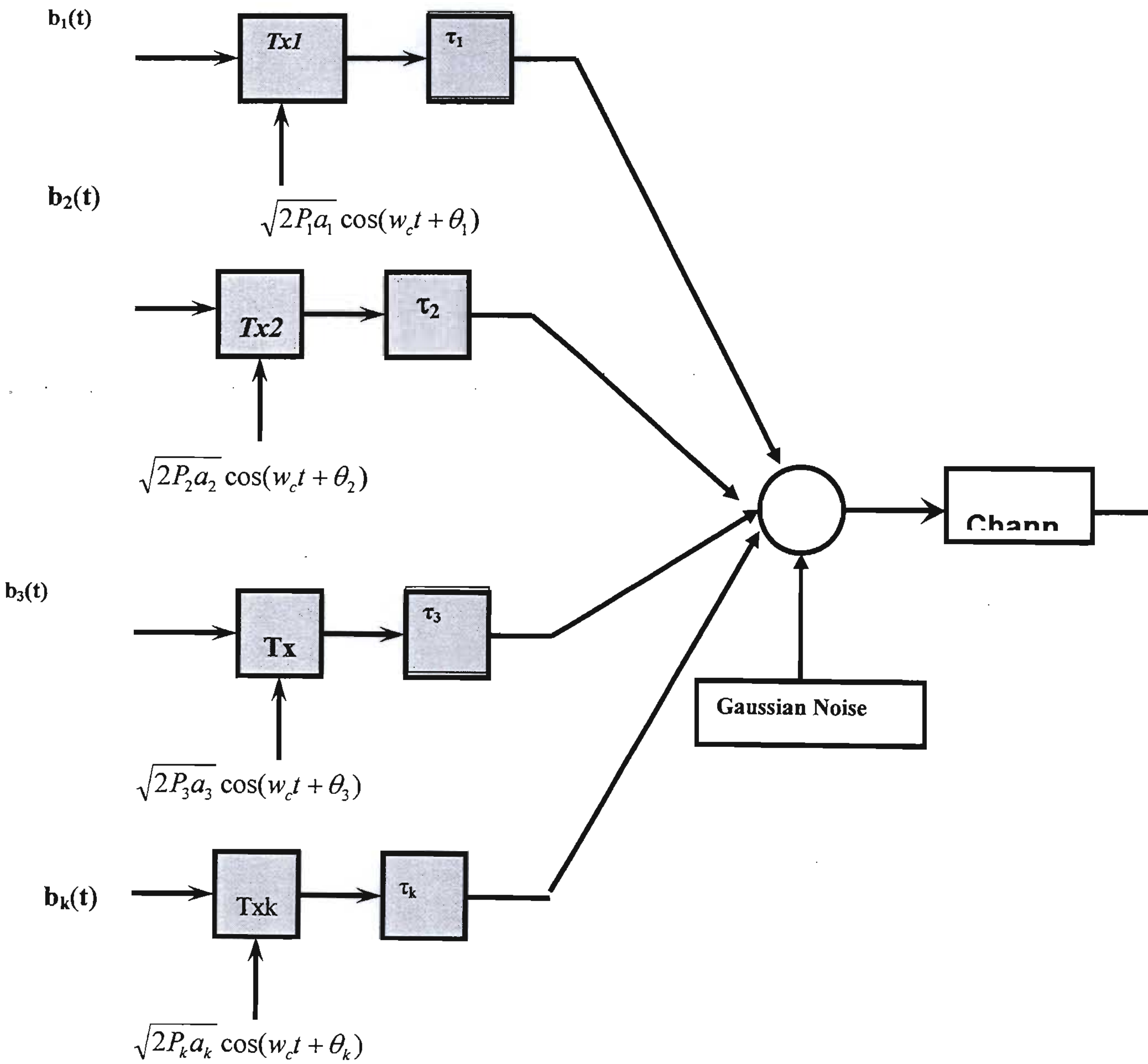

Figure 33: DS CDMA system model

Let us consider a data signal

$$b_k(t) = \sum_{i=-\infty}^{\infty} b_{k,i} p_T(t - iT) \tag{4.22}$$

where $b_{k,i}$ is the ith data bit transmitted by the k^{th} user during the interval [iT, (i+1)T] and $b_{k,i}$ is equiprobable. Lets consider the spreading signal be

$$a_k(t) = \sum_{j=-\infty}^{\infty} a_{k,j} p_{T_C}(t - jT_C) \tag{4.23}$$

where, $a_{k,j} \in \{\pm 1\}$ is the *j*th chip of the *k*th user, and each rectangular chip pulse has duration T_c is the Processing gain $N = \frac{T}{T_c}$. The signal $s_k(t)$ transmitted by the *k*th user is given by,

$$s_k(t) = \sqrt{2P_k}\, a_k(t) b_k(t) \cos(\omega_C t + \theta_k) \tag{4.24}$$

where P_k is the signal power and θ_k is the phase respectively of the *k*th user, and ω_c is the common carrier frequency. The receiver signal $r(t)$ is given by,

$$r(t) = n(t) + \sum_{k=1}^{K} s_k(t - \tau_k) \tag{4.25}$$

Let us take

$$s_k(t - \tau_k) = \sqrt{2P_k}\, a_k(t - \tau_k) b_k(t - \tau_k) \cos(\omega_C (t - \tau_k) + \Phi_k) \tag{4.26}$$

where phase of one user is taken as a reference. Then decision statistics:

$$Z_{1,0} = \int_0^T r(t) a_1(t) \cos(2\pi f_c\, t) dt \tag{4.27}$$

Since the received signal is given by:

$$r(t) = s_1(t) + n(t) + \sum_{k=2}^{K} s_k(t - \tau_k) \tag{4.28}$$

We can rewrite the decision statistics as:

$$Z_{1,0} = I_1 + \eta + \sum_{k=2}^{K} I_k \qquad (4.29)$$

where,

Desired user's signal: $$I_1 = \int_0^T s_1(t) a_1(t) \cos(2\pi f_c t) dt \qquad (4.30)$$

Noise: $$\eta = \int_0^T n(t) a_1(t) \cos(2\pi f_c t) dt \qquad (4.31)$$

Multiple access interference (MAI) from user k:

$$I_k = \int_0^T s(t - \tau_k) a_1(t) \cos(2\pi f_c t) dt \qquad (4.32)$$

After manipulation we get the desired signal,

$$I_1 = \sqrt{\frac{P_1}{2}} T \qquad (4.33)$$

Since noise is a Gaussian random process it has a mean zero and variance $N_o T/4$
After some manipulation the multiple access interference becomes,

$$I_k = \sqrt{\frac{P_k}{2}} \cos(\theta_k) \int_0^T b_k(t - \tau_k) a_k(t - \tau_k) a_1(t) dt \qquad (4.34)$$

It is noted that the bit $b_{1,0}$ from user 1 overlaps in time with bits $b_{k,-1}$ and $b_{k,0}$ from k user.

$$I_k = \sqrt{\frac{P_k}{2}}\cos(\theta_k)\left[b_{k,-1}\int_0^{\tau_k} a_k(t-\tau_k)a_1(t)dt + b_{k,0}\int_{\tau_k}^{T} a_k(t-\tau_k)a_1(t)dt \right] \quad (4.35)$$

Lets now divide the delay τ_k into two components:

$$\tau_k = \lambda_k T_c + S_k \quad (4.36)$$

Where:

$$\lambda_k = \left\lfloor \frac{\tau_k}{T_c} \right\rfloor \quad \text{(Integer \# of chips in delay)}$$

$$S_k = \tau_k - \lambda_k T_c$$

The capacity in a CDMA is interference limited and the performance degrades for all the users as new users are added. The capacity performance of a CDMA system with users of different spreading factors is given as:

$$\frac{E_b}{N_o} = \frac{P \times (SF)}{P_i \times (N-1) + Noise} \quad (4.37)$$

where P is the average power of the desired user, P_i is the power of the other user that is seen as interference, SF is the spreading factor and N is the number of users.

The forward link of the CDMA system modelled uses orthogonal Walsh (PN codes) codes to separate the users. Each user is randomly allocated a Walsh code to spread the data to be transmitted. The transmitted signals from all the users are combined together, then passed through a radio channel model. This allows for adding multipath interference, and adding white Gaussian noise to the signal.

The receiver uses the same Walsh code that was used by the transmitter to demodulate the signal and recover the data. After the received signal has been dispread using the Walsh code, it is sub-sampled back down to the original data rate. This is done by using an integrate-and-dump filter, followed by a comparator to decide whether the data was a 1 or a 0. The received data is then compared with the original data transmitted to calculate the bit error rate (BER).

4.5.1 CDMA SYSTEM PERFORMANCE

The spreading- dispreading operation does not affect the noise spectral and probability density function. For this reason, the bit error probability P_e associated with the coherent QPSK spread spectrum signal is the same as with the QPSK signal in AWGN channel if there is no multiple access interference (MAI) and is given by [11]:

$$P_e = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_o}}\right) = Q\left(\sqrt{2\frac{E_b}{No}}\right) \tag{4.38}$$

Where multi-access interference is taken into account, the BER has been shown to be [18]:

$$P_e = Q(\overline{SNR}) \tag{4.39}$$

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{\frac{u^2}{2}} du \tag{4.40}$$

$$\overline{SNR} = \sqrt{\frac{P_k}{Var\{MAI\} + Var\{AWGN\}}}$$

(4.41)

$$= \sqrt{\frac{1}{\frac{(K-1)}{3G}\left(1 - \frac{1}{4G}\right) + \frac{N_o}{2E_b}}}$$

where K is the total simultaneous number of users in a network, G is the processing gain and $\frac{E_b}{N_0}$ is the AWGN value. It can be seen that if the number of active users, K, is low the average SNR increases. This feature can be used to compensate either for increased coverage or decrease in the bit energy E_b for same BER. For the multipath summation, we obtain an approximation for the SNR to be

$$SNR = \sum_{l=1}^{L} \beta_l \sqrt{\frac{1}{\frac{(K-1)}{3G}\left(1-\frac{1}{4G}\right)+\frac{N_o}{2E_b}}} \tag{4.42}$$

4.6 CDMA HANDOFF

CDMA has 3 primary types of handoff, namely: Soft, Hard and Idle

4.6.1 SOFT HANDOFF

A soft handoff establishes a connection with the new base station prior to breaking the connection with the old one. This is possible because CDMA cells use the same frequency and because the mobile uses a rake receiver. The CDMA mobile assists the network in the handoff. The mobile detects a new pilot as it travels to the next coverage area. The new base station then establishes a connection with the mobile. This handoff is also called **make-before-break.**

4.6.2 HARD HANDOFF

A hard handoff requires the mobile to break the connection with the old base station prior to making the connection with the new one. CDMA phones use a hard handoff when moving from a CDMA system to an analogue system because soft handoff is not possible in analogue systems. Usually a pilot unit at the analogue cell site alerts the phone that it is reaching the edge of CDMA coverage. The phone then switches from digital to analogue mode. This mode is also called **break-before-make.**

4.6.3 CDMA IDLE HANDOFF

An idle handoff occurs when the phone is in idle mode. The mobile will detect a pilot signal that is stronger than the current pilot. The mobile is always searching for the pilots from any neighbouring base station. When it finds a stronger signal, the mobile simply begins attending to the new pilot. This handoff occurs without any assistance from the base station.

4.7 LIMITATIONS OF A CONVENTIONAL CDMA SYSTEM

A conventional CDMA system treats each user separately as a signal, with other users considered as either interference known as Multiple Access Interference (MAI) or noise. The detection of the desired signal is protected against the interference due to the other users by the inherent interference suppression capability of CDMA, measured by processing gain. Simply there two major limitations present to CDMA:

1. All users interfere with all other users and the interferences add to cause performance degradation.
2. The near far problem is serious and tight power control, with little complexity, is needed to combat it.

4.8 CDMA CAPACITY

TDMA and CDMA are said to be emerging as clear digital technology choices for the wireless local loop environment. There are a number of unique features and benefits of CDMA technology over TDMA and FDMA in mobile and fixed radio environment.

CDMA has a frequency reuse of 1 and its capacity can be expressed as [14]

$$M = \frac{G_p}{(E_b / N_0)} \times \frac{1}{1+\beta} \times \alpha \times \frac{1}{v} + 1 \qquad (4.43)$$

where:

G_p = gain = B/R

B = total bandwidth = 1.2288 MHz

R = transmission rate = 9.6 kbps

β = Interference from neighbouring cells = 0.5

α = Power control accuracy factor = 0.85

v = voice activity factor = 0.6

Due to the above facts, CDMA system remains the best candidate for rural application due to the following reasons [14]:

- CDMA systems can overlay other systems and services already in place without much interference
- The lower sensitivity levels imply significant extension of the coverage range
- Due to the low-density traffic nature of rural telecommunications, CDMA will not suffer much from co-channel interference that causes Multiple Access Interference (MAI) and therefore simple multi-user detectors such as MAI Cancellers can be used with satisfactory results.

This research is based on rural areas and it is very clear from this work that rural traffic is low compared to urban traffic, so we are not going to deal with WCDMA in rural areas. WCDMA is a high bandwidth system and is not necessary in rural areas at this point in time. Instead of WCDMA, CDMA is considered and maybe at a later stage when bandwidth becomes an issue in rural areas, the former can be considered.

4.9 COST COMPARISON BETWEEN CDMA AND GSM

The cost of wire line technologies is usually more compared to the wireless technology [17]. The major reason for this is the fact that conductors that are used in signal transportation are usually expensive. Copper is a commonly used conductor in South Africa. Imagine the cost of a 100 Km copper cable and the cost of deploying. In South Africa we have a serious problem of cable theft and the service provider is forced to use underground cabling to avoid this. This will definitely adds more to overall cost. In spite of this, underground cables are still dug out and stolen, thus making wireless technologies ideal.

The cost of deploying wire line technology in Kwazulu-Natal will be more expensive because Kwazulu-Natal has heavy vegetation and is very hilly. The cost comparison will be done between WCDMA and GSM. The GSM is currently used in the country, but because of telecommunication evolution moving towards 3G we will compare GSM with WCDMA, which is a 3G technology. CDMA is a narrowband version of WCDMA and is 2.5G system. CDMA can accommodate mobile users and fixed mobile users. Due to the above advantages CDMA, we feel that CDMA is a better system for rural Kwazulu-Natal.

GSM is chosen because it has footprints in many countries in the world including South Africa. Radio coverage influences the propagation measurements in rural environment [18]. Parameters that will be considered are fade margin, path loss and market penetration.

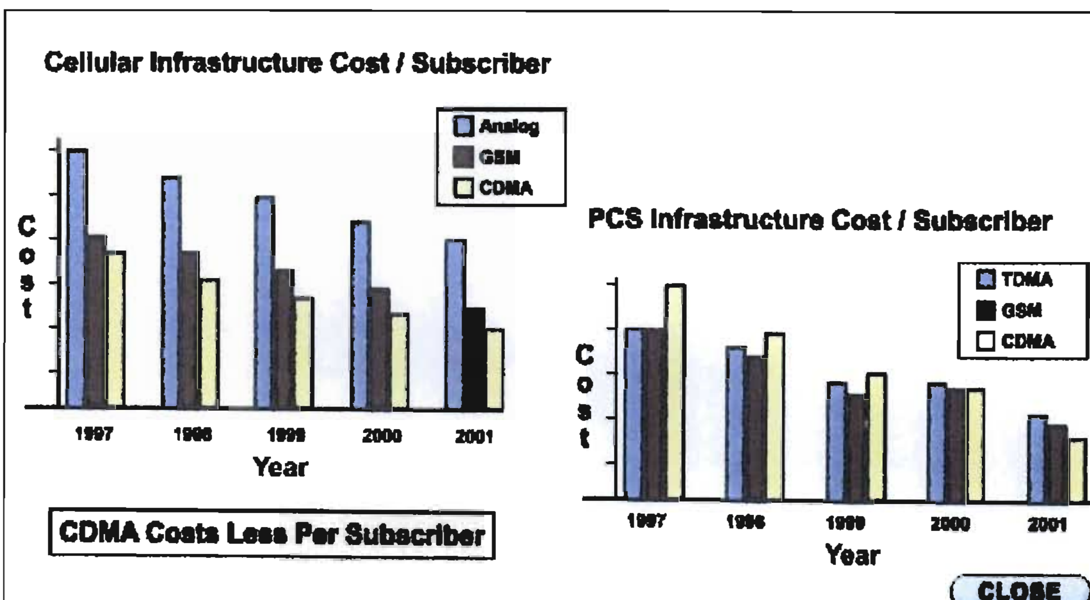

Figure 34: Costs comparison between CDMA and GSM systems

Figure 34 above shows that CDMA system is superior in infrastructure cost compared to GSM.

4.9.1 FADE MARGIN

The Strategic Wireless Analysis Tool (SWAT) is used for this study. SWAT is a feature rich PC-based software system developed by Telcordia Applied Research for the technical and economic analysis and planning of wireless networks [18]. In this section WCDMA is compared to GSM system, but in our rural area CDMA system will actually be deployed. This is due to the fact that we do not need a wideband system in a rural area because of its spatiality in population.

The assumption here is that we receive 5 calls per month each lasting 5 minutes, this can be represented in Minute of Use (MOU) = 25 min/month. The penetration rate is assumed to be 50% and fade margin of 10 dB. In these analysis path loss exponents of 4.2, 5.3 and 7.2 are analysed.

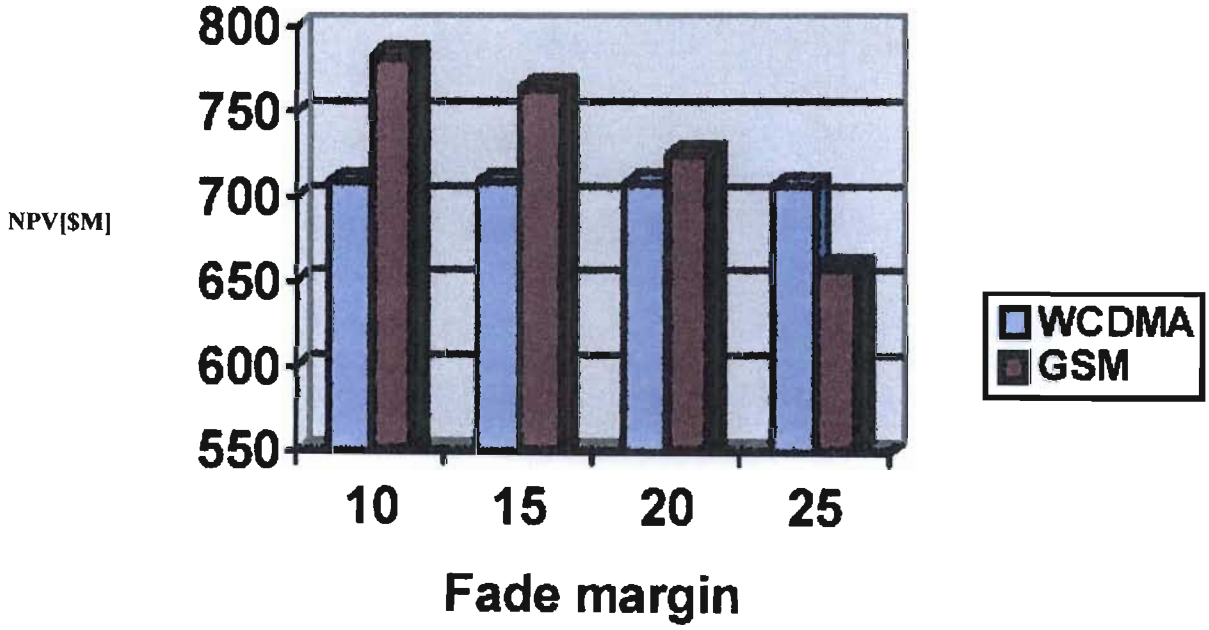

Figure 35a: Effect of fade margin: Minute of Use (MOU) = 25, per minute usage charge = $0.5, path loss exponent, $\alpha = 4.2$ [18]

Figure 35a above shows that the number of base stations required for WCDMA system and the corresponding Net Value Profit (NPV) remains the same as the fade margin increases while the number of GSM base stations increases. It implies that the WCDMA systems are in a capacity limited case, and the decrease in the link budget does not affect the number of base stations. On the other hand, GSM systems are very sensitive to the increase of fade margin hence the number of base stations increases.

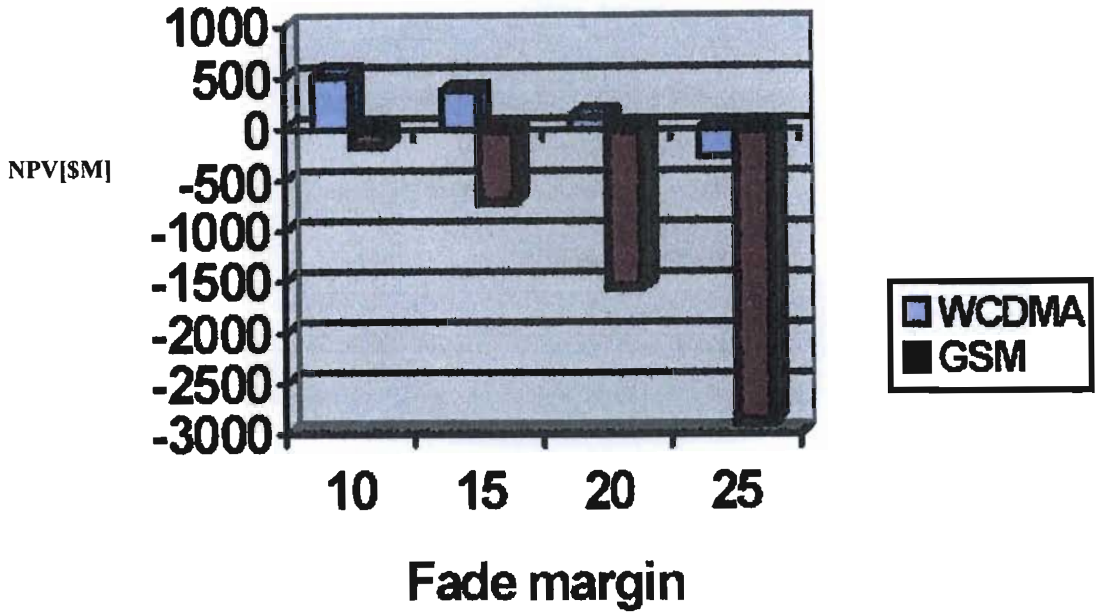

Figure 35b: Effect of fade margin: Minute of Use (MOU) = 25, per minute usage charge = $ 0.5, path loss exponent, $\alpha = 5.3$ [18].

Figure 35b above shows that both systems are in coverage-limited scenario, but WCDMA base station count is less than GSM base station count. 5 dB increase of fade margin increases the number of base stations for both systems by bout 1.5 times the original number of base stations [18].

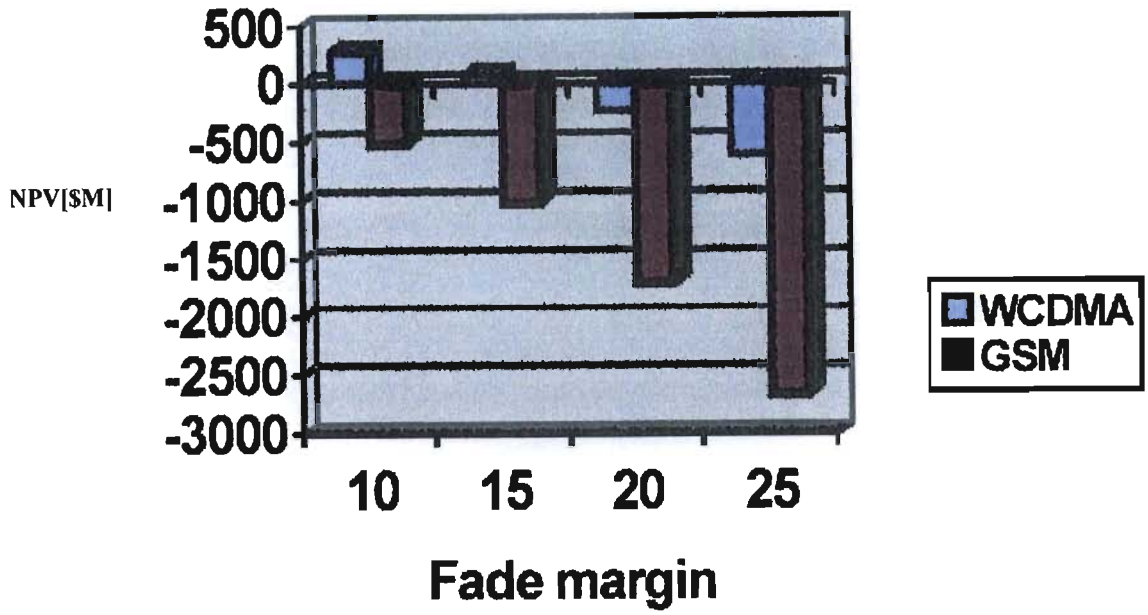

Figure 35c: Effect of fade margin: Minute of Use (MOU) = 25, per minute usage charge = $ 0.5, path loss exponent, α = 7.2 [18].

4.9.2 PATH LOSS EXPONENT

Path loss exponents reflect the degree of propagation difficulties. The smaller path loss exponents imply the longer the radio signals can travel, which will results in a wider coverage area. In figure 19c, path loss exponent of 7.2 is used which indicates that both the GSM and WCDMA systems are in coverage limited, because the radio signal travels a small distance. GSM base stations count is 2.44 times of the WCDMA base station count. For every 5 dB increase of fade margin, the numbers of base stations increases to about 1.3 times of the original in both systems.

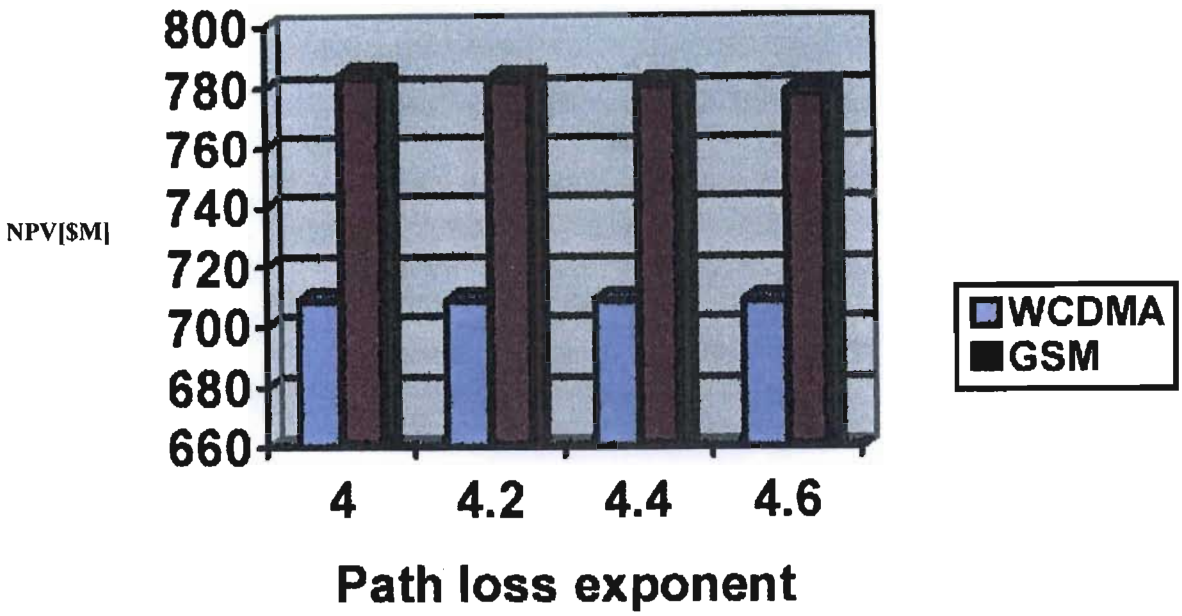

Figure 35d: Effect of path loss exponent: Minute of Use (MOU) = 25, per minute usage charge = $0.5, path loss exponent, $\alpha = 4.2$ [18].

It has been observed that for smaller path loss exponents, GSM technology requires fewer base stations than WCDMA technology. This thus means GSM system outperforms WCDMA systems in terms of profitability. When the propagation environment becomes difficult, WCDMA systems are better than GSM system. This is due to the fact that WCDMA requires less receiver sensitivity and has a wider coverage area.

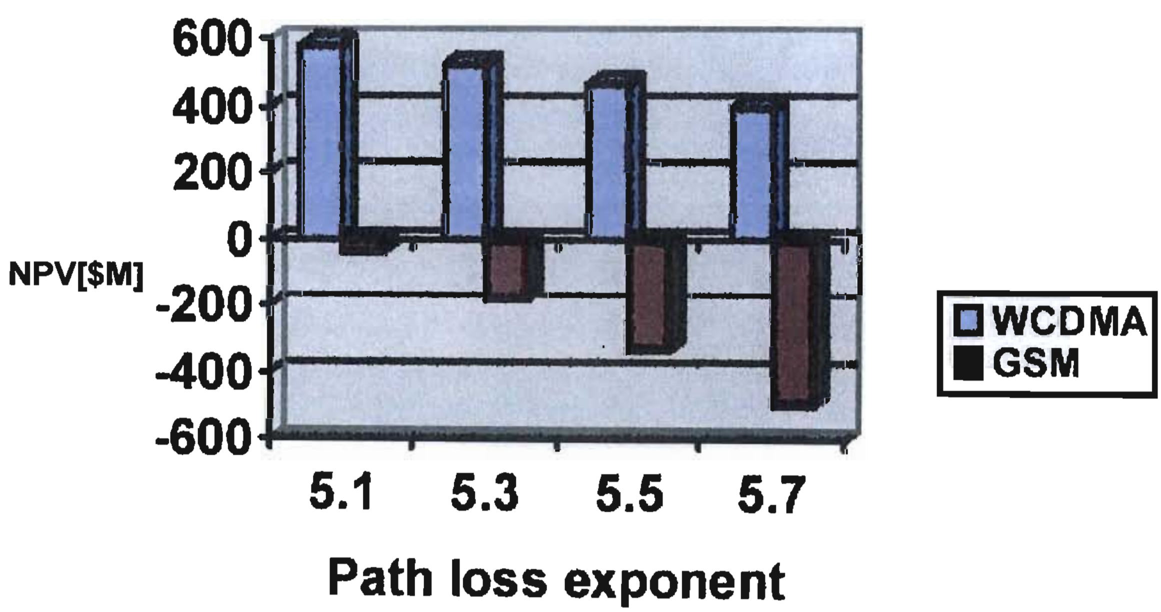

Figure 35e: Effect of path loss exponent: Minute of Use (MOU) = 25, per minute usage charge = $0.5, path loss exponent, α = 5.3 [18].

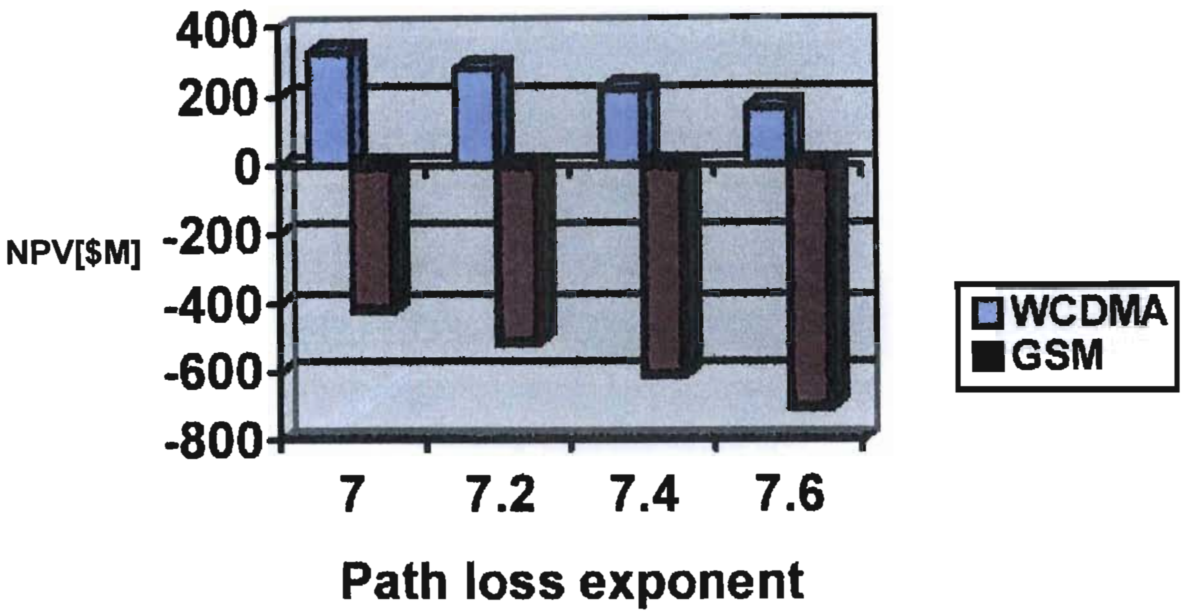

Figure 35f: Effect of path loss exponent: Minute of Use (MOU) = 25, per minute usage charge = $0.5, path loss exponent, α = 7.2 [18].

4.9.3 PENETRATION RATE

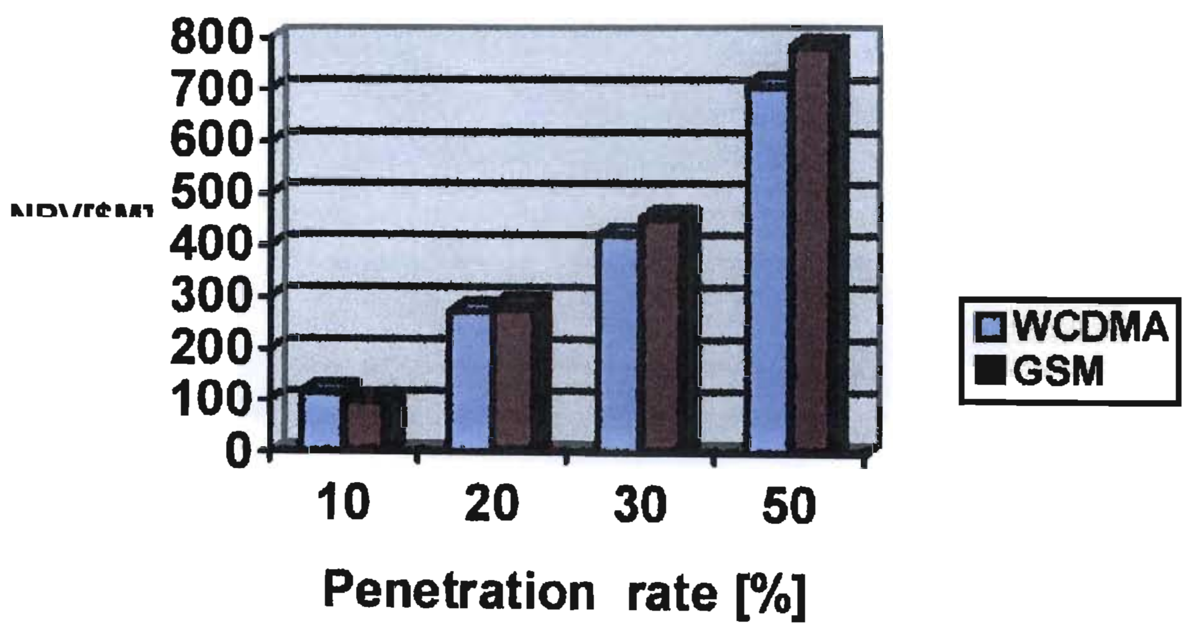

Figure 35g: Effect of path loss exponent: Minute of Use (MOU) = 25, per minute usage charge = \$0.5, path loss exponent, $\alpha = 4.2$ [18].

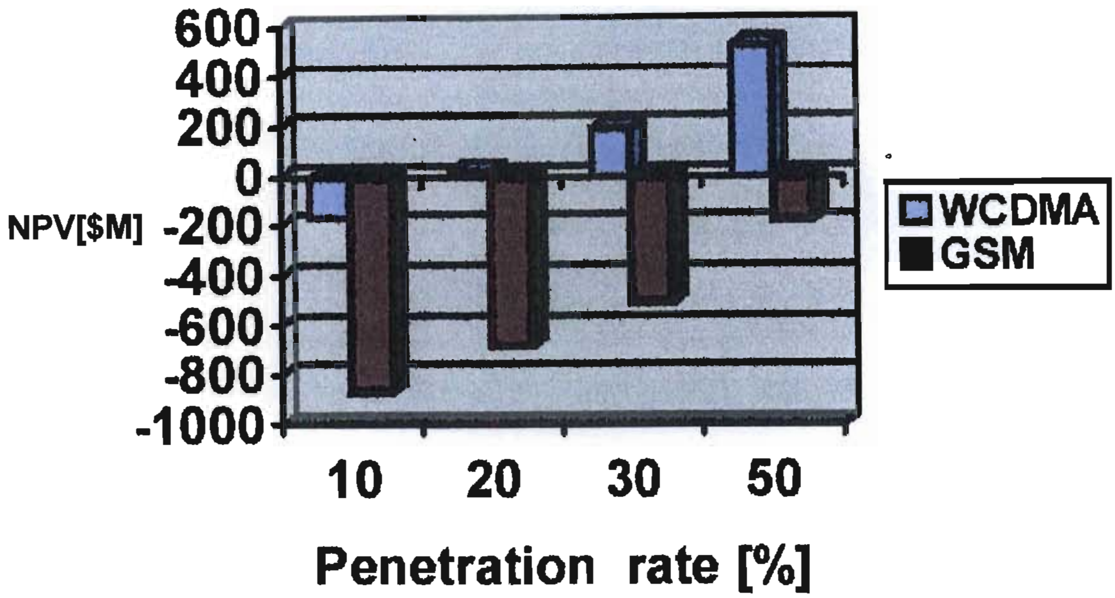

Figure 35h: Effect of path loss exponent: Minute of Use (MOU) = 25, per minute usage charge = \$0.5, path loss exponent, $\alpha = 5.3$ [18].

In terms of revenue, both WCDMA and GSM systems make fairly good profits in an environment with path loss exponent of 4.2. GSM systems perform slightly better at the high end of the penetration rates. When the path loss exponent increases, GSM system can hardly make any profit and performs worse than WCDMA systems.

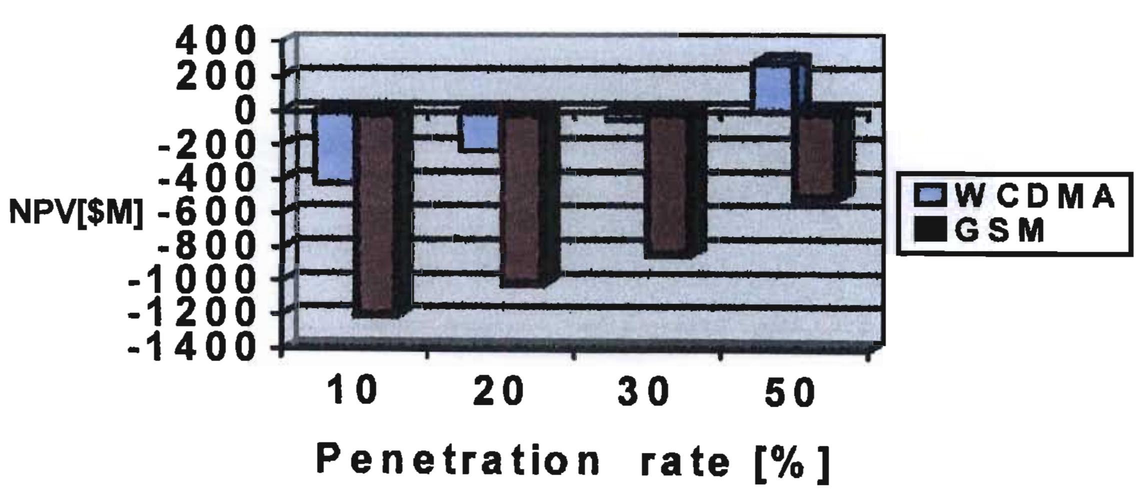

Figure 35i: Effect of path loss exponent: Minute of Use (MOU) = 25, per minute usage charge = $0.5, path loss exponent, α = 7.2 [18].

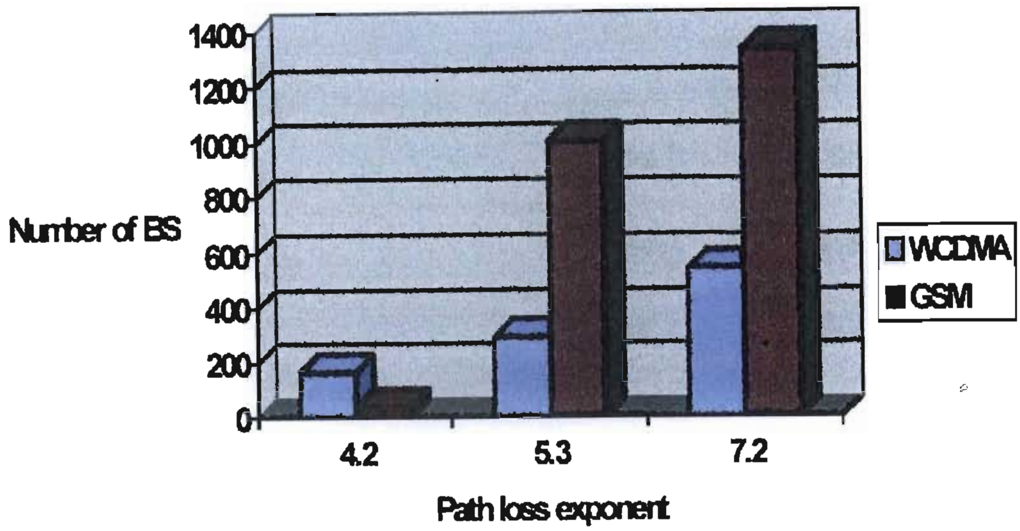

Figure 35j: Numbers of Base Stations, 25 MOU [18]

In Figure 35i, WCDMA systems are making profits with penetration rates of 30% and 50% in an environment of path loss exponent of 5.3 while the GSM systems remain in deficit. Only WCDMA system can make profits in an environment of path loss exponent of 7.2 and only with penetration rate of 50%. This implies that WCDMA systems are preferable in a difficult propagation environment.

In Figure 35j shows the relationship between the number of base station required verse path loss exponent. For the path loss exponent of 4.2, WCDMA system requires about 200 base stations while GSM system requires just under 100 base stations. The situation changes when the path loss exponent is increased to 5.3 and 7.2. At path loss exponent of 5.3, GSM system requires about 1000 base station while WCDMA requires 300 base stations. At path loss exponent of 7.2 GSM system requires 1300 base stations as compared to 600 base station required by WCDMA system. This result is very important because it means GSM system will be very expensive to deploy, because of the number of base stations required as compared to WCDMA system.

4.10 CHAPTER CONCLUSIONS

The capacity of a CDMA system is not fixed, but depends on the quality of service needed. More voice users can be accommodated because quality of service is not too important than for multimedia services.

A GSM system performs better than CDMA system for fade margin of 20dB and above for the path loss exponent of 4.2. When the path loss exponent is increased, CDMA system performs better. CDMA system performs better for penetration rate of less than 50% for the path loss exponent of 5,3 and above. The number of base stations needed for GSM is almost double the ones needed for CDMA system

Therefore CDMA system will definitely perform far better than GSM system in rural Kwazulu-Natal because the path loss exponent of Kwazulu-natal is greater than 4.2.

CHAPTER 5

PERFORMANCE EVALUATION OF THE CDMA SYSTEM IN A RURAL ENVIRONMENT

In this chapter we are investigating the performance of a CDMA system in a rural environment. The capacity of a CDMA system can be increased by modifications to the detector. In this project simulations are performed using MATLAB software. The simulation will only be done on an uplink because it is asynchronous in nature.

5.1 CDMA SYSTEM DESIGN FOR RURAL KWAZULU-NATAL

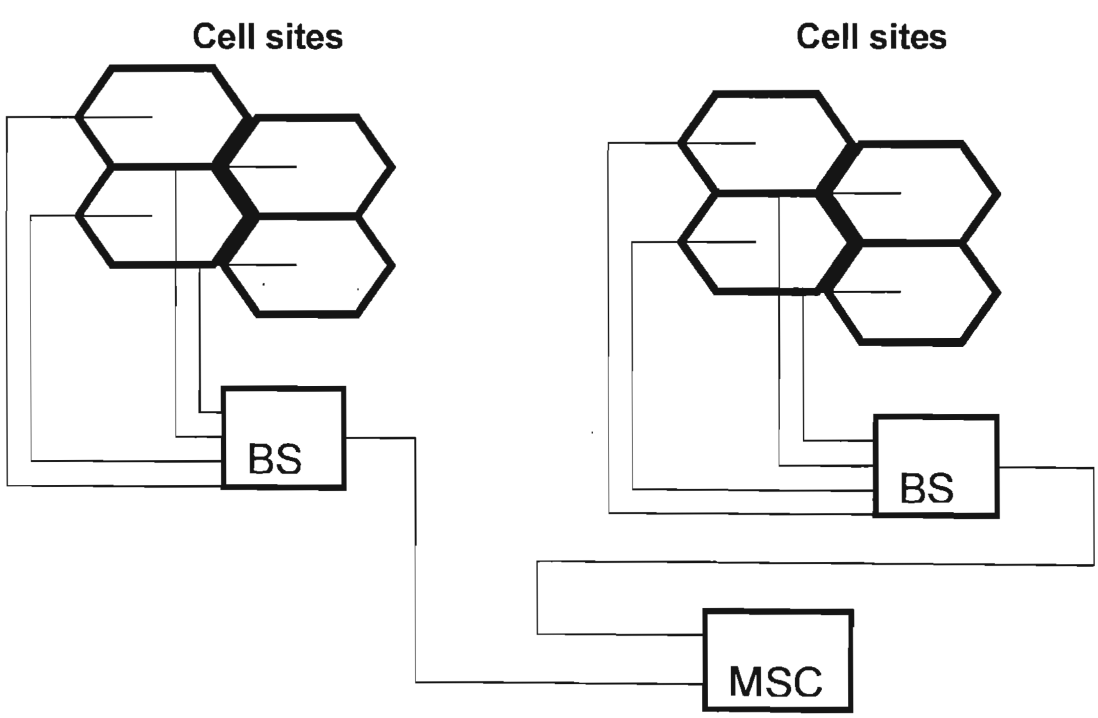

Figure 36: Four-level structure for Kwazulu-Natal

Figure 36 above shows the system design of a CDMA system in a rural Kwazulu-Natal area. This type of network is called four-layer network with end user being the first layer. The network starts with the user making a call that will go through the base station, base station controller (BSC) and finally mobile station controller (MSC) for switching. The mobile station control switches the users request to the required base station controller and finally to the next base station. This type of network can be represented as figure 37 below.

Base stations can be connected to the base station controller through copper cables. The size of the cable can be 1.554 Mbps link since the rural traffic is less. This link can be changed to 2.048 Mbps later when the traffic generated from this areas increases. In urban areas where speed is essential, service providers are using optical fiber links to connect base stations to base station controller and mobile station controller. Base station controller is connected to the mobile station controller using a 2.048 Mbps link.

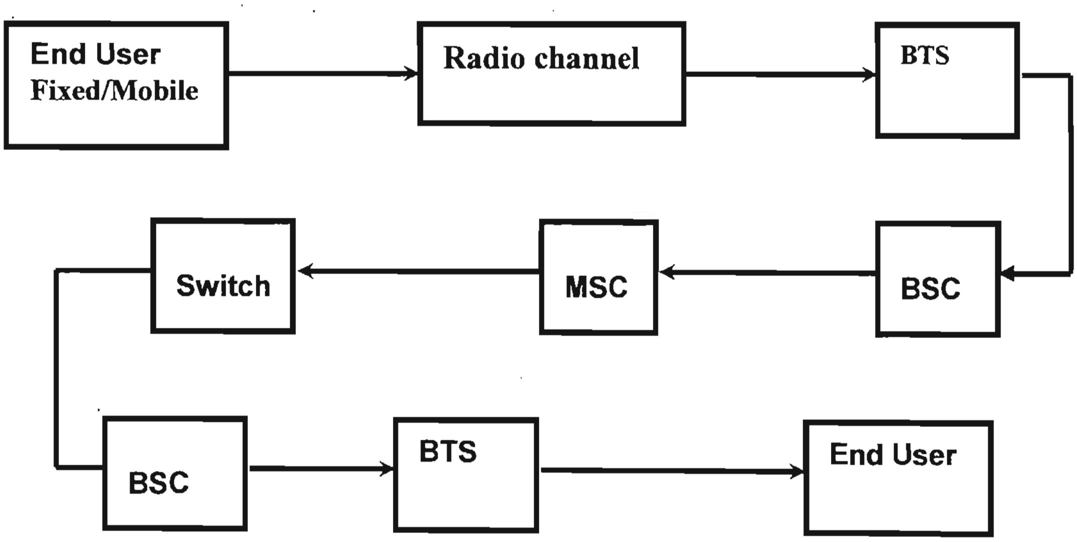

Figure 37: Call processes from one user to the next user

5.1.1 CDMA COVERAGE IN RURAL KWAZULU-NATAL

A hexagon diagram gives the theoretical cell coverage for a base station. The cell area for this hexagon is given by $\mathbf{2.598R^2}$. Practically it is impossible to have hexagonal cell coverage, usually cell area is in a circular form and the cell area is given by $\boldsymbol{\pi R^2}$. These expressions will help us to calculate the estimated traffic that can be generated from our rural areas.

Kwazulu-Natal has population density of about 105 persons per km^2 and the land area of 92 100 km^2. In Kwazulu-Natal, 57% of the population resides in rural areas. This means 52 497 km^2 land area in Kwazulu-Natal is rural. Correspondingly traffic is 0.2 Erlang per km^2. Traffic in Erlang is calculated as follows:

There are two services of primary importance, voice and data services. Our voice call rate is 0.02 calls/hour with average holding time of 5 minutes and an average data call rate of 0.02 calls/hour and a holding time of 5 minutes. BER is 0.0001 and $P_B = 2\%$. Voice service of 14.4 kbps at 50% of activity and data at 64 kbps at a duty cycle of 100% and activity of 10%.

Erlang per customer = [call rate $\times$ minute of use $\times$ activity factor] + [call rate $\times$ minute of use $\times$ activity factor].

$$E = \left[0.02 \times \frac{5}{60} \times 0.5\right] + \left[0.02 \times \frac{5}{60} \times 0.1 \times 6.4\right] \tag{5.1}$$

$$= 1.9 \times 10^{-3} \text{ per customer}$$

Coverage Area = πR^2

Total population = Coverage Area $\times$ number of persons per Km^2

Maximum Traffic Generated = Total population $\times E$

The **number of trunks** is checked from the tables (blocked-Calls-Cleared)

BS Coverage (radius) **km**	Coverage Area **Km^2**	Total Population **(persons/km^2)**	Maximum Traffic generated **(Erlang)**	Equivalent number of trunks
2.5	19.63	2061.15	3.916	9
3	28.27	2968.80	5.64	11
5	78.54	8246.71	15.66	23
7.5	176.71	18554.55	35.25	45
10	314.17	32986.80	62.67	74
15	706,86	74220.30	141.02	155

Table 11: Estimated traffic from rural Kwazulu-Natal

Total number of cells in rural Kwazulu-Natal area:

$$N_C = \frac{CoverageArea}{\pi R^2}$$

$$= \frac{52497}{\pi(7.5)^2}$$

$$\approx 298 \text{ Cells}$$

N_C is the total number of cells required for rural Kwazulu-Natal

where *Coverage Area* = 52 497 km^2

R is the cell radius in Km

R is chosen to be 7.5 km for a rural area.

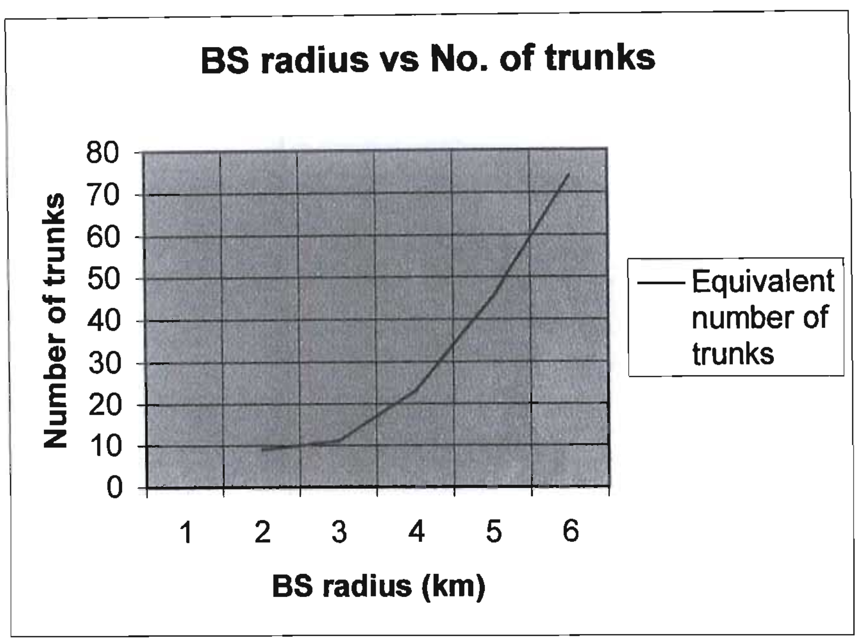

Figure 38: Number of trunks vs. Base station radius

Figure 38 above shows the relationship between the base station radius against the equivalent number of trunks. As the radius increases, the number of trunks that can be supported also increases. This relationship is exponential, which is very clear from the graph that when we increase the radius by 1 km, the number of trunk line increases drastically. From 4km to 5km radius the trunk lines increases from about 35 to 60.

When we assume 25 minutes of usage, that is, 5 calls per month each lasting 5 minutes at a path loss constant of 5.3 and vary the penetration rate from 10 to 50%. CDMA starts making visible profits at a penetration rate of 30%. This is not bad because in that period GSM performs far badly. If fact GSM starts making profit at a penetration rate that is greater than 50%. Even with that in mind we still find GSM in other rural areas. For that reason it is reasonable that CDMA should be given a chance in rural areas.

Due to the spatiality nature of rural area, the number of users generated is less compared to urban areas. This means we will generate few mobile users and keep base stations fixed. This is done to help us calculate the overall power required to the base station. The area that we chose to work on is 50km length and 30km in width. This will give us $50km \times 30km = 1500km^2$. We then calculate number of base stations for 1500 km^2, which comes to 9 base stations. See table 11 and figure 41.

But from table 11, 1 base station has about 45 trunks, which means we have about 405 trunks for 9 base stations in 1500km^2 coverage area. In the simulations we will generate 15 base stations and 675 users. Since 9 base stations have about 405 trunk lines, 15 base stations have about 675 trunks. We choose propagation constant $\boldsymbol{n} = 5.3$ to suite our rural environment, now we can calculate the overall power at the base station. Noise power is set to be $\sigma^2 = 10^{-12}$ watts.

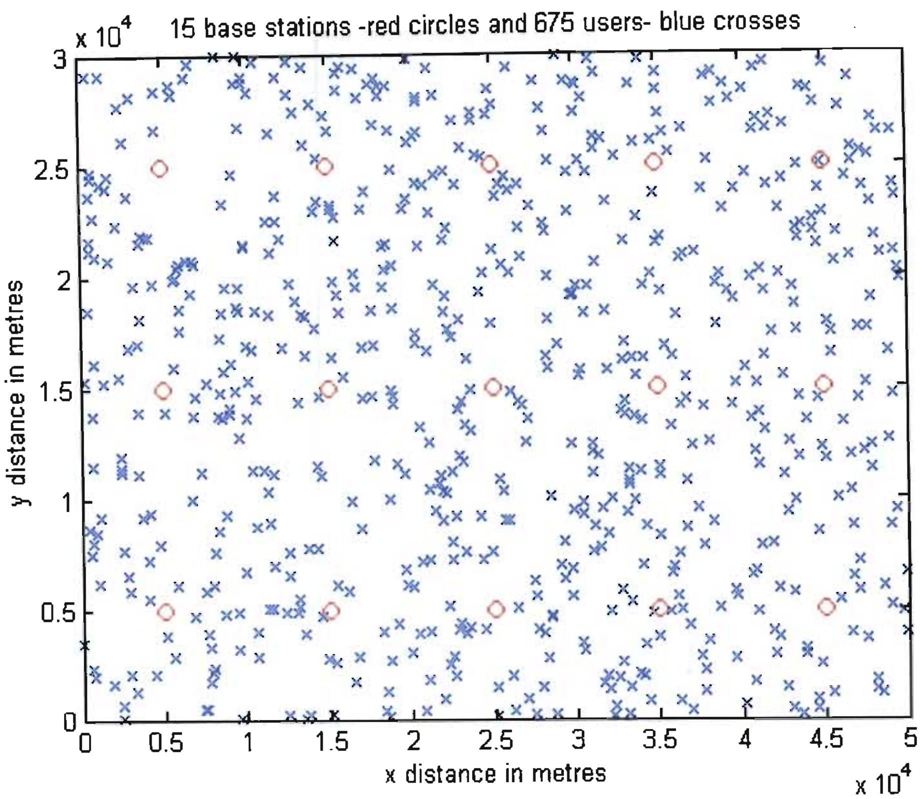

Figure 39: Generated base stations and mobile users

Each user is assigned to the its nearest base station. The channel gain h_{ij} is calculated as

$$h_{ij} = \frac{1}{d_{ij}^{\alpha}} \qquad (5,2)$$

where d_{ij} is the distance between user j and the base station of user I and α is the path loss exponent and is chosen as 5.3 in the simulations. The processing gain G is chosen to be 63 in this simulation. A randomly generated signature sequence of length G is assigned to each user. In this simulation, the aim is to show that the total transmitting power for less mobile nodes converges faster than the total transmission power for large mobile nodes.

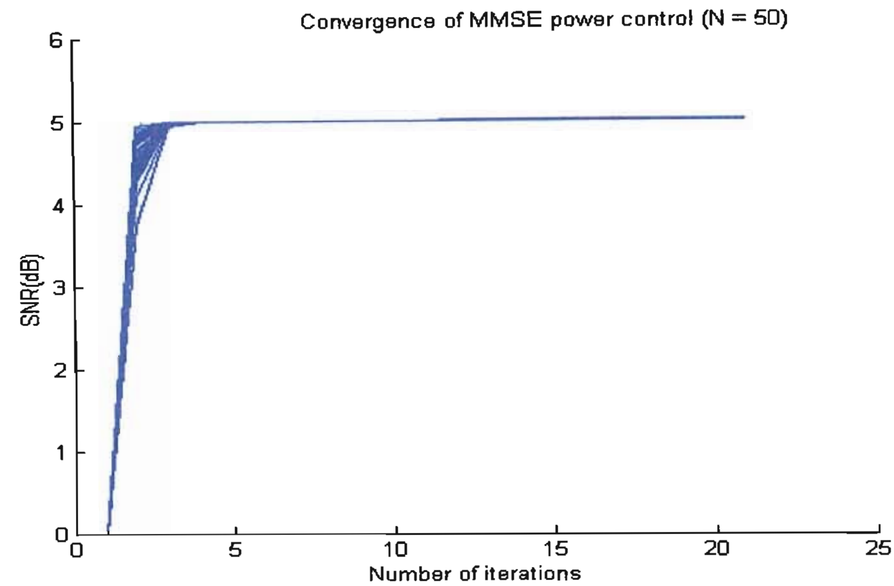

Figure 40a: Convergence of MMSE power control algorithm for 50 users

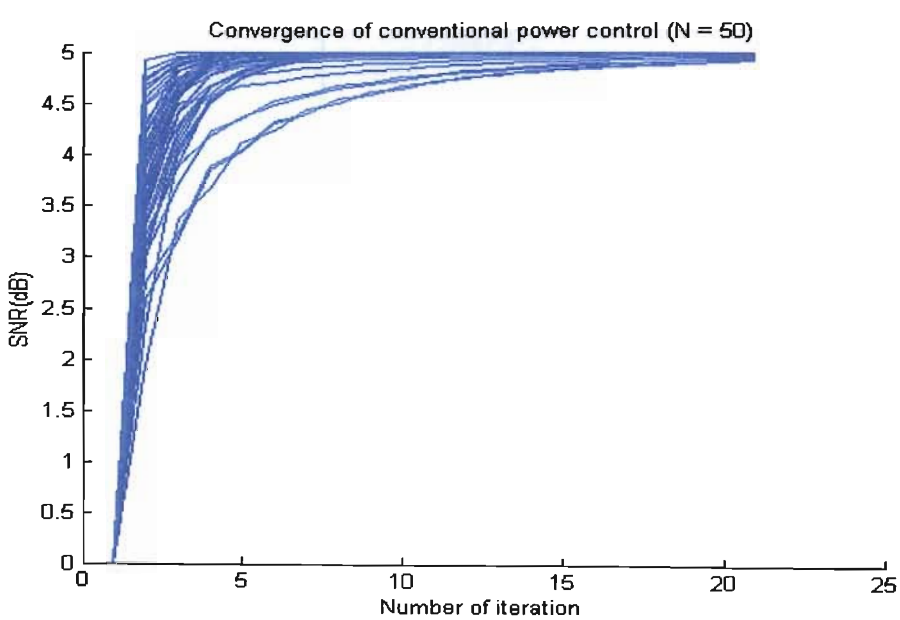

Figure 40b: Convergence of conventional power control algorithm for 50 users

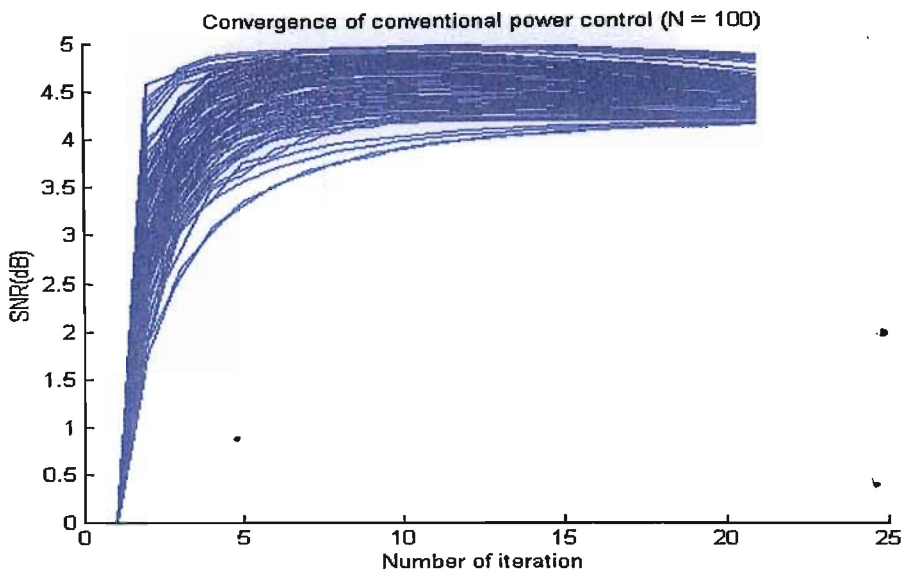

Figure 40c: Convergence of conventional power control algorithm for 100 users

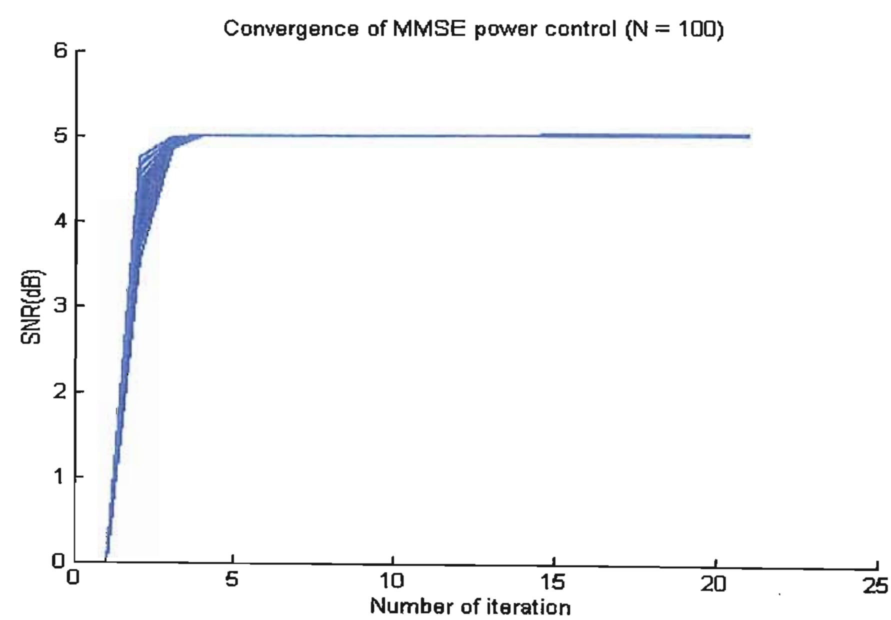

Figure 40d: Convergence of MMSE power control algorithm for 100 users

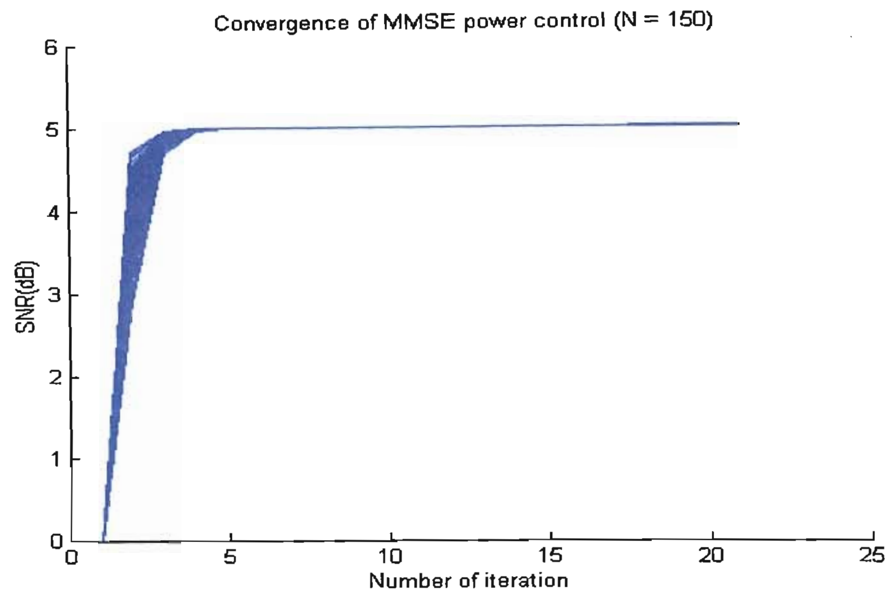

Figure 40e: Convergence of MMSE power control algorithm for 150 users

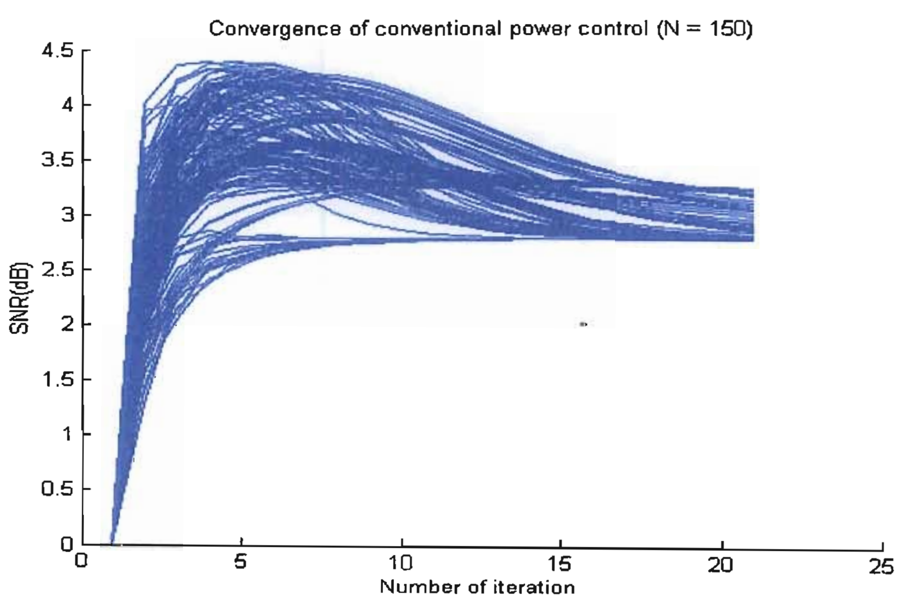

Figure 40f: Convergence of conventional power control algorithm for 150 users

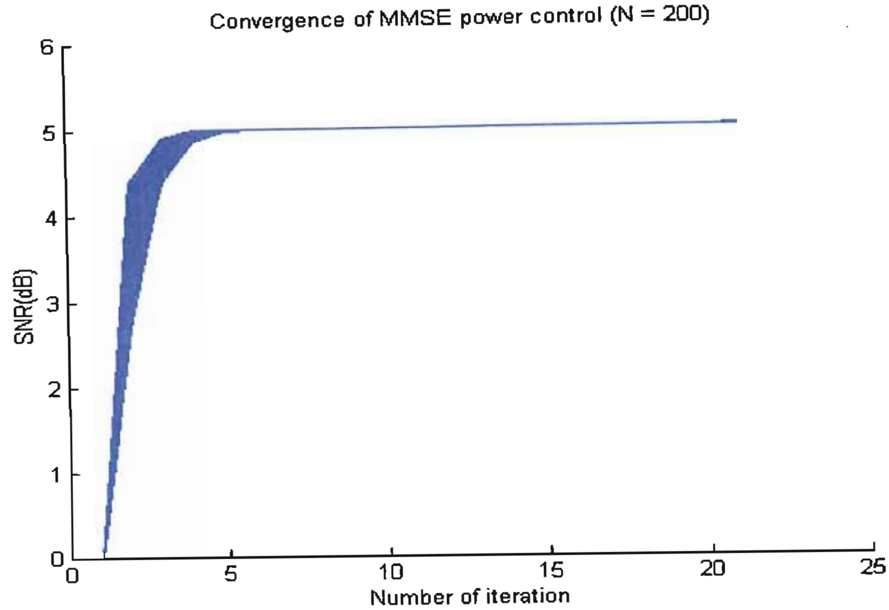

Figure 40g: Convergence of MMSE power control algorithm for 200 users

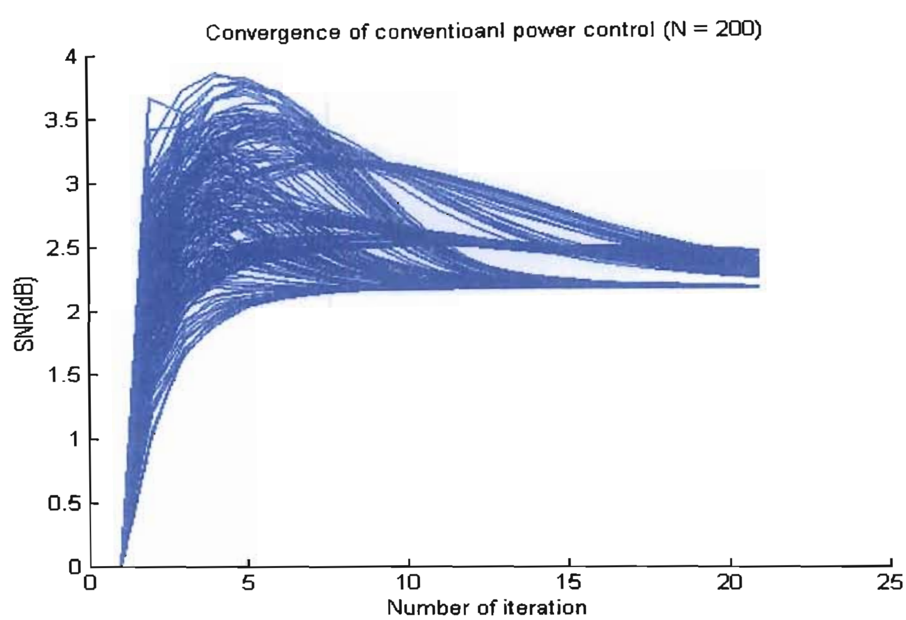

Figure 40h: Convergence of conventional power control algorithm for 200 users

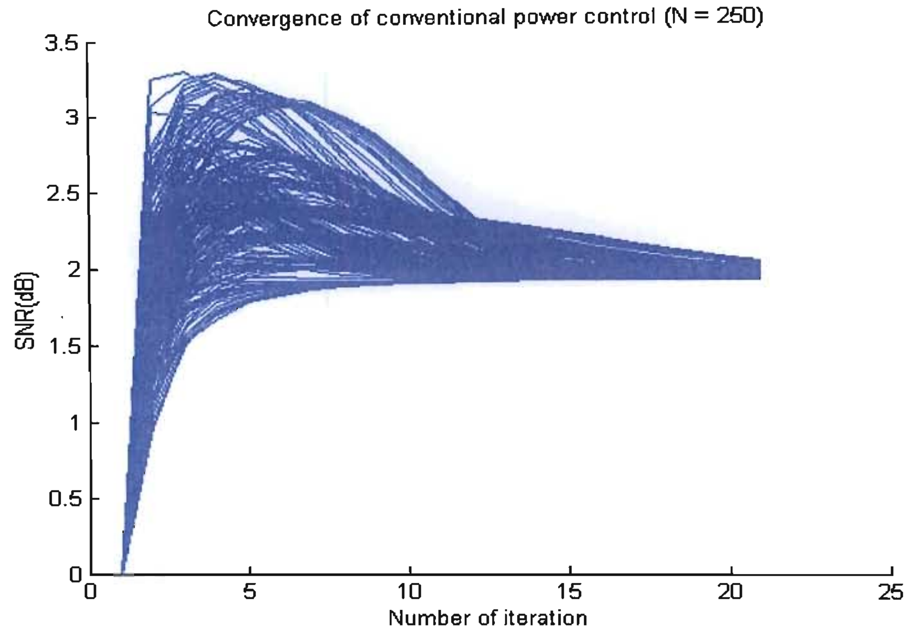

Figure 40i: Convergence of conventional power control algorithm for 250 users

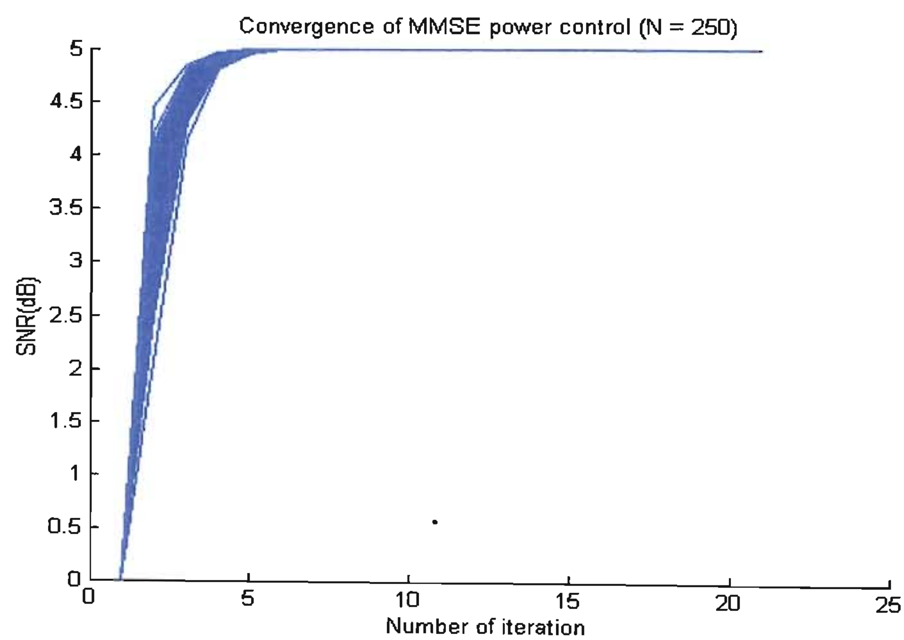

Figure 40j: Convergence of MMSE power control algorithm for 250 users

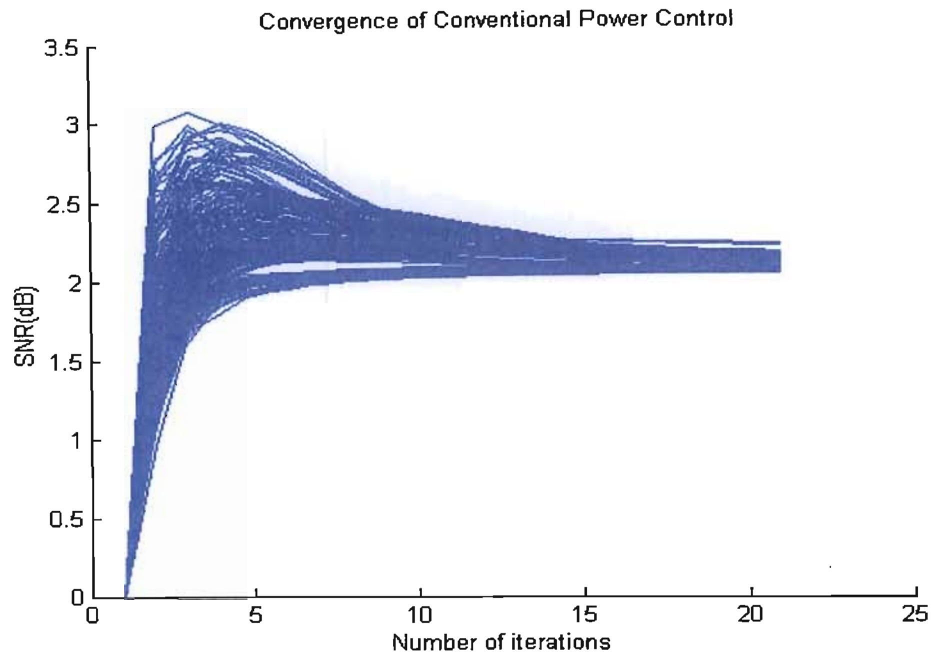

Figure 40k: Convergence of conventional power control (N=300)

Figure 40k shows convergence of conventional power control with N = 300 active users. The target SNR is 5.3 dB and it can be seen that the system converges slower to SNR of 2 dB, which is less that the targeted SNR. It took 10 iterations for the system to reach 2 dB.

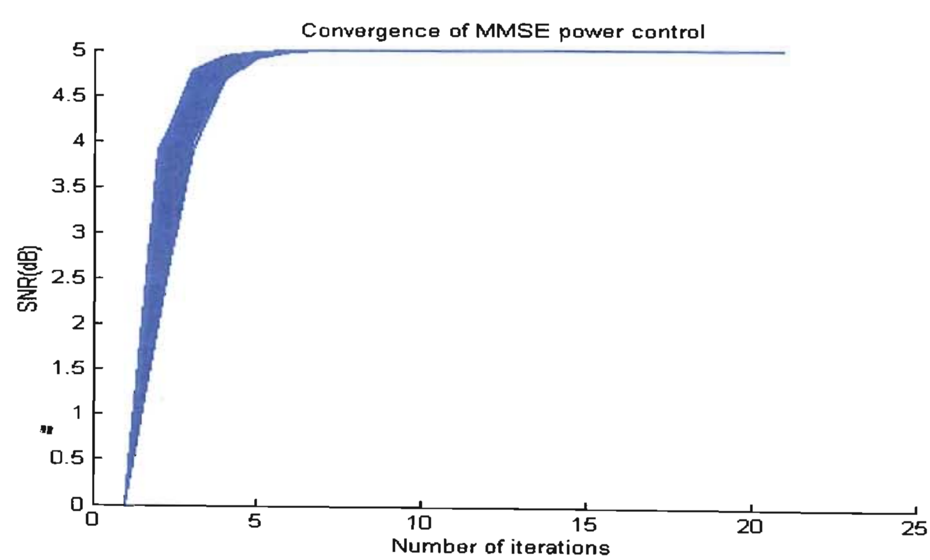

Figure 40l: Convergence of MMSE power control N = 300

Figure 40l shows the convergence of the MMSE power control with N = 300 active users. It can be seen in this figure that the algorithm converges to the targeted SNR in less than 10 iterations. This means we can reach our targeted obligations in terms of SNR for all users with a faster convergence.

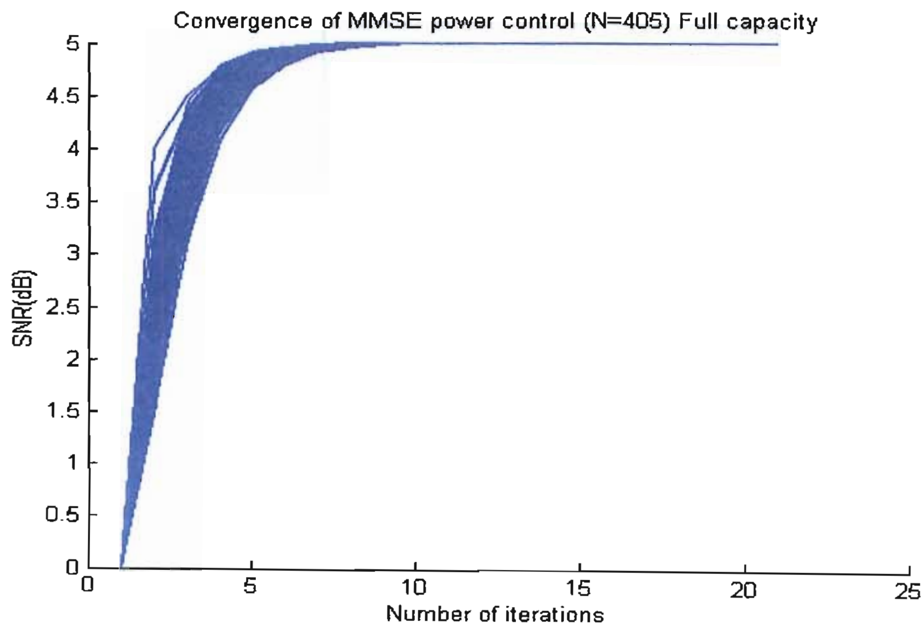

Figure 40m: Convergence of MMSE power control (N=405) full capacity

Figure 40m shows the convergence of MMSE power control algorithm with increased number of users (N = 405) full capacity. In this figure the convergence occurs and the targeted SNR is reached within the first 10 iterations. This is attractive since we are able to reach convergence with the network fully utilized.

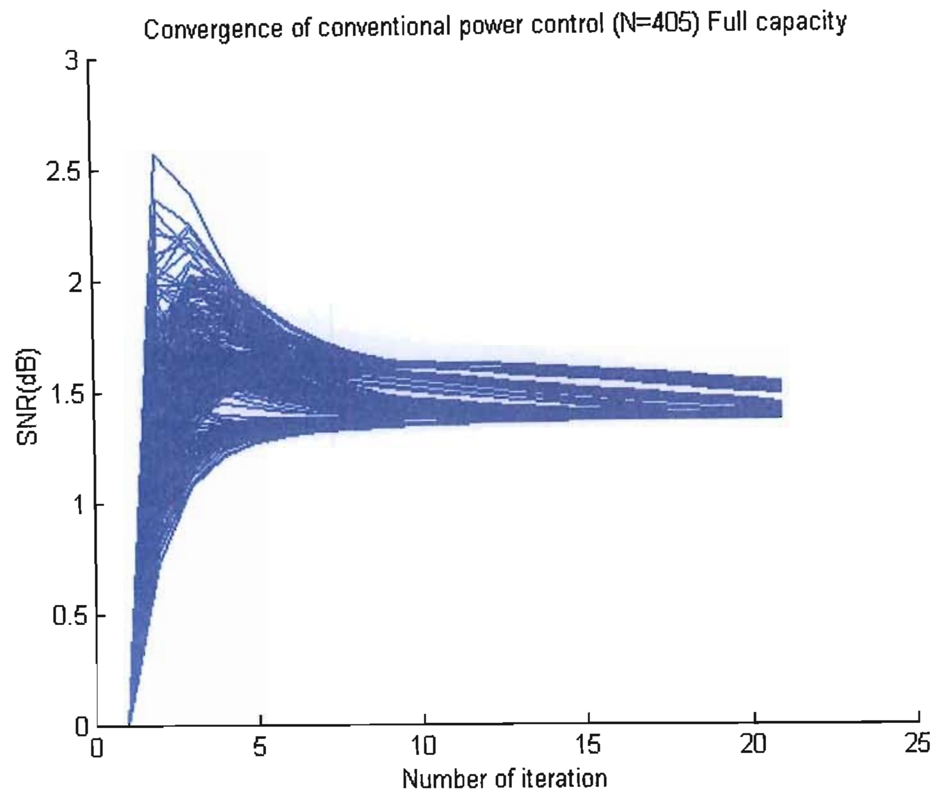

Figure 40n: Convergence of conventional power control N = 405

Figure 40n shows the convergence of power control algorithm with 405 users. Clearly for N = 405 there is slight convergence after about 15 iterations, but the targeted SNR of 5.3 dB is not attained. This might be bad especially for signals that requires a certain quality of service.

Figure 40a to Figure 40n shows the power convergence of MMSE and conventional power control algorithms. In telecommunications systems, quality of service is very important, as a result, we have a choice of which type of power control algorithm to use for our CDMA system. Due to the faster convergence of MMSE power control, we recommend MMSE power control to be used with our CDMA system.

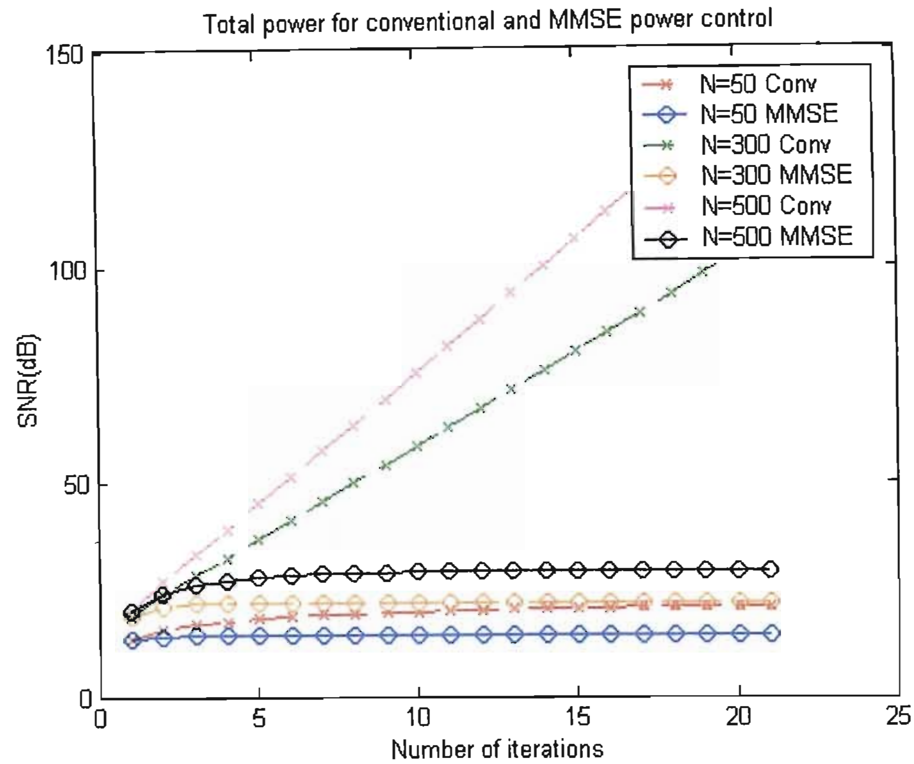

Figure 40o: Total power for conventional and MMSE power control algorithm

The near-far problem in CDMA can degrade the performance of the system. It is always important to improve the performance so as to increase the capacity of our system. The above diagrams from figure 40a to figure 40n, shows the speed of convergence in a CDMA system. In this simulation, conventional and Minimum Mean Square Error (MMSE) power control were used. The number of users were varied from N = 50 to N = 405. In all cases, the MMSE power control outperforms the conventional power control. In both cases, for N=300 we needed only less than 10 iteration to achieve convergence and for N = 405 we needed more iterations in order to reach convergence.

In both these cases the MMSE power control outperforms conventional power control. In fact for N = 300, conventional power control takes too long to converge. MMSE power control algorithm converges in all cases while the conventional power control algorithm converges when the number of users is less than 100 at the most.

5.2 BIT ERROR RATE PLOTS

The received data is compared with the original data transmitted to calculate the bit error rate (BER). In the reverse link the same procedure was followed except that Walsh code is not used[34].

To enable statistically valid simulation results in a reasonable simulation time, Monte Carlo methods are used. For a given number of users, channel model, and link configuration, the aim of the simulation is to produce a bit error rate curve as a function of SNR. For each SNR value, the uplink is simulated until a reliable estimate of the bit error rate at the output of the detector is obtained. A simulation loop is defined as the transmission and reception of a 10ms frame. Simulation loops are continued until both the following conditions are satisfied:

- The number of bit error detected by the receiver is greater than a specified minimum number of errors, and
- The number of simulation loops performed is greater than a specified minimum number of loops.

With the above two conditions met, the simulation will continue until one of the following conditions is true:

- The number of simulation loops reaches a specified maximum number loops, and
- The current bit error rate is less than a specified minimum rate.

General Simulation Assumptions

- Inter-cell interference is not modelled.
- Narrowband interference is not modelled as a component of the channel model.
- Linear power amplifiers at both the transmitter and receiver.
- The uplink and downlink simulation operates in Frequency Division Duplex mode.
- The Rake receiver is provided with excess delays for each multipath component processed.

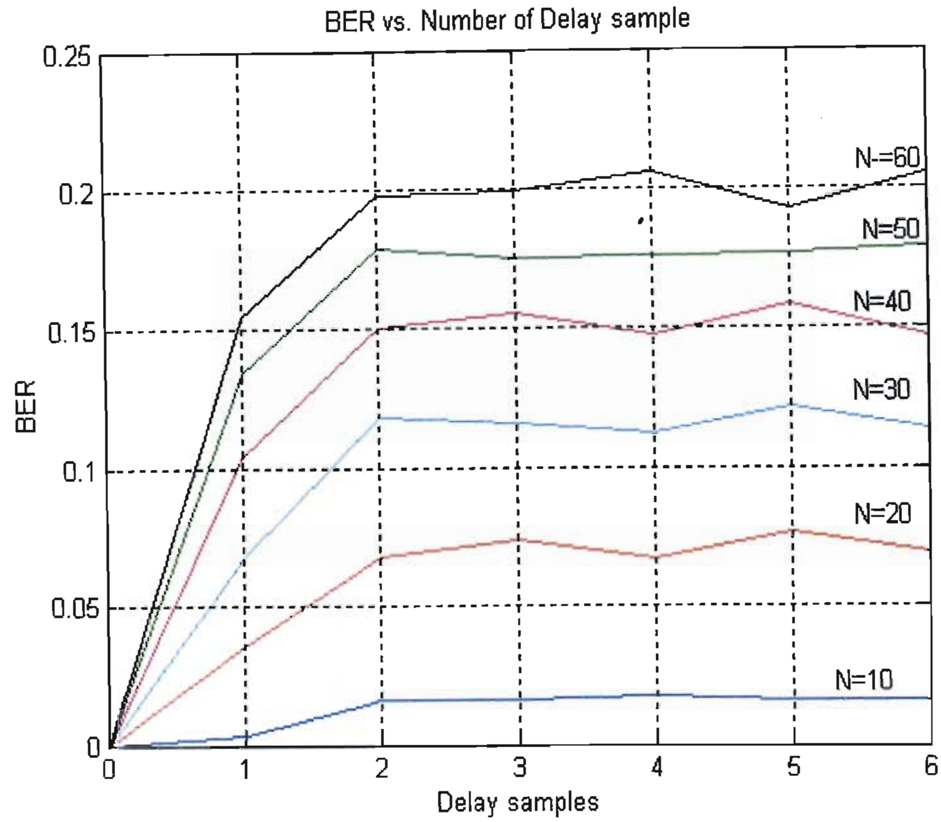

Figure 41: BER vs. Delay Samples

CDMA is inherently tolerant to multipath delay spread signals as any signal that is delayed by more than one chip time becomes uncorrelated to the PN code used to decode the signal, this leads to multipath signal simply appearing as noise. This noise increases the amount of interference seen by each user subjected to the multipath and thus increases the received BER. The multipath delay spread leads to an increase in the equivalent number of users in the cell, as it increases the amount of interference seen by the receiver. There are techniques that are used to limit the multipath impact in the received signal.

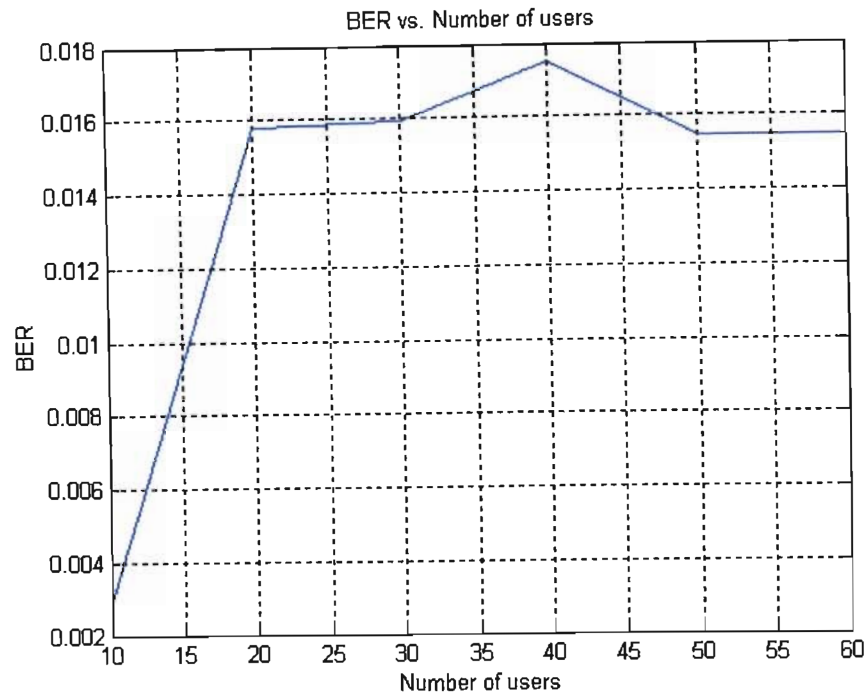

Figure 42: BER vs. Number of users when rake receivers are used

The BER for the reverse link of a CDMA system, increases as more users use the same cell. Figure 42 shows the relationship between the bit error rate (BER) and the number of users in a cell. It can be seen that the BER becomes significantly large as the number of users increases above 8 users. With the use of other techniques such as advanced error correction, voice activity detection and cell sectorization the number of users can be increased.

Figure 43 shows the plot of a BER against Signal to noise ratio in an AWGN channel. With 1 user the performance of the system is best, but with increase in number of users the performance degrades. This clearly explains the fact that CDMA uses 1 frequency band and when the number of active users increases the noise floor increases. This is why the performance degrades when the number of users increases.

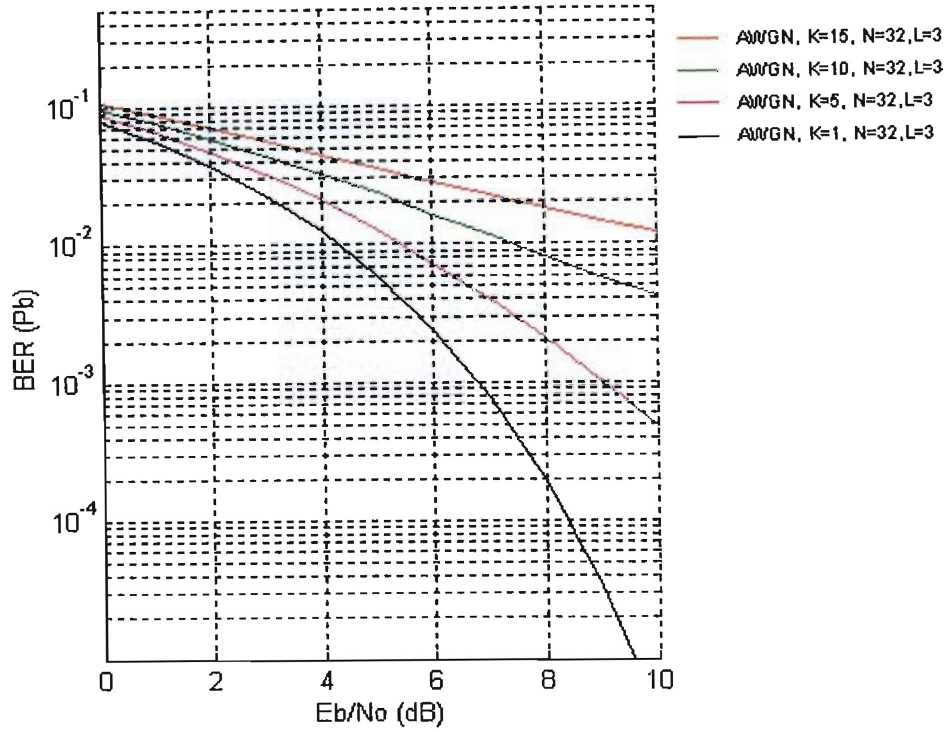

Figure 43: Graph of BER verses Signal to noise ratio in a AWGN channel

Figure 44 shows the graph of BER against Signal-to-noise ratio in a multirate traffic. In this simulation the traffic with processing gain (SF) of 32 and 16 were transmitted at the same time. It should be noted that traffic with high processing gain transmits at lower kilobits/sec. That is SF = 32, transmission rate is 128 kbps

SF = 16, transmission rate is 256 kbps

SF = 4, transmission rate is 1024 kbps

In this simulation, traffic with SF = 32 and SF = 16, were transmitted simultaneously. It can be seen that the traffic at high processing gain performed better compared to the traffic with low processing gain. Throughout this simulation, the traffic with low processing gain performed badly.

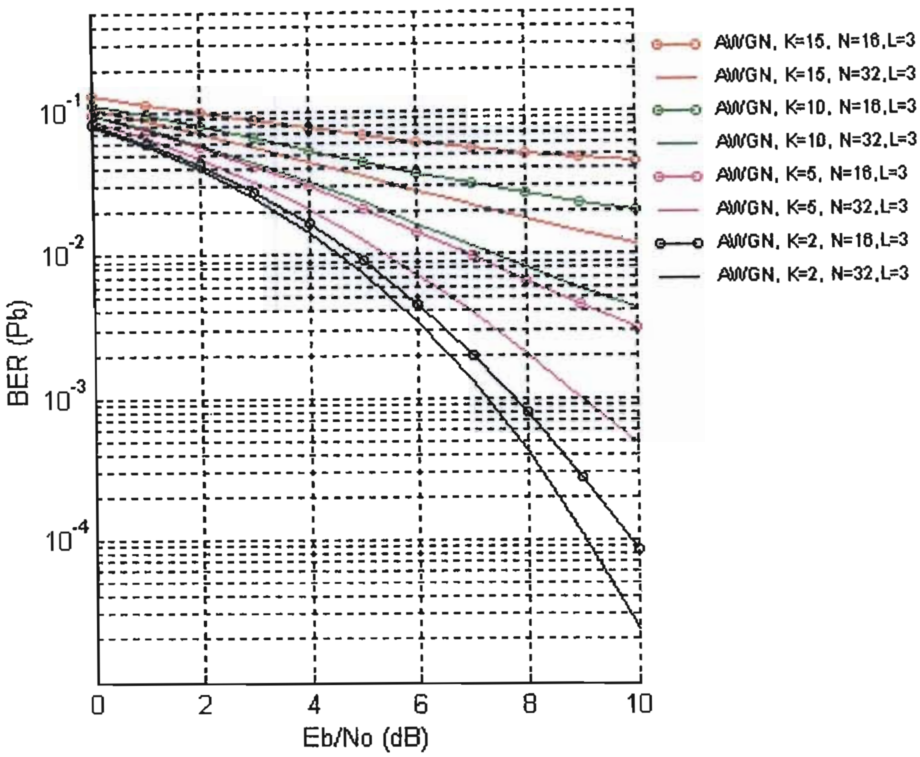

Figure 44: Graph of BER verses Signal-to-noise ratio of multirate traffic (SF = 16 and SF = 32)

Figure 45 shows the graph of BER vs. E_b/N_0 in a multirate traffic, but in this case we have SF = 4 and SF = 32. Traffic with low SF, transmits at high data rate of 1024 kbps and thus it performs badly. The performance of the system on traffic with high SF is the same as that of figure 45.

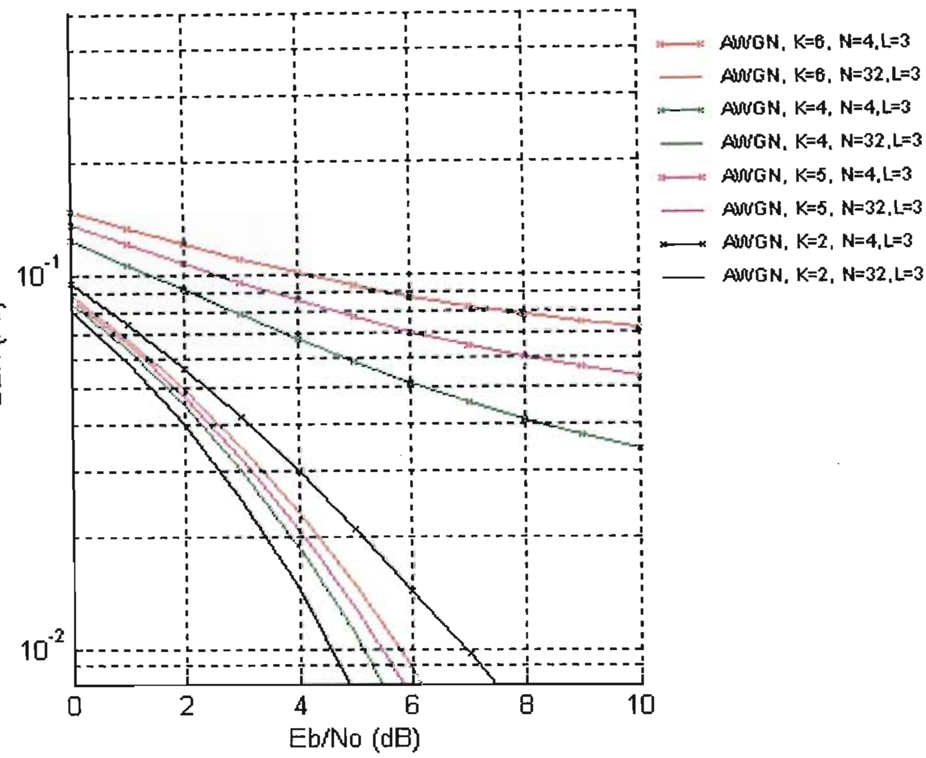

Figure 45: Graph of BER verses Signal-to-noise ratio (SF = 4 and SF = 32)

Figure 46 shows BER against Signal-to-noise ratio in a multipath environment. In this simulation we use 2-ray multipath signals. The system performs best when only one user is active, but as the number of active users increases the performance degrades. Overall, the BER level at $E_b/N_0 = 0$ dB is high compared to the performance of figure 47. This implies that in the multipath environment the number of active users is less compared to multipath-free environment.

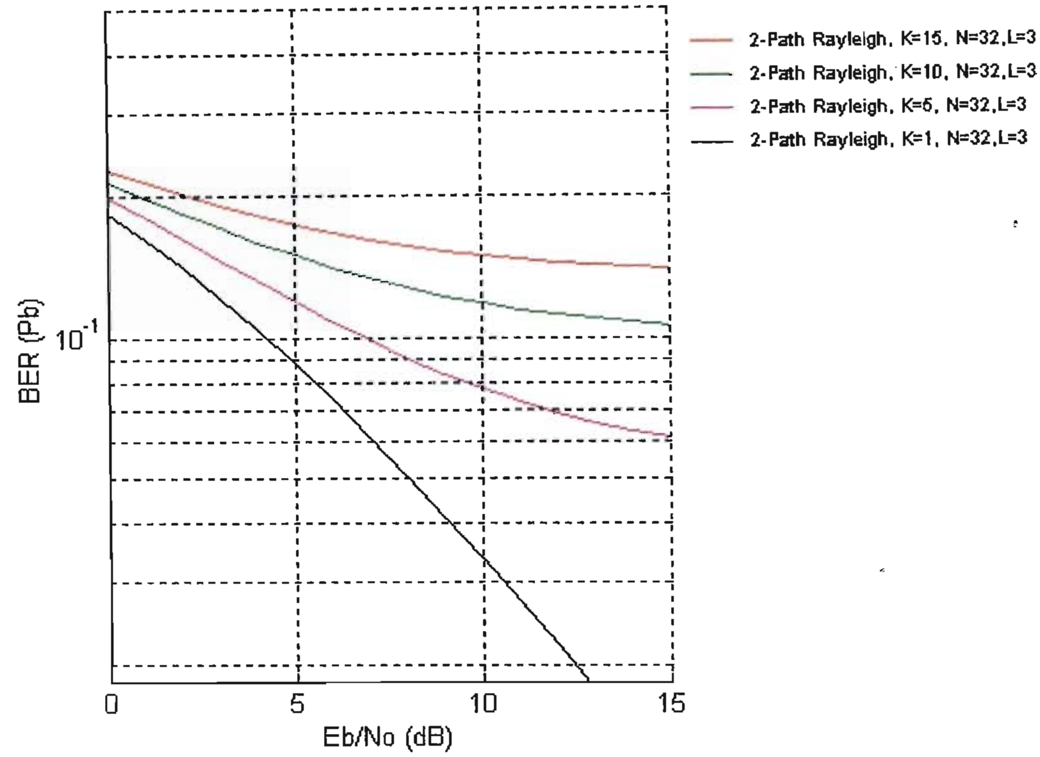

Figure 46: Graph of BER verses E_b/N_o in a multipath environment

Figure 47 shows CDMA can accommodate mobile users. When only one user is active in the system, the performance of the system is not bad, but it degrades with increase in number of users. If we compare graphs of figure 46 and figure 47 we can see that the performance of the system with moving mobile users is not much different from stationary users.

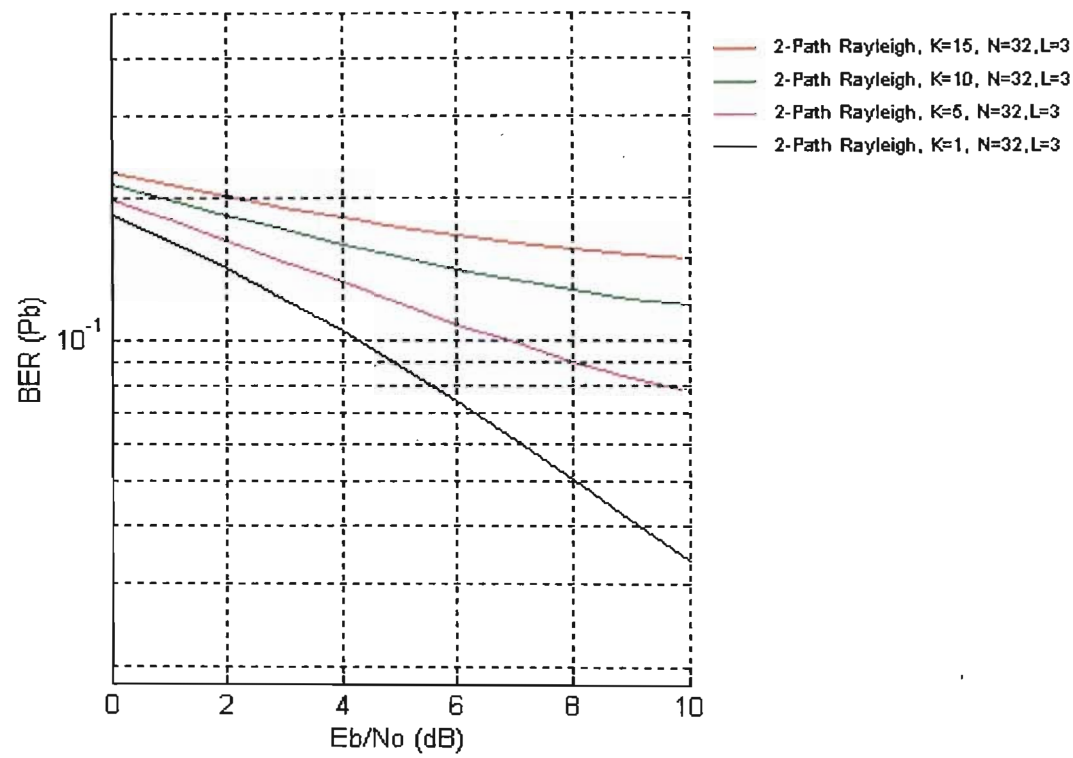

Figure 48: Graph of BER verses E_b/N_o when users are moving at 60 Km/h

5.3 SYSTEM IMPLEMENTATION

This is the most important section of our research because this is were we try and fit our system to our targeted areas in this case rural areas. There are a number of points that need to be explained or solved. The current second generation (2G) technologies deliver digital voice but third generation (3G) technologies deliver voice, data and even video to mobile phones and other mobile devices.

Kwazulu-Natal has good roads and links Swaziland and Mozambique with South Africa, so it is important to have cell sites next to major highways that are adjacent to locations. Other important areas are transmission towers and poles on hilltops. This will be ideal since Kwazulu-Natal is a hilly province. Wireless backhaul from these sites maybe the only practical way to tie them into the network. The very remoteness and height of such sites often makes the engineering of a point-to-point (line of sight) wireless connection easier.

The deployment of 3G systems means they have to coexist with the current system for some time to come. This is due to the fact that a significant installed base of equipment (both infrastructure and customer handsets) that will take time to upgrade. When we add 3G systems to the network, the backhaul solution must be modified to efficiently support all the technologies in use.

The key distinction of 2.5G and 3G systems for the user is improved support for data applications. The 2.5G systems are an enhancement of 2G systems, offering up to 172 kbps of packet data capability. Emerging 3G solutions typically offer 144 kbps, up to as much as 2 Mbps of data. More over, many 3G systems deployed internationally operate in different frequency allocations than 2G and 2.5G systems. Therefore these new systems require changes to the backhaul.

There are 3 reasons we need to change the backhaul:

- The coverage area of cells is smaller due to the higher data rates supported for voice and high-speed data and, in the case of some 3G systems, the higher frequency bands are used.
- The data rate per cell site is higher. As 2.5G are added to existing sites, the initial backhaul requirement from those sites will typically more than double.
- The type of connections to the Base Transceiver Stations (BTS) changes. Traditional 2G systems use Time Division Multiplexing (TDM) over 2.048 Mbps communication system or 1.544 Mbps communication system, while 2.5G and 3G systems employ Asynchronous Transfer Mode (ATM) or Internet Protocol (IP) transport over a variety of links including 2.048 or 1.544 Mbps links.

The reason such packet transports are used is that there is a fundamental change in the type of traffic carried. Second generation systems traffic is primarily voice with some connection-oriented data, while 2.5G and 3G add increasing amounts of packet oriented data. The 3G Universal Mobile Telecommunications Systems (UMTS) systems transport the voice traffic as compressed voice packets. More importantly, more data oriented applications are used; the overall traffic pattern becomes burstier. Packet-oriented transport can efficiently accommodate such burstiness, whereas a TDM channel sized for such bursts of traffic has to be over dimensioned and is never idle, even during periods of light activity.

Connecting each cell site to its Base Transceiver Station (BTS) requires transport facilities capable of handling current and perhaps future traffic at each cell site These transport facilities represent a significant expense in the construction and operation of a cellular system. Typically these connections are achieved by leasing suitable wire-line transport from the local exchange carrier or other local provider. It is not possible for us to lease a line through Telkom because they do not have such equipment in other areas of Kwazulu-Natal. Moreover Kwazulu-Natal is a hilly province and might take longer than necessary to implement such systems.

An alternative solution is to use a point-to-point wireless radio to achieve these connections. Wireless backhaul with its associated switching technology is not only cost and schedule efficient; it is also rapidly deployed and has inherent provision for growth. For best coverage planning, many cell sites must be located in areas where wired access is difficult.

In this research we will use radio as our backhaul. There are important points to consider when radio is used as backhaul, such as:

- Earth bulge, *h(m)*

$$h(m) = \frac{0.078 d_1 d_2}{K} \tag{5.2}$$

where d_1 and d_2 are distances from point A and point B respectively

- K-factor

$$K = \frac{r}{r_0} \tag{5.3}$$

where r is the effective earth radius and r_0 is the true earth radius

- Effective earth radius, r

$$r = \frac{r_0}{\left[1 - 0.04665 e^{0.005577 N_s}\right]} = K r_0 \tag{5.4}$$

where N_s is the surface refractivity

- Line-of-sight (LOS)
- Fresnel clearance and zone

$$R_m = 17.3 \sqrt{\frac{d_1 d_2}{fD}} \tag{5.5}$$

where f is the propagation frequency in giga hertz and D is the distance between point A and point B.

Our system must be scalable in 2 ways

i. New traffic capacity for existing sites must be accommodated, and

ii. New sites must be easily added.

In radio network adding new cell sites is easy provided the radio network topology can accommodate such growth. South African rural areas are excluded in the telecommunications network so there is a great potential for growth in these areas.

5.3.1 BACKHAUL TOPOLOGIES

Traditional backhaul topology shown in figure 49 has been a star network, with the (MSC) Mobile Switching Centre at the centre of the star and Base Station Controls' (BSC) at the branches, with Base Transceiver Station as the leaf nodes from the BSC. This network is easy to implement with the traditional 1.544 Mbps and 2.048 Mbps communications systems. This allows us to accommodate previously installed communication equipment with ease. Without switching or routing, it is difficult to usefully implement other topologies, like ring or mesh. To provide protection against loss of a path, multiple paths with protection switching are often provisioned.

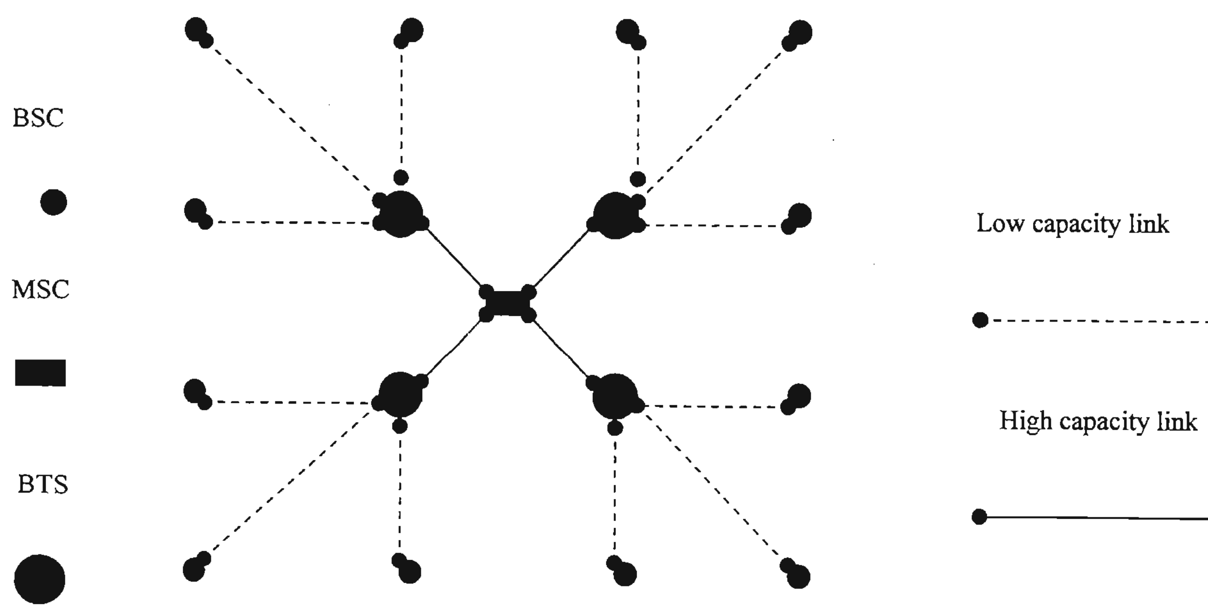

Figure 49: Star connection of BSC and BTS

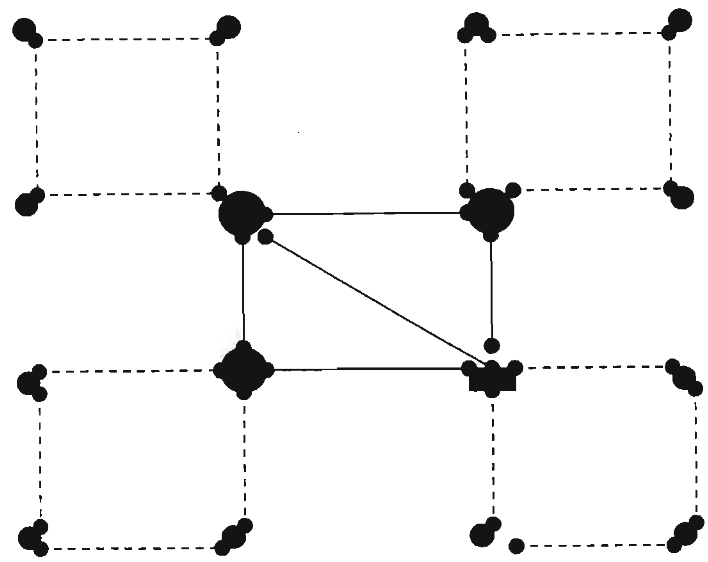

Figure 50: Mesh connection of BSC and BTS

Mesh radio architecture shown in figure 50, is the preferred mechanism for radio backhaul. This is so because of the following reasons:

- **Reliability** – using mesh architecture, redundant routes are available, should a radio path fail. This allows more economical radios to be used, and allows the route to be engineered with less than the highest levels of reliability.
- **Maintenance** – A mesh network simplifies network maintenance and expansion. A particular radio connection can be taken off the air without affecting service. This enables easier upgrades, for example, when adding new cell sites to the network.
- **Scalability** – In a radio system, a mesh network will have a fewer number of radios connecting to a common node, compared to an equivalent star network.
- **Interference Mitigation**

In Kwazulu-Natal mesh will be ideal connection since it will give us a room to add new cell sites. We do not have to put high capacity links all over the place, since villages are small we can put BTS with low capacity and link to BTS with high capacity link. This will help us install the system that will be fully utilized. In areas were communities is small we deploy a low capacity BTS and in bigger communities we deploy high capacity BTS.

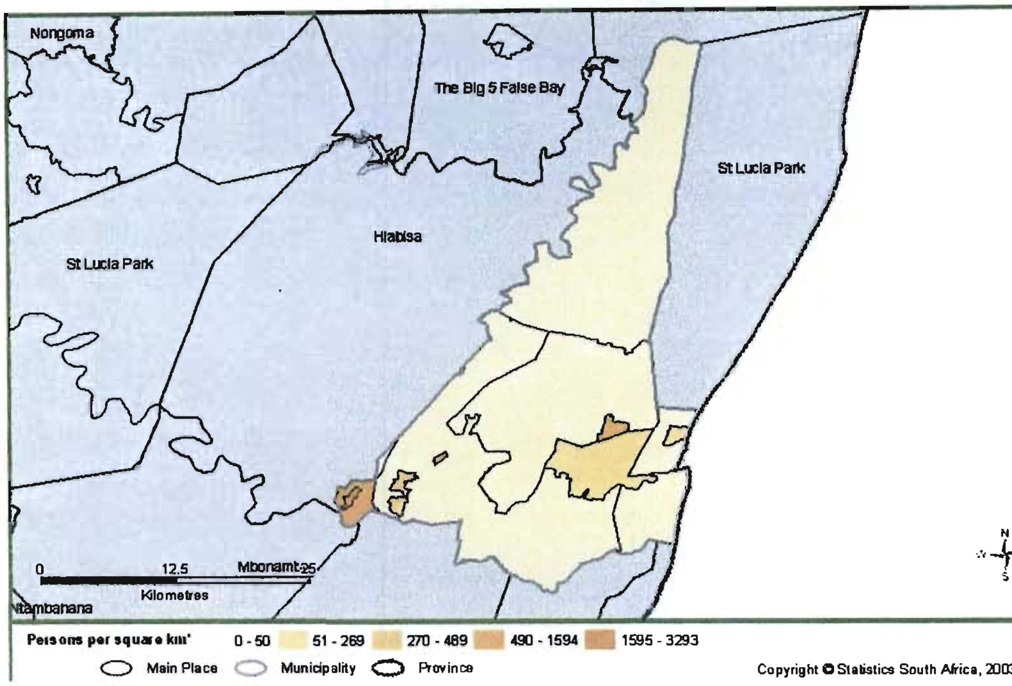

Figure 51: Map of Mtubatuba municipality [6]

Mtubatuba municipality is chosen for the implementation of our CDMA system. This municipality is shown in figure 51 above. It has an average of 44 persons/km^2 as shown in figure 52 below. Using this information, the traffic estimate can be generated for Mtubatuba municipality.

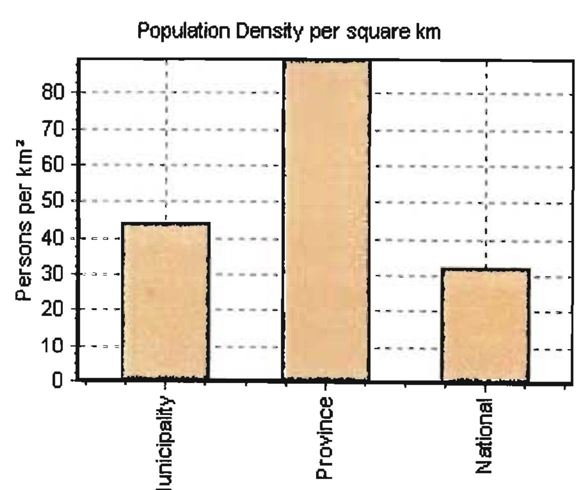

Figure 52: Population density per square km of Mtubatuba municipality

BS Coverage (radius) **km**	Coverage Area **Km²**	Total Population **(persons/km²)**	Maximum Traffic generated **(Erlang)**	Equivalent number of trunks
2.5	19.63	863,72	1,64	5
3	28.27	1243,88	2,36	7
5	78.54	3455,76	6,56	13
7.5	176.71	7775,24	14,77	23
10	314.17	13823,48	26.26	37
15	706,86	31101.84	59.09	74

Table 12: Estimated traffic for Mtubatuba municipality in Kwazulu-natal

The radius of 7,5Km is chosen arbitrarily and the number of trunks at this radius is 23. It has been shown that 1500 km^2 has about 9 base stations. We then use the estimated traffic for Mtubatuba municipality, which gives 207 trunks. This figure can be increased if the processing gain is lower. Voice signal requires a small processing gain, as a result, more than 207 users can be accommodated within a rural Mtubatuba municipality. The other way of increasing the number of trunk line is to use a bigger radius. This proves that a CDMA system is coverage limited and not capacity limited in a rural Kwazulu-natal.

5.4 CHAPTER SUMMARY

This chapter looks at the performance evaluation of the CDMA system in a rural environment. The base station radius is varied between 2.5 km to 15 km and the estimated traffic is calculated per cell radius in a rural area. It is also shown that the number of trunks increase exponentially with an increase in the number of base stations. Simulations were carried out to show the difference in convergence between conventional and MMSE power algorithms.

Both the conventional and MMSE power control algorithms converges to the required signal-to-noise ratio for 50 users, but as the number of users increase, MMSE power algorithm converges faster than conventional power algorithm. This means that conventional power control algorithm can be used initially when the number of users is low, but as the number of users increase MMSE power control algorithm should be preferred. Finally a specific design is proposed for Mtubatuba in rural Kwazulu-Natal. The CDMA system so implemented is coverage-limited rather than capacity-limited. This is a vital plus for a rural area.

CHAPTER 6

Conclusion

In Kwazulu-Natal, 57% of the total population resides in rural areas. Many of the communities in rural areas have no access to telecommunications and this hinders the delivery of other basic services such as health care and education. There is a need for telecommunication services to help improve health care and education. In Kwazulu-Natal there are 2 ports that are some of the key drives of the South African economy. Agriculture and tourism are part of rural development because rural communities depend on these services for survival. Therefore, telecommunication infrastructure in rural areas is a must.

The world is faced with a problem of people moving from rural areas to urban areas to search for work and better life. This problem is fuelled by the fact that urban communities are benefiting from better services compared to rural areas. Clearly, service providers are unable to meet the challenges of delivering telecommunications services to all areas. Increasing the involvement of ICASA can reduce this problem. This is the right time to introduce regional licenses for telecommunications services. Areas that are currently not on the system can be assigned to new licensees. This will reduce pressure on major service providers.

In South Africa, wireless service providers are finding it difficult to operate especially on GSM systems, because users are assigned channels and they are not utilizing the service. This is very difficult since GSM uses TDMA, and as the number of users increases there is a need to get more and more channels for them. This waste resources because the system is always idling and resources are lost. CDMA will definitely help in this regard because all users share the same channel.

CDMA is the only system that is best suited for South African rural areas. Unlike other poor countries of the world, it has been shown that there are many mobile phones in Kwazulu-Natal rural areas and this puts some restriction on the type of system we deploy in those areas. If we deploy a system that has limited mobility we are running a risk because people might not support such a system, so it is important to deploy a system that we get support from communities. Very Small Aperture Terminal is a good system for rural areas but it has little or no mobility. The mobility part of this system comes at a price, since it is used with DECT for the mobility part.

CDMA is part of the 2.5G family and it supports increased data, voice and video. This makes CDMA ideal for South African rural areas. It is better to move from 2.5G to 3G because the major difference between the two is bandwidth. Experience that would have been gathered from 2.5G will be valuable in 3G systems. CDMA can be transported over ATM or IP. This is attractive because other areas might have ATM in place already.

Due to the wireless nature of CDMA makes it easy and quick for deployment. There is an urgent need for us to deploy telecommunication infrastructure in rural areas. In 1993, MTN and Vodacom were licensed to provide cellular telephony, however, it came to light that the distribution of community telephones was skewed in favour of certain provinces and rural areas were not covered. That is why we need to act very quickly this time around.

CDMA system is cheap compared to both analogue systems and GSM. In the late 1990s CDMA was expensive because it was still new in the market. This has changed and favours rural populations because the money that they will have to pay is less. In low path loss, both CDMA and GSM makes fairly good profits but as the path loss because high GSM performs badly compared to CDMA. This means we can invest in a CDMA system in difficult conditions and guarantees profit. CDMA system implemented is coverage-limited rather than capacity-limited. This is a vital plus for a rural area.

Power control algorithms play major part in wireless systems. This is so because near-far problem in wireless systems can degrade the signal. There are many types of power control algorithms but conventional and MMSE are the two that we considered for this thesis. The conventional power control algorithm determine optimal filter coefficients and fixes the power of transmission. MMSE power control updates filter coefficients according to current power levels. Conventional power control performs well for few users e.g. N=50 and as the number of users is increased to 100, then the speed of convergence decreases.

When the number of users is increased to full capacity of N = 405, conventional power control fails to converge to the targeted SNR, whilst MMSE power control converges and reaches targeted SNR. This can be used to our advantage, in areas were there are more users with quality of service needs, then MMSE power control can be used otherwise we can use conventional power control algorithm.

CDMA is cost-effective technology that requires fewer, less-expensive cells and no costly frequency reuse pattern. The average power transmitted by the CDMA mobiles averages about 6 – 7 mW, which is less than one tenth of the average power for GSM system.

CHAPTER 7

References

[1] South African Hotels, Accommodation/ South African Travel website: http://www.sa-venues.com

[2] South African department of Land affairs website: http://www.gov.za

[3] Trade and Investment Kwazulu-Natal (tikzn) website: http://www.tikzn.co.za

[4] South African Department of Health website: http://www.gov.za

[5] The South African Policy Document, "Telecommunications Policy White Paper, 15 March 1996 - Department of Communications.

[6] The Statistics South Africa, "Population Growth", 2001 http://www.stassa.gov.za

[7] P. Wolthers, "Study of rural and urban traffic patterns in order to establish network dimensioning models", SATNAC 2001, 2-5 September 2001, Wild Coast Sun. ISBN 0-620-27769-6.

[8] The South African Universal Service Agency http://www.usa.org.za

[9] The Regulator- Independent Communications Authority of South Africa

http://www.icasa.org.za

[10] The International Electronic Consortium, "Local multipoint Distribution System" http://www.iec.org

[11] Multi channel Multipoint Distribution Service (MMDS) website: http://www.linktionary.com/m/mmds.html

[12] A, Hayn and R, Jakoby, "Radio propagation Aspects for Digital Microwave Video Distribution Systems (MVDS) at 42 Ghz", Proceedings of COST 259, Greek, Jan. 1999.

[13] P. Govind, Agrawal, *Fiber-Optic Communication systems*, 3rd edition, Wiley Series in Microwave and Optical Engineering, Handbook, June 2002, ISBN: 0471215716.

[14] T. S. Rappaport, *Wireless Communications*, Principle & Practice, Prentice Hall PTR, Upper Saddle River, New Jersey 07458, 1999.

[15] V. K. Garg, K. Smolik and J. E. Wilkes, *Application of CDMA for wireless/personal communications*, Artech House, Inc 1998.

[16] Doug Capps, Josh Dickman, Tom Jensen and Steve Konish, "Local Multipoint Distribution System (LMDS) as a solution for broadband application", Artech Inc. 1993.

[17] "VSATs at work in rural Argentina", Telefonica De Argentina, STM wireless, California, 1998.

[18] Peter. J. Chitamu and Pi-Chun Chen, "Impact of rural radio channel variability on economic viability of cellular network technologies for rural Kwazulu Natal", SATNAC 2001, 2-5 Sept.2001, Wild Coast Sun. ISBN 0-620-27769-6.

[19] Ramjee Prasad and Tero Ojanpera, "Wideband CDMA for third generation mobile communications" Boston: Artech House Publishers, 1998.

[20] G. C. Hess, "Land-Mobile radio system engineering", Boston: Artech House, 1993.

[21] N. Aleksandar, N. Natasa and P. George, " Modern Approaches in Modeling of Mobile Radio Systems Propagation Environment", IEEE Survey communications, Third Quarter, 2000.

[22] S. X. Wei, "An alternative derivation for the signal-o-noise ratio of an SSMA system", IEEE transaction of communications, vol. 42, no. 6 June 1994, 2224 – 2226.

[23] Jan Uddenfeldt, "Digital Cellular—Its Roots and Its Future", Proceedings of the IEEE, vol.86, no. 7, July 1998, pp. 1319 – 1323.

[24] P. J. Chitamu and S. J. Braithwaite, "Pathloss Prediction for a Digital Radio Telephone Application in Rural Tanzania at 300MHz", Proceedings of IEEE Africon '96, 4th September 1996, Stellenbosch, South Africa, pp.303-307.

[25] John G. Proakis, *Digital Communications*, 3rd ed., New York: McGraw-Hill, 1995.

[26] Ali F. Almutairi, Scott L. Miller, Haniph A. Latchman and Tan F. Wong, "Power Control Algorithm for MMSE Receiver Based CDMA Systems", IEEE Communications letters, vol.4, no.11, November 2000, pp 346 - 348.

[27] Vijayan, Logeshwaran and James Roberts, "BER Performance of 2D-Rake Receivers in DS-CDMA Over Frequency-Selective, Slow Rayleigh Fading Channels", IEEE Communications letters vol.6, no.10, October 2002, pp. 434 – 436.

[28] Savo Glisic and Branka Vucetic, *Spread Spectrum CDMA system for Wireless Communications*, Artech House: Boston, 1997.

[29] H. Vincent Poor and Sergio Verdu, " Single-User Detectors for Multi-user Channels" , IEEE transactions on communications, vol. 36, no. 1, January 1988.

[30] Alexandra Duel_Hallen, Jack Holtzman and Zoran Zvonar, " Multi-user Detection for CDMA Systems", IEEE Personal Communications, April 1995.

[31] H. Vincent Poor and Sergio Verdu, "Probability of Error in MMSE Multi-user Detection", IEEE Transactions of information theory, vol. 43, no.3, May 1997.

[32] Krysztof Wesolowski, " Mobile Communication Systems", New York: John Wiley & Son, 2002.

[33] A. Jagoda and M. de Villepin, *Mobile Communications*, John Wiley & Sons Ltd, West Sussex, England 1995.

[34] Pieter van Rooyen, Michiel Lötter and Danie van Wyk, *Space-time Processing for CDMA mobile Communications*, Kluwer Academic Publishers, UK, Feb. 2000.

[35] INTELSAT, *Satellite-based rural telephony: effective solution for infrastructure development*, case study, Washington DC, 2001.

[36] Vijay K. Garg, Kenneth Smolik and Joseph E. Wilkes, *Applications of CDMA Wireless/Personal Communications*, Prentice-Hall, Simon & Schuster Company, New York, 1997

[37] G. L. Turin, "Introduction to spread-spectrum anti multipath techniques and their application to urban digital radio," Proc. *IEEE*, vol. 68, pp. 328–353, Mar. 1980.

[38] J. S. Lehnert and M. B. Pursley, "Multipath diversity reception of spread-spectrum multiple access communications," *IEEE Trans. Commun.*, vol. 35, no. 11, pp. 1189–1198, Nov. 1987.

[39] J. Luo, S. Ulukus and A. Ephremides, " Probability One Joint Stochastic Power Control and Blind MMSE Interference Suppression", 2003 Conference

on Information Sciences and Systems, The Hopkins University, March 12-14, 2003.

[40] Ali. T. Koc, Ozgur Ozdemir, Murat Torlak and William P. Osborne, "Opnet Simulation of Random Access CDMA", University of Texas, Dallas

[41] William C. Y. Lee, *Mobile Cellular Telecommunications Systems*, McGraw-Hill, 1989.

[42] Andrew Dymond and Sonja Oestmann, 'Rural Telecommunications Development in a Liberalizing Environment: An Update on Universal Access Funds', Intelecon Research and Consultancy Ltd, July 2002.

[43] South African port Authority Website: http://wwwnpa.co.za

[44] Kwazulu-Natal Horticulcure website: http://www.nda.agric.za/docs/Trends2003/Horticulture.pdf

[45] P. J. Chitamu, " Multiple Access Interference (MAI) canceller Enhanced Rake Receiver for Asynchronous CDMA System in Multipath Channels", Proceedings of IEEE Africon Conference, 28 September-01 October, 1999, Cape Town.