WIRELESS WIDEBAND DS-CDMA POINT-TO-MULTIPOINT SYSTEM FOR DISTANCE EDUCATION SERVICES

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by

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Abstract

A review of possible distance education services is given. These services range from narrowband to broadband, from real to non-real time and from broadcast to fully interactive services. The service target groups include the rural schools and communities who are scattered in remote areas.

The performances of multiple access techniques, FDMA, TDMA and CDMA when in use for the provision of point-to-multipoint multimedia services is compared. A hybrid of the satellite and terrestrial access networks for the implementation of the distance education services is presented.

The feasibility of implementing the proposed satellite network as part of the total network using the FDMA technique is presented. The rest of the work done in the thesis concentrates on the terrestrial network. The terrestrial part of the network is based on fixed cellular DS-CDMA techniques.

The fixed cellular network's specifications, modelling and a discussion of the capacity, BER performance, bandwidth requirements and coverage are presented. The link budget estimation of the performance is given. Lastly a review of propagation characteristics for a terrestrial rural environment and a review of DS-CDMA concepts are presented in the appendix.

Acknowledgements

My appreciation to my supervisor Prof. S.H Mneney. Thanks for all the help, guidance and perspective you provided during the course of the thesis. Many thanks to our program co-ordinator Dr. P Chitamu, for making sure we had what we needed and for your help.

I thank my family for their love and support. I wish to thank my colleagues and friends for their encouragement and friendship. I'm also grateful to our sponsors Telkom SA Ltd, Ericsson, and THRIP. Thank God, for who can do anything without Him?

I hereby declare that all the work contained in this thesis is as a result of my own work and all the literature that was referenced is indicated.

E. O Maragela

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Date ____________

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Abbreviations

AWBN	Additive white Gaussian noise
BER	Bit error rate
BPSK	Binary phase shift keying
BS	Base station
CDMA	Code division multiple access
DS	Direct sequence
FDD	Frequency division duplexing
FDMA	Frequency division multiple access
FH	Frequency hopped
FM	Frequency modulated
ISO	International standard organisation
MAI	Multiple access interference
Mcps	Mega chips per second
Sps	Symbols per second
PMP	Point to multipoint
QPSK	Quadrature phase shift keying
RF	Radio frequency
RS	Remote station
SCPC	Single channel per carrier
SNR	Signal to noise ratio
TDMA	Time division multiple access

WCDMA	Wideband code division multiple access
WLL	Wireless local loop

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1 INTRODUCTION

In the effort to meet the national 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. These resources include providing school buildings with lights, electricity, and telephone lines, qualified mathematics, science and commerce teachers, libraries, textbooks and computers.

The majority of the populations in both the rural and urban areas have no access to these resources. The large size of the population that need these resources have made the effort by the ministry of education very expensive and take a very long time. The distance education system proposed here 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.

The service target groups include, to a large extent, the rural schools and communities in areas where there is a lack telecommunications and power infrastructure. It was estimated in 1995 that 45% of the total 37.9 million South Africans live in the rural areas [19]. Past political scenario in South Africa played a big role in ensuring geographical separation, minimum development and low allocation of resources to the rural areas. These resulted in the exclusion of the provision of the telecommunication services to communities who resided in rural areas.

In general most of the rural areas have severe climatic conditions, sparse and scattered population distributions which makes it very difficult and expensive to provide public facilities such as electricity, good roads, and telecommunication infrastructure.

The lack of public facilities, scarcity of locally available qualified technical staff, low and seasonal incomes and the high cost of wire-line telecommunication links to such communities are factors that also contribute to the underdevelopment of the rural telecommunication infrastructure in these rural areas. It is clear that we have to look at wireless solutions to improve or as is the case in most rural areas, to provide basic, cost effective and affordable telecommunication services.

The distance education system proposed here is a hybrid of a broadcast satellite network and terrestrial wireless access network for the rural area environment. The terrestrial wireless access network will provide users with access to multimedia services. A discussion of the type of services to be provided will now be discussed.

1.1 Distance Education Services

The term distance education services refer to services relevant to education scenario and are offered by a communication system to remote locations. These services can be classified into three: non-real time, real time and a hybrid of the two.

Non-real time services are those that need not be delivered on real time or 'live'. These include file transfers, archiving in databanks, and service akin to e-mail and voice mail. It should be possible to transfer educational material in the form of graphics, mosaics, pictures and text with voice. The bandwidth requirement for such services is small and off-peak times can be used. Audio and video recordings fall under this category of services.

Real time services are those that need to be delivered on real time or 'live'. These services have very strict delay and data rate constraints. Real time services include voice, text and voice, handwriting and voice (scribophone) or (video and voice). One might need to broadcast a lesson and notes given by a teacher or an expert to remote stations as the lesson is being delivered. It would be even better if the students can hear and see the expert at the same time, thus we are led to transmit data or video and voice.

The hybrid of the real-time and non-real time services include still-pictures with voice, where voice is a real time service and still-pictures falls under the category of non-real-time services. The resulting service is formed by multiplexing the two services.

1.2 Multiple Access Schemes

The proposed distance education system requires some form of wireless access network, where traffic flows between a central point and many subscribers. Clearly, there is a need for a multiple access protocol to allocate available resources intelligibly to the subscribers. Wireless communications systems use several different common access techniques, sometimes referred to as "air interfaces". Four basic resources, which can be utilised for multiple access methods are time, frequency, power and space.

Consequently, four basic methods can be distinguished as follows:

- ***Time Division Multiple Access*** (TDMA): subscribers access the network at different times, each of which constitutes an independent circuit. Each call is assigned a time slot.
- ***Frequency Division Multiple Access*** (FDMA): Different frequency bands are available to the subscribers. Subscriber baseband signals or a group of subscriber baseband signals are assigned different carrier frequencies.
- ***Code Division Multiple Access*** (CDMA): Access is by unique individual subscriber codes; the physical resource is power. CDMA has the widest frequency spectrum. CDMA fills the entire spectrum with coded data packets. The unique codes allow the receiving terminal to receive only packets intended for it. Once the packets arrive at the receiving terminal, they are reassembled into their original voice or data form.
- ***Space Division Multiple Access*** (SDMA): subscribers are connected through specific individual radio beams using electronically controlled antennas.

Some of these methods can and have been used in combination with one another within limits to achieve optimal network conditions. The method GSM chose is a combination of Time and Frequency Division Multiple Access (TDMA/FDMA)[23]. Each method has its individual advantages and disadvantages under specific background conditions.

1.2.1 Frequency Division Multiple Access

In an FDMA scheme, the bandwidth of the channel allocated for wireless communication is divided among the population of stations, into a number channels, each of which can carry voice or, carry digital data. FDMA was one of the earliest forms of multiple access schemes to be used because of its simplicity and low cost implementation requirements.

FDMA is a basic technology in the analog Advanced Mobile Phone Service (AMPS) which is a widely installed cellular phone system in North America. FDMA is also used in the Total Access Communication System (TACS). The Digital-Advanced Mobile Phone Service (D-AMPS) also uses FDMA but adds time division multiple access to get three channels for each FDMA channel, tripling the number of calls that can be handled on a channel.

FDMA systems can be implemented in two ways, Single Channel per Carrier (SCPC) and Multiple Channel Per Carrier (MCPC). In SCPC each channel modulates a separate radio frequency carrier and the resulting modulated carriers are then summed. For MCPC a number of channels are multiplexed at baseband and the resulting baseband signal modulates a radio frequency carrier.

The major advantages of FDMA are that it is simple algorithmically and from a hardware standpoint. For FDMA co-channel interference from other users is reduced by allocating inter-frequency protection bands called guardbands between any two user-allocated bands. For more users in a given frequency segment, more guardbands are needed. As a result, the efficient use of the frequency spectrum drops with increase in the number of users since guardbands waste bandwidth. The width of the guardbands also depends on the maximum allowable co-channel interference.

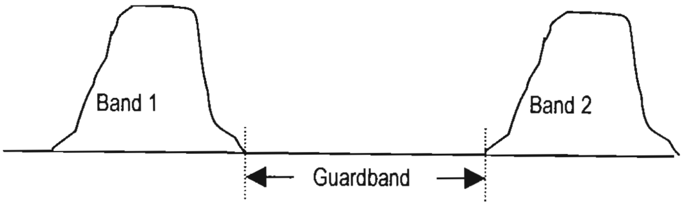

Fig 2.1: Frequency allocation in FDMA showing guardbands

1.2.2 Time Division Multiple Access

TDMA, like FDMA, is one of the earliest and widely used forms of multiple access technique and has proven itself to be a reliable technology capable of providing a large number of users with good quality service. In a traditional system, the total allocated bandwidth is divided into frequency channels. The channels are then divided into a number of time slots. Subscribers are each allocated timeslots, and thus access the network during the allocated times.

TDMA allows flexible bit rates and allows more efficient use of bandwidth than FDMA since no frequency guard band is required. To accommodate for the clock stability inaccuracies and transmission delay, TDMA transmits each signal with sufficient guard time between the time-slots. The disadvantages include a substantial amount of processing for filtering and correlation detection for synchronising with time slot; and demands for high peak power on the uplink for mobile or fixed sets [16,17].

Some of the well known digital TDMA/ FDMA systems include the North American IS-54 (now upgraded to IS-136), E-TDMA from General Motors and Global System for Mobile Communications (GSM) also known as PCS-1900 [17]. Fast pace of today's wireless communications market has led many companies and service providers to invest in their existing TDMA systems [6] than in new technologies like CDMA.

1.2.3 Comparison of CDMA, TDMA and FDMA

Review of CDMA is included in the appendix A. 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.

We make a capacity comparison between the IS-95 CDMA, IS-136 TDMA, ETSI GSM, and TACS FDMA systems and wireless local loop environment. CDMA has a frequency reuse factor of 1 and its capacity can be expressed as [22]

$$M = \frac{G_p}{(E_b / N_0)} \times \frac{1}{1+\beta} \times \alpha \times \frac{1}{\nu} + 1 \qquad (1.1)$$

where:

G_p = processing gain $=B/R$

B = total bandwidth = 1.2288 MHz

R = transmission rate = 9.6 kb/s

β = interference from neighbouring cells = 0.5

α = power control accuracy factor =0.85

ν = voice activity factor = 0.6

For a required E_b/N_0 ratio, the cellular TDMA and FDMA frequency reuse factor N can be calculated as [6, 22]

$$N = \frac{1}{3}\left[6\left(\frac{E_b}{N_0}\right)\right]^{\frac{2}{\gamma}} \qquad (1.2)$$

where:

γ = propagation path-slope(assume to be 4 for macrocell)

E_b/N_0 = design signal-to-interference-ratio

The total capacity M is

$$M = \frac{\lfloor B_w / b_c \rfloor}{N} \tag{1.3}$$

where:

B_w = total spectrum bandwidth,

b_c = channel bandwidth.

Equations 1.1 to 1.3 can be can be used to yield the comparison values shown in table 1.1. The total allocated bandwidth is assumed to be 5 MHz each way and each cell has only three sectored. Capacity for each of the systems is obtained form the Erlang-B curves for the indicated number of channels and grade of service of 2%. Erlangs per cell per MHz is obtained by dividing the total capacity per cell by the allocated bandwidth of 5 MHz.

Table 1.1 Capacity comparison of radio systems [17] (except FDMA TACS column)

	TDMA **IS-136**	**GSM** **ETSI**	**CDMA** **IS-95**	**FDMA** **TACS**
Channel Bandwidth(kHz)	30	200	1250	25
Number of channels	167	25	3	200
Design E_b/N_0	14 dB	12 dB	6 dB	18dB
Frequency Reuse	4	3	1	7
Effective traffic channels per sector	167 / (4 x 3) = 13.92	25 / (3 x 3) = 2.78	3	200 / (7 x 3) = 9.52
Users per sector per traffic channel	3	8	31	1
Voice channel per sector	113.92 x 3 = 41.76	2.78 x 8 = 22.24	31 x 3 = 93	9.5 x 1 = 9.52
Capacity- Erlangs per sector (2% blocking)	32.7 E	15.2 E	81.2 E	9.3 E
Erlangs per cell (2% blocking)	98.1 E	45.6 E	243.6 E	27.9 E
Total number of cells for 1000 E	10	22	4	36
Erlangs per cell per MHz	19.6 E	9.12 E	48.7 E	5.58 E

Table 1.1 shows that for fixed cellular or wireless local loop system the capacity of IS-95 CDMA is about 2.5 times that of IS-136 TDMA, 5.4 times that of GSM, and about 8.73 times that of TACS FDMA system. For distance education application, M is small, resulting in reduced multiple access interference (MAI in the case of where CDMA is employed.

The reduced MAI can therefore be traded with increased coverage range for the same signal-to-noise ratio. Other unique features and benefits of CDMA technology over TDMA and FDMA observed in mobile and fixed radio environment are soft capacity, protection against multipath interference, reduced average transmitted power, interference rejection, and the enhanced privacy and security [4, 16, 17]:

***Soft capacity*:** There is no absolute limit of number of users in CDMA, but system performance improves with reduction of users and degrades with increase of users. This feature is desirable for this particular application, since the number of channels required is very small and it is relatively easy to add more users.

Protection against multipath interference: In a multipath channel, the different multipaths can be resolved and summed coherently to produce a strong signal for detection. TDMA systems experience flat fading, since its multipath resolving capability is limited to symbol period and most of the strong multipath appear at less than symbol period, resulting in non-coherent summation.

Reduced average transmitted power: Processing gain is traded against transmitter power. The benefits are: reduced average transmitted power, more sensitive receivers resulting in improved coverage characteristic, and reduced interference to other electronic devices.

***Interference rejection*:** CDMA possesses higher interference rejection capability than TDMA and CDMA due to its operation technique [3,4,5,10].

Enhanced Privacy and security: Only if the generating code is known can data be recovered from the transmitted signal. Reduced transmitted power level in CDMA makes it difficult for the transmitted signal to be detected by all other but the intended receiver.

Variable data rates are important in communication systems in order to support different services. In CDMA increase or reduction in data rate can be achieved by mapping more or less data sources to orthogonal data words. This does not affect the overall transmission rate, thus there is no need to modify the transmission and detection system. For these reasons we, investigate the possibility of implementing a spread spectrum technique for the proposed terrestrial radio system.

In the following chapters, chapter two contains a detailed system description. The specification of the proposed system is done along with the description. Chapter three covers the mathematical models of the transmitter, propagation channel and receiver. Chapter four covers the bit error performance of the models in an AWGN channel and light to heavy multipath channel. Link budget computations are also used to predict the feasibility of the possible terrestrial radio links. Conclusions are given in chapter five. The appendix covers review of both CDMA and the propagation channel characteristics.

2 SYSTEM DESCRIPTION AND SPECIFICATION

The long distances, hostile terrain, difficult vegetation, severe climatic conditions, sparse and scattered population distributions are some of the challenges facing rural telecommunication. These conditions render wireline telecommunication solutions uneconomical for the provision of distance education services described in section 1.1 in rural areas. The proposed system is a hybrid of the satellite and the terrestrial radio network.

The possible network configuration can consist of regional and national centres. The national centres will act as the main sources of programs and will provide these resources to the regional centres several hundreds of kilometres away via the existing satellite networks. The satellite network configuration will consist of a transmit-only satellite earth station at the national centres and receive-only satellite earth stations at regional centres. The advantages of using wireless links (here satellite links) to existing wireline links are:

- Regional centres can be optimally located for maximum subscriber coverage and not necessarily be restricted to locations close to terminations points of wireline network.
- Cost of broadcasting information on wireline networks increase with distance involved and the number of connections or destinations involved. For broadcast satellite links the cost would not be significantly dependent on coverage and number of destinations involved.

This is a star network as shown in figure.2.1.

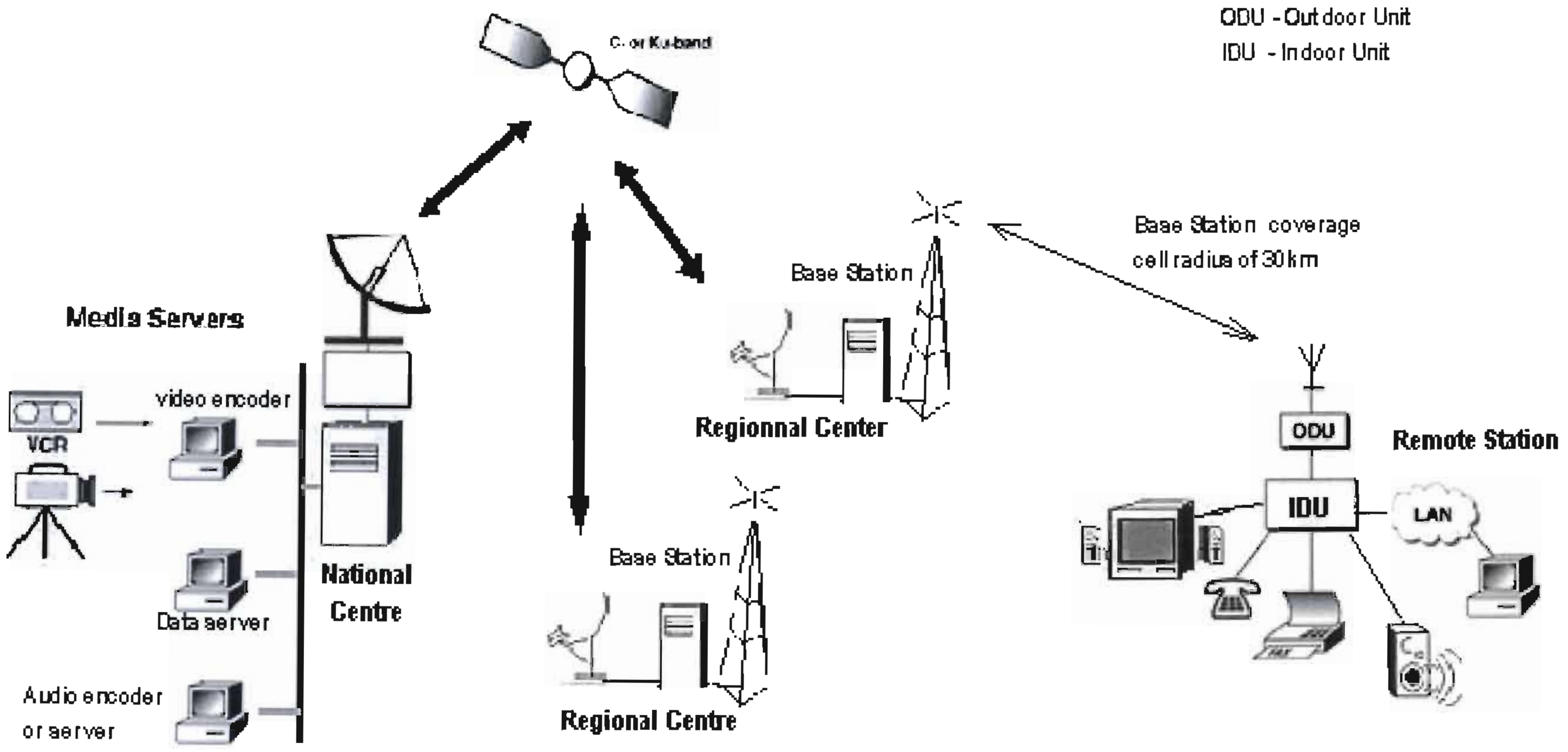

Figure.2.1 The complete proposed distance learning network

The regional centres will act as the main storage and distribution points of resources. Subscribers will only gain access to the resources via the terrestrial radio links to regional centres several kilometres away (maximum coverage distance of at least 30 km).
Terrestrial radio links are used since subscriber interaction via satellite links is prohibitively expensive. The work that follows presents the feasibility of the satellite link and the description and specification of terrestrial radio links.

2.1 1 The Satellite Link

The interconnection between terrestrial radio base stations is an essential part of the network. For rural cellular radio systems, the microwave links, minilinks, satellite links and VSAT (Very Small Aperture Terminals) are normally used to interconnect base stations.

The microwave radios have long been the choice for meeting low and medium capacity needs to rural subscribers [32]. The frequencies used for microwave links range from the long-haul 2 and 6 GHz bands to the relatively short-haul 11, 18, 23 GHz bands. The short lead times, low installation cost, and often the availability of existing microwave towers make microwave links particularly attractive for operators.

The mini links were originally designed for short hops (from 1 to 3 kilometres), and for applications where cost is more important than system reliability. The minilinks operate in the 10.5-10.68 GHz. Minilinks differ from conventional microwave in that the electronics are located in a module, either on the or near the antenna. This has the advantage that expensive radio frequency feeders are not needed to feed the antenna. These links are less than one half the cost of the conventional microwave units [30].

The VSATs are physically small, low capacity earth stations, which may have capacities of up to 30 channels. VSAT terminals are much cheaper than full earth station terminals and are more portable. VSATs operate mainly in the C and Ku- bands. By VSAT standard links to cellular base stations are "wide bandwidths" systems, thus they are scarcely used for this application.

The satellite links are not very often encountered in cellular networks as are microwave links. But due to its wide coverage and direct access to remote locations, the satellite links are a very efficient means of conveying information to the rural areas of developing countries. For the purpose of this application we propose satellite links for its much wider coverage. For cost effectiveness we propose a broadcast link from the national centre to the regional centres or local base stations.

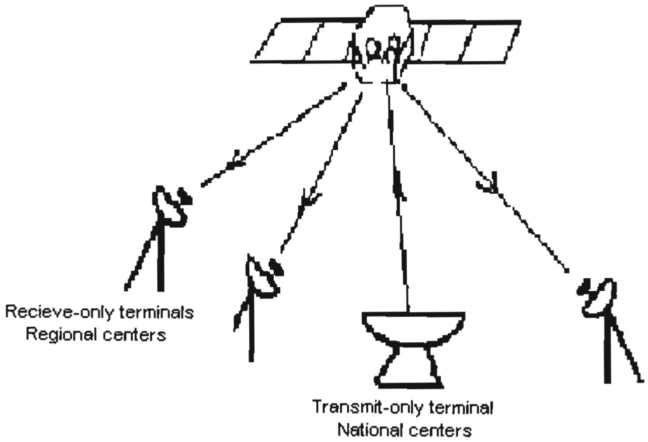

Figure.2.2 The proposed distance learning satellite network

The satellite links will be used for broadcasting information from the sources at the national centre to the base stations. Subscriber interaction will thus be limited to the base. There are countries that have their own satellite systems but many Third-World countries depend on the international satellite systems, satellite operators, for international communication and for distribution of local television programs.

South Africa does not operate its own Geostationary satellites and will therefore have to rent capacity from the INTELSAT satellites for projects like distance learning. The Ku band has been used successfully for the Digital Satellite Television (DSTV). The attraction in such a band is that the antennas used are small, about 1m in diameter. This means that the whole earth station is easily transportable and relatively inexpensive.

Satellite links are also subjected to terrestrial and adjacent satellite interference; attenuation due to distances involved and atmospheric absorption and propagation delay. Propagation delay is not a problem for broadcast system and forward error correction codes (FEC's) are used to improve performance. The proposed national to regional centres broadcast satellite link requires only a few channels among channels used for other services. When an FDMA satellite link is deployed, several channels among the Single Channel per Carrier (SCPC) systems may be dedicated for this purpose. SCPC channels are normally used in low traffic density areas.

The type of access used here is FDMA [25]. CDMA technique in satellite communication is used for multipoint systems, whereas TDMA has found most applications with point-to-point satellite communication systems. As mentioned in section 1.2.1, the major advantage of FDMA is its simplicity algorithmically and from a hardware standpoint.

2.1.1 The Link Budget Computation

The performance of the satellite links can be estimated through a link budget computation based on [25]

$$\left(\frac{C}{N}\right)_{down} = EIRP - L_d + \left(G/T\right)_E - 10\log_{10}(B_{IF}) - BO_o \qquad (2.1)$$

where,

EIRP : effective isotropic radiated power of the satellite,
L_d : the down link clear sky path loss, and
BO_o : output backoff power.
G/T : earth station figure of merit
B_{IF} : noise bandwidth at IF stage

If E_s is the symbol energy, R_s the symbol rate, and N_o the single sided noise power spectral density then

$$\left(C/N\right)_{downlink} = \left(\frac{E_s}{N_o}\right)\left(\frac{R_s}{B}\right) \qquad (2.2)$$

The performance of a receive-only standard K2 earth station, 1.8 m antenna dish with G/T = 21.6 dB/K is computed for the distance education channel among other data channels of equal capacity. The parameters of the INTELSAT 702 above the Indian Ocean at 66° East are used. The link budget is shown in table 2.1.

Table 2.1: The Satellite link budget (downlink)

[EIRP]	Effective Isotropic radiated power	45	dBW
[N]	1125 channels, each 32 kHz bandwidth	-30.5	dB
[BO_{o+}]	Satellite output backoff	-0.5	dB
[L_d]	Clear sky path-loss for the longest distance to SA	-205.9	dB
[G/T]	Earth station figure of merit	21.6	dB/K
[K]	Boltzman's constant	-228.6	dB/K-Hz
[B_{IF}]	Noise bandwidth 32 kHz at IF stage	-45.05	dBHz
[C/N]		13.25	dB

Using equation 2.2 and the *C/N* from the link budget computation obtained from 2.1, it can be shown that the E_b/N_o = 13.25 dB can be achieved. This is a good value, since most systems operate at about 12 dB. Cost reduction in can be achieved by reducing the antenna size until $E_b/N_o \approx 12$ dB. For this particular example the FEC coding is necessary only to compensate for rain attenuation, since Ku-band satellite systems experiences significant attenuation due to weather conditions.

A much more economic satellite network will consist of one national centre with a transmit-only earth station broadcasting to the all the regional centres in the country. The regional centres can thus be placed in close proximity to the subscribers. The work to follow concentrates mainly on the terrestrial wireless links through which the subscriber can access the resources at the regional centres

2.2 Terrestrial Radio Links

The total distance education network was described in the introduction of section 2 to be a hybrid of satellite and terrestrial networks. Terrestrial star topology point-to-multipoint wireless links will enable subscribers to access and interact with the resources stored at the regional centres, figure 2.3. The base stations of these links will be placed at the regional centre location.

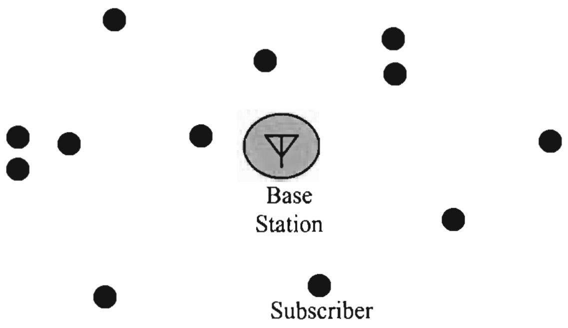

Figure 2.3: Terrestrial Point-to-multipoint wireless system

The coverage of these links will span a radius of at least 30 km about each base station. The regional centres and consequently the base stations will be conveniently located for optimal subscriber number coverage. The choice of the multiple access technique for terrestrial rural links has already been shown with reasons in section 1.2.3 to be CDMA.

This will be a full-duplex cellular wideband (5 MHz spreading bandwidth) CDMA network. It is also possible to assign less bandwidth to uplinks from subscribers to base station compared to downlinks from base station to subscribers. This is because much less traffic is expected from the uplinks compared to down links. We proceed to describe and specify the system following the system block diagram in figure 2.4

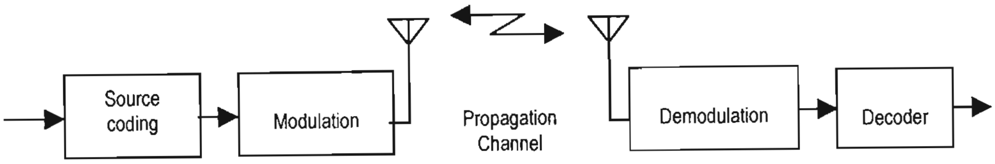

Figure 2.4: System block diagram

2.2.1 Source Coding

Voice and other applications require conversion from analogue source to digital form before transmission. Source coding here refers to converting analogue source signal to digital form ready for transmission and the decoder would convert digital signal information to appropriate analogue signals. Source coding and decoding is not required for the pilot channel, the paging channel, the sync channel and some traffic channels where the information already exits in digital form.

For distance education purposes, the educational material source may be a real time or recorded voice source. When a voice source is analogue, there is a need to convert information from analogue to digital form of the specified rate. Different encoders can be used, and the most basic and inexpensive one being a digital pulse code modulator (PCM) encoder. A 64 kbits/s digital data rate is achieved when encoding an analogue source by a PCM encoder [23].

Radio channels inherently have much higher order error rates compared to wireline and it is more efficient for these channels to transmit at lower raw data rates than that offered by PCM. For this reason PCM is not widely used for radio channels. The existing CDMA systems use more efficient methods of voice coding and extensive techniques to reduce transmitted raw data rates. These are the Code-Exited Linear prediction systems (CELP) used for narrowband CDMA at rates 8 kbits/s and 32 kbits/s, and a modified version of Adaptive Differential PCM (ADPCM) used for wideband CDMA outputs 32 kbits/s [9, 23, 26-28]. The lower the bit rates the higher the CDMA processing gain, resulting in better bit error rate performance or lower requirement in signal-to-noise ratio for same bit error rate.

One has to also take into consideration the complexity and cost of these methods, since our target is also cost effectiveness. ADPCM will be used since it has the least complexity and is the least expensive.

There are many well-known wireless data systems; these can be divided into Wide-area data systems and High-speed Wireless local-area networks (WLAN). Wide-area data services are used for transaction processing, interactive broadcast and multicast services [9]. High-speed wireless local area networks support limited number of users in an indoor environment and are used to extend wired local area networks for convenience and mobility. Our application falls into the wide area type and we wish to transmit data at variable rates up to wireline network rate of 64 kbits/s.

2.2.2 Pre Modulation Processing

The basic pre-modulation processing involves error or channel coding, symbol repetition and block interleaving, shown in figure 2.5. Pre-modulation processing is mostly implemented to decrease the effect of errors and achieve reliable communication. Pre-modulation processing is usually performed on every channel individually before being multiplexed with other channels.

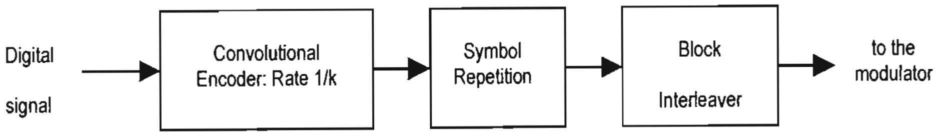

Figure 2.5: Channel coding and pre-modulation blocks

2.2.2.1 Channel Error Coding

To decrease the effect of errors and achieve reliable communication over noisy radio channels, it is necessary to transmit sequences that are as different as possible so that the channel noise will not change one sequence into another. This leads to introduction of redundancy, which results in transmission of extra bits and reduction of the transmission data rate.

Channel coding schemes are generally divided into two classes, the convolutional codes and the block codes. The convolutional encoders are widely used in CDMA applications. In block coding, binary source output of length k are mapped into channel input sequence of length n. The rate of resulting code is k/n bits per transmission. The mapping of the information source output into channel inputs is done independently and the output of the encoder depends only on the current input sequence of length k and not on the previous input sequences [11,12].

In convolutional encoding, source outputs of length k are mapped into n channel inputs, but the channel inputs depends not only on the most recent k source outputs, but also on the last $(K-1)\ k$ inputs of the encoder. K is the constraint length. Coding gain is defined as the reduction in the required *Eb/No* to achieve a specified bit error probability of the coded system over an uncoded system with the same modulation and channel characteristics.

The convolutional coding gains depend very much on the rate *k/n*, the constraint length *K*, the bit error probability P_e, the transfer function of the convolutional encoder and the decoding method used. The coding gain increase with increases in *K* and decrease in P_e and *k/n*. The upper bound in decibels is shown to be [11,12,14]

$$coding \quad gain \leq 10 \log_{10}\left(\frac{k}{n} d_{free}\right)$$

where d_{free} is minimum free distance which can be increased either by decreasing the code rate or by increasing the constraint length or both. The constraint length is dictated by the desired coding gain. Viterbi decoding is mostly used for short constraint lengths ($K \leq 10$), and for long constraint lengths sequential decoding is used since the complexity of Viterbi decoding becomes prohibitive.

For an AWGN channel, hard decision decoding is inferior to soft decision decoding by approximately 2 dB. The rate 1/2 convolutional encoder will be used, converting a 64 (or lower) kbits/s channel to the inphase and quadrature channel, each one at 64 (or lower) kbits/s. A soft decision decoder will be used.

2.2.2.2 Symbol Repetition

The nominal data rate is specified to be 64 kbits/s. When the data to be transmitted is at a lower rate (1200, 2400, 4800, 9600, 16000 or 32000 bits/s), then, the data bits are rate multiplied or repeated n times to increase the rate to a constant 64 kbits/s.

2.2.2.3 Block Interleaver

Large numbers of consecutive errors can be caused by deep fades that characterise communication over a radio channel. Convolutional codes are known to have better performance when it comes to random errors than on bursty or blocks of errors [9]. By making sure that no two adjacent blocks are transmitted near to each other we effectively randomise bursty errors. This process is called interleaving of data and its implementation introduces delay.

There are numerous ways interleaving can be implemented, the details of which will not be covered here, but can be obtained from [24]. It should be noted that this is a very important process in radio communication since it ensures good performance of convolutional codes in channels with bursty errors.

2.2.3 Reverse Modulation Channel

The reverse channel is the communication channel from the remote station to the base station. The reverse link contains an access channel and a traffic channel. Each channel includes a reverse pilot channel. The base station acquires, tracks and drives a phase reference for the reverse channel links using the pilot channel. All the reverse link channels share the same wideband CDMA frequency assignment using DS-CDMA techniques. Each of the access and reverse traffic channels is identified by a distant user long code sequence.

The access channel consists of a reverse pilot channel and a reverse access channel, shown in figure 2.5. The remote station to initiate communication with the base station uses the reverse access channel. The reverse access channel modulation parameters are given in table 2.2.

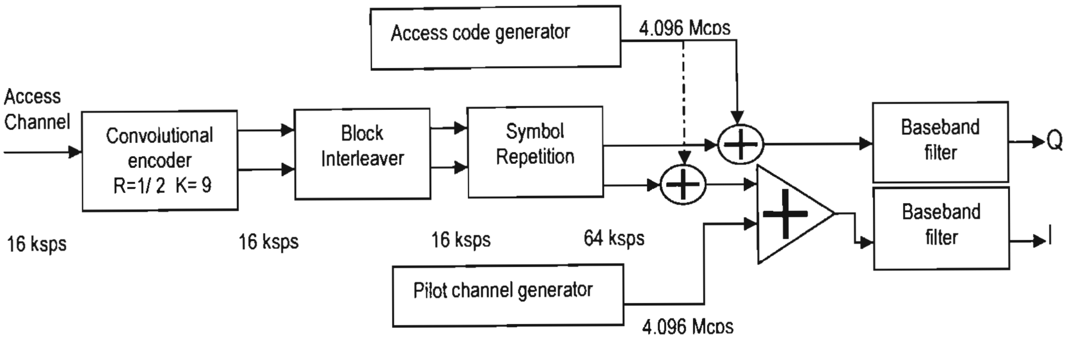

Figure 2.6 Reverse Access channel structure

Table 2.2 Access channel modulation parameters

Parameter	**Data Rate (bps)** **16000**	**Units**
PN chip rate	4.096	Mcps
Code rate	½	bits/symbol
Symbol repetition	4	
Symbol rate	64000	sps
PN chips/ symbol	64	PN chips/symbol
PN chips/ bit	256	PN chips/ bit

The reverse traffic channel is used for transmission of user and signalling information to a base station. The reverse traffic channel consists of a reverse pilot channel, a reverse information channel and reverse signalling channel. The supported data rates for each channel are shown in figure 2.7 and modulation parameters on table 2.3 and table 2.4.

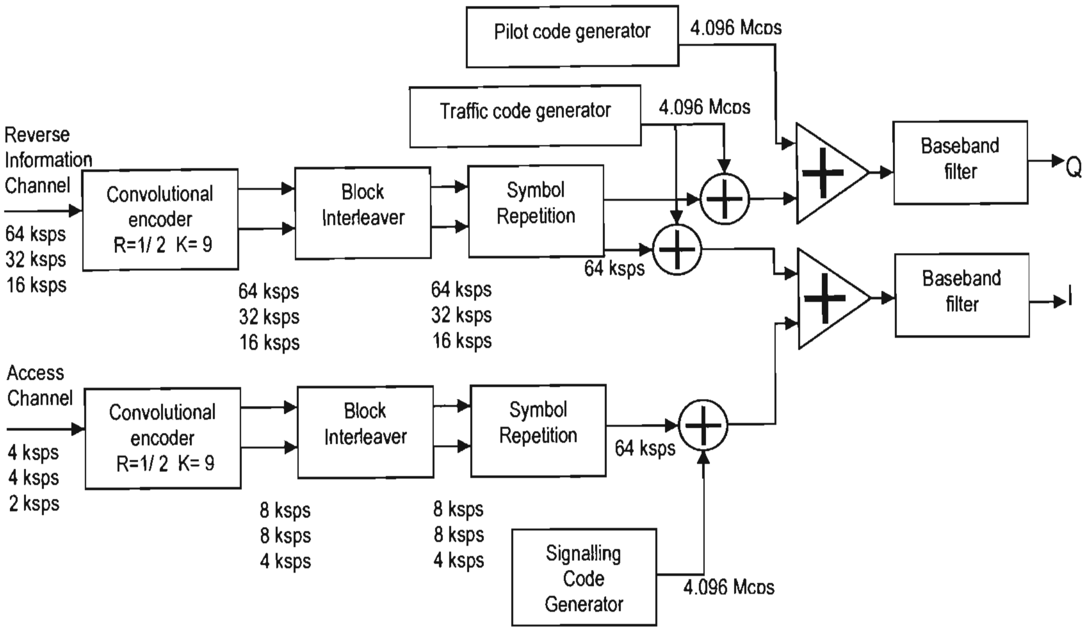

Figure 2.7 Reverse traffic channel structure

Table 2.3 Reverse Information Channel Modulation Parameters

Parameter	**Data Rate (bps)**			**Units**
	64000	32000	160000	
PN chip rate	4.096	4.096 s	4.096 s	Mcps
Code rate	1/2	1/2	1/2	bits/symbol
Symbol repetition	1	2	4	
Symbol rate	64000	64000	64000	sps
PN chips/ symbol	64	64	64	PN chips/symbol
PN chips/ bit	64	128	256	PN chips/ bit

Table 2.4 Reverse Signalling Channel Modulation Parameters

Parameter	**Data Rate (bps)**		**Units**
	4000	**2000**	
PN chip rate	4.096	4.096 s	Mcps
Code rate	1/2	1/2	bits/symbol
Symbol repetition	8	16	
Symbol rate	64000	64000	sps
PN chips/ symbol	64	64	PN chips/symbol
PN chips/ bit	512	1024	PN chips/ bit

2.2.4 Forward Modulation Channel

The forward channel is the communication channel from the base station to the remote station. The forward wideband CDMA link operates with a pilot channel, a sync channel, and several traffic channels.

The pilot channel is sent from base station to aid in clock recovery at the remote station, it contains all zero patterns and is modulo-2 added to Walsh 0 function, see figure 2.8. Each base station uses a time offset of the pilot pseudo-noise (PN) sequence to identify a forward channel.

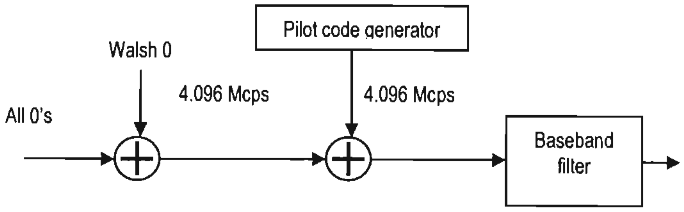

Figure 2.8 Pilot channel structure

The sync channel is transmitted by base station to enable the remote station to obtain frame synchronisation. The sync channel is spread by Walsh function 32 and spread by a pseudo-noise sequence at fixed rate of 4.096 Mcps, see figure 2.9. The sync channel modulation parameters are given in table 2.5.

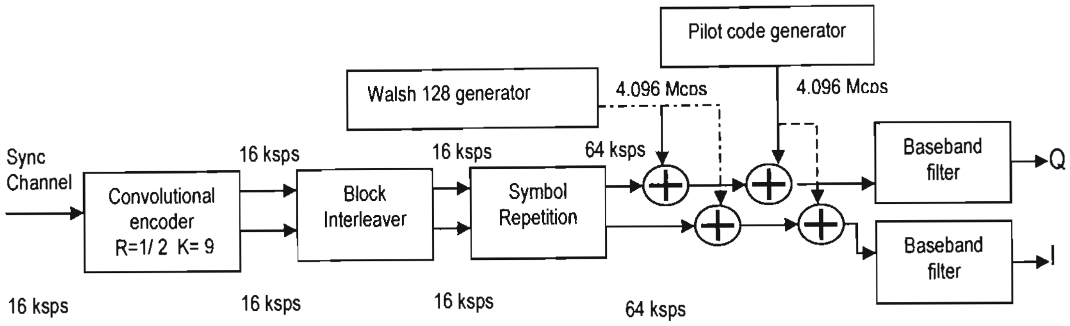

Figure 2.9 Sync channel structure

Table 2.5 Paging Channel Modulation Parameters

Parameter	**Data Rate (bps)** 16000	**Units**
PN chip rate	4.096	Mcps
Code rate	1/2	bits/symbol
Symbol repetition	4	
Symbol rate	64000	sps
PN chips/ symbol	64	PN chips/symbol
PN chips/ bit	256	PN chips/ bit

The traffic channels are used for transmission of user and signalling information to a specific remote station. The traffic channel consists of a forward information channel and forward signalling channel, see figure 2.10. Forward traffic channel is orthogonaly spread by an appropriate Walsh *n* and spread by a pilot pseudo-noise sequence identifying the particular base station at fixed rate of 4.096 Mcps. The modulation parameters for the forward wideband CDMA channel are given in table 2.6 and table 2.7.

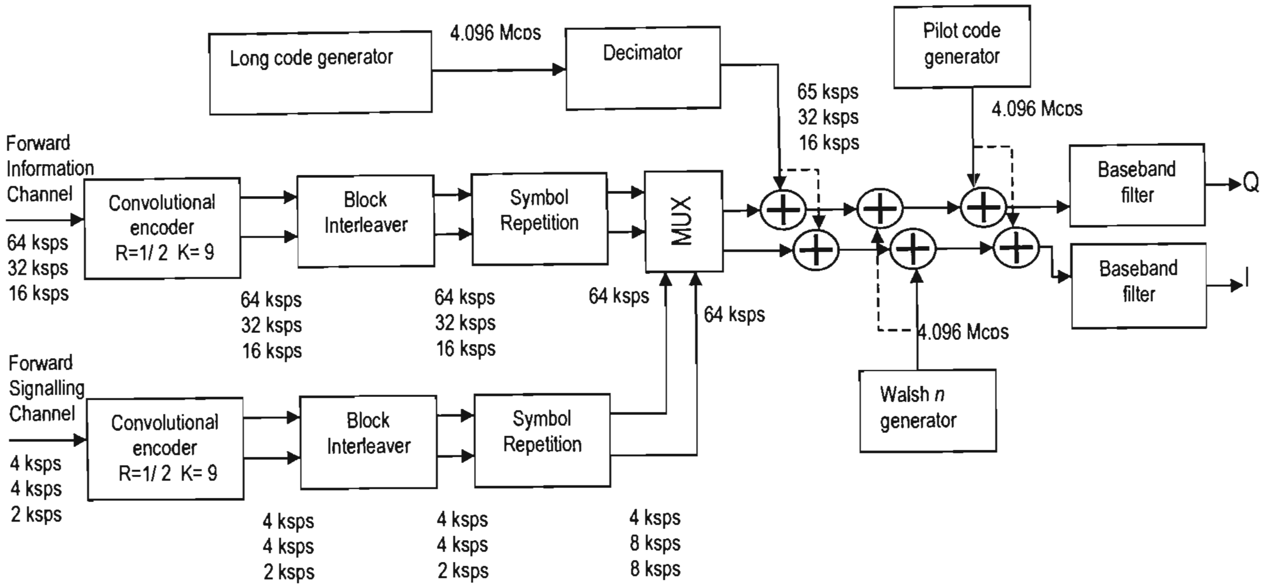

Figure 2.10 Forward traffic channel structure

Table 2.6 Modulation Parameters For Forward Information Channel

Parameter	**Data Rate (bps)**		**Units**
	4000	**2000**	
PN chip rate	4.096	4.096 s	Mcps
Code rate	1/2	1/2	bits/symbol
Symbol repetition	1,2	4	
Symbol rate	4000, 8000	8000	sps
PN chips/ symbol	64	64	PN chips/symbol
PN chips/ bit	64,128	256	PN chips/ bit

Table 2.7 Modulation Parameters For Forward Information Channel

Parameter	**Data Rate (bps)**			**Units**
	64000	32000	160000	
PN chip rate	4.096	4.096 s	4.096 s	Mcps
Code rate	1/2	1/2	1/2	bits/symbol
Symbol repetition	1	2	4	
Punctured rate	29/32	26/32	24/32	
Effective code rate	16/29	8/13	4/6	bits/symbol
Symbol rate	64000	64000	64000	sps
PN chips/ symbol	64	64	64	PN chips/symbol
PN chips/ bit	58	104	192	PN chips/ bit

2.2.5 Baseband Filtering

After modulation all the channels are individually sent to baseband filters. The base band filter parameters for the reverse and forward wideband CDMA channel are given on table 2.8. All the individual channels of the reverse wideband CDMA channel use identical individual baseband filters.

Table 2.8 Baseband Filter Parameters for the Forward and Reverse Wideband CDMA Channels

Parameters	Forward Channel	Reverse channel
Filter Bandwidth	5.0 MHz	5.0 MHz
Passband Ripple	3	3
Upper Passband Frequency	1.96 MHz	4.94 MHz
Lower Stopband Frequency	2.47 MHz	4.94 MHz
Minimum Stopband Attenuation	40 dB	40 dB

2.2.6 Gain Control and RF Carrier Modulation

The resulting baseband filtered inphase channels signals from all links are sent to a linear adder with gain control, similarly for the baseband filtered quadrature signals, see figure 2.11. This is done in both the forward and reverse wideband CDMA links allowing individual channels to be assigned different power levels. The resulting baseband signals are modulated by the inphase (I) and quadrature (Q) carrier signals, combined together, amplified and then sent to the antenna.

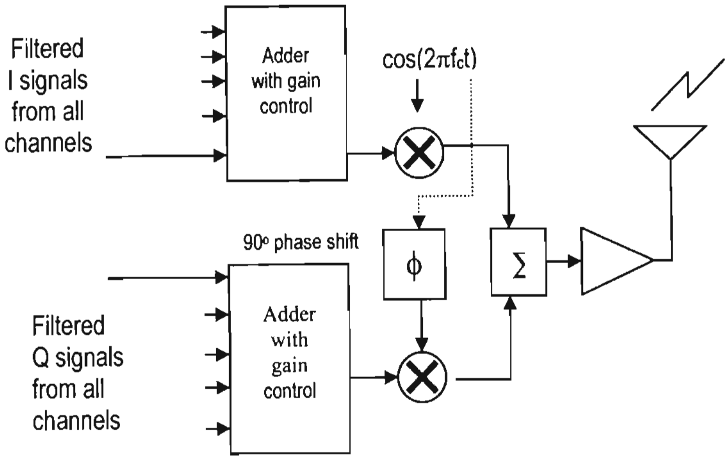

Figure 2.11 Carrier modulation of Wideband CDMA channels

An important aspect in radio communication is the transmission frequency band, since the bit error rates, the available bandwidth and the signal propagation distances depend on the position of this band on the radio spectrum. In the radio spectrum radio communication bandwidth is limited, and there is high need and competition for one with fairly good propagation characteristics.

The CDMA technology is very robust when it comes to narrowband interference [3]. CDMA pioneers claim that the technology can coexist with other narrowband systems in the same frequency band. The cellular, wireless local loops and personal communication systems (PCS) systems have been allocated different frequencies in different countries. This is due to different decision of governments, standardisation bodies and technologies. The cellular frequencies are mostly allocated around the 850 MHz and PCS frequencies around 1800 MHz. The North American countries are currently using the 1800 MHz band for 2G PCS systems, for which the rest of the world is planning to deploy the 3G systems.

To operate in such allocated frequency bands, one has to acquire a license from the authorities in that specific location, usually involving very high competition and enormous amounts of money. It is also possible to deploy a system on an unlicensed radio frequency band centred on 2.4 GHz, no license or permission is required, and it is free of charge.

There is uncertainty about system performance within unlicensed radio frequency bands with time, since one does not have the knowledge or control over other interfering systems being deployed within the same radio frequency band and operational area. Thus the drawback is that the co-channel interference from other systems changes with time and operational area. In South Africa the unlicensed band is not free for all at the moment. Telkom South Africa has exclusive rights to this band.

The South African frequency allocation plan has been under review since 1995 by a project called South African Band Replanting Exercise (SABRE) [31]. We propose the use of 1800 MHz PCS band for distance education system. The next section covers the system transmitter, channel and receiver models

3 TERRESTRIAL RADIO SYSTEM MODELLING

The model is based on a point-to-multipoint CDMA network with P subscribers scattered randomly at remote locations about the base station, figure 3.1. Each subscriber is assigned a unique DS-CDMA code.

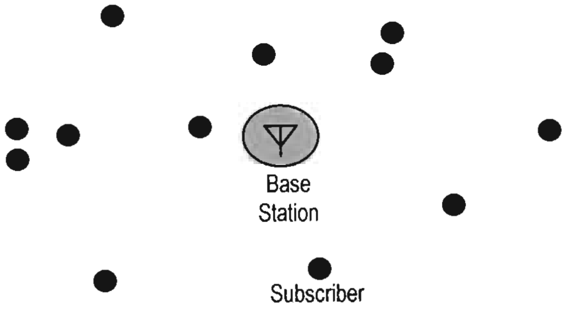

Figure 3.1: Point-to-multipoint communication system

3.1 Transmitter Model

In a wireless CDMA environment either PSK or differential PSK modulation is used. PSK gives better error performance than differential PSK but since coherent detection is more difficult to establish in a mobile environment, differential PSK is often preferred.

We opt for PSK (QPSK) modulation because there is no or very little mobility required by this application and also performance will improve by 3dB gain of PSK over deferential PSK signalling. Transmitter block diagram is given in figure 3.2.

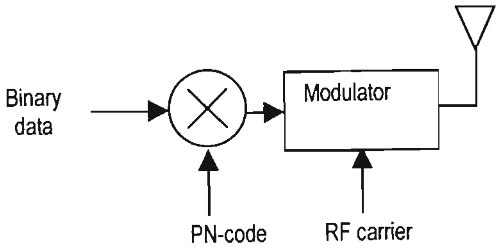

Figure 3.2: B lock diagram of a BPSK DS-CDMA transmitter

The transmitted DS-CDMA QPSK signal can be represented by

$$s_k(t) = Aa_k(t)b_k(t)\cos(\phi_k)\psi_1(t) + Aa_k(t)d_k(t)\sin(\phi_k)\psi_2(t) \tag{3.1}$$

where $\psi_1(t) = \cos(\omega_c t)$; $\psi_2(t) = \sin(\omega_c t)$; $\phi_k = \frac{\pi}{2} i$; $1 \le i \le 4$

$$a_k(t) = \sum a_k^i P_{Tc}(t - kT_c) \qquad a_k^i \in \{-1,1\}$$

$$b_k(t) = \sum b_k^i P_{Tb}(t - kT_b) \qquad b_k^i \in \{0,1\}$$

$$d_k(t) = \sum d_k^i P_{bc}(t - kT_b) \qquad d_k^i \in \{0,1\}$$

a_k^i is the i^{th} chip of the direct sequence code $a_k(t)$ of the k^{th} channel. b_k^i , d_k^i are the inphase and quadrature i^{th} data bits of channel k^{th} channel., P_{Tc} , P_{Tb} are rectangular pulses of unit height and duration T_c and T_b respectively. T_b and T_c are the bit and chip duration respectively. It is assumed that $T_b/T_c = N$, where N is the length of the direct sequence code.

3.2 Terrestrial Channel Model

One important aspect in radio communication is the radio propagation channel characteristics. The channel propagation characteristics are important for modelling and designing of an efficient radio communication system. There is often no line of sight between a transmitter and receiver in rural a environment because of vegetation, hills, mountains and sometimes, high buildings. This results in shadowing and the radio signal gets around these obstacles by diffraction, reflection and scattering. A review of the propagation channel characteristics is given in Appendix B. The complex low pass equivalent of the radio channel's impulse response is given by:

$$h(\tau)=\sum_{l=1}^{L}\beta_l \exp\{j\gamma_l\}\delta(\tau-\tau_l) \tag{3.2}$$

where β_l is the path gain, τ_l is the propagation delay, γ_l is phase shift and j is the imaginary number defined as $j^2 = -1$. It is assumed that the path phase of the received signal, $(\omega_c\tau_l+\gamma_l)$, is an independent random variable uniformly distributed over $[0,2\pi]$. The path delay is also an independent random variable and is assumed random over $[0,T_b]$.

The path gain is modelled as Rician random variable for light multipath channel and Rayleigh random variable for heavy multipath channel. The number of paths may be either fixed or randomly changing. Here fixed values L are used according to

$$L=\left[\frac{T_{\max}}{T_c}\right]+1 \tag{3.3}$$

where T_{max} is the maximum delay spread.

3.3 Receiver Model

The receiver model consists of matched filter for a particular spread spectrum code and coherent QPSK demodulator and diversity processing, shown in figure 3.3. The received signal is the convolution of $s(t)$ and $h(t)$, plus the zero-mean AWGN $n(t)$ given by

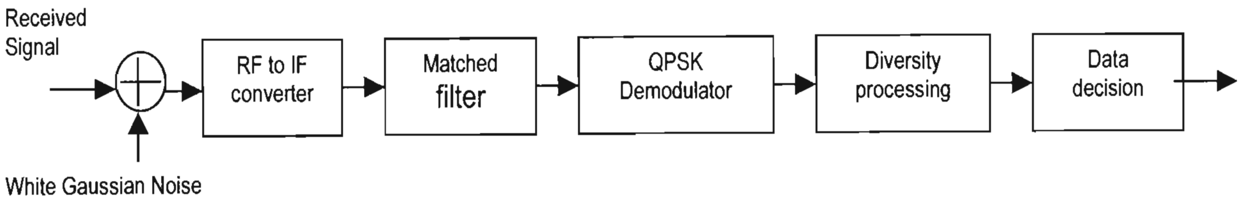

Figure 3.3: QPSK DS-CDMA Receiver block diagram

$$r(t)=\sum_{k=1}^{K}\sum_{l=1}^{L}A\beta_{lk}a_k(t-\tau_{lk})\left[b_k(t-\tau_{lk})\cos(\phi_{lk})\psi_1(t)+d_k(t-\tau_{lk})\sin(\phi_{lk})\psi_2(t)\right]+n(t) \quad (3.4)$$

where $n(t)=n_c(t)\cos(\omega_c t)+n_s(t)\sin(\omega_c t)$

The parameters τ_{lk}, ϕ_{lk} are, respectively, the difference in arrival time and phase between the j^{th} path of the reference user and the l^{th} path of the k^{th} user. It is assumed that ϕ_{lk} is uniformly distributed over [0,2π]. Assuming that channel 1 is reference channel, one can show that the output of the filters matched to the code of reference channel, sampled at $t=T_b$ can be expressed as [3].

$$\begin{aligned} g_x(t)&=\sum_{k=1}^{K}\sum_{l=1}^{L}A\beta_{lk}\cos(\phi_{lk})\left[b_k^{-1}R_{1k}(\tau_{lk})+b_k^{0}\hat{R}_{1k}(\tau_{lk})\right]+\eta \\ g_y(t)&=\sum_{k=1}^{K}\sum_{l=1}^{L}A\beta_{lk}\sin(\phi_{lk})\left[d_k^{-1}R_{1k}(\tau_{lk})+d_k^{0}\hat{R}_{1k}(\tau_{lk})\right]+v \end{aligned} \quad (3.5)$$

where d_k^{-1}, b_k^{-1} and d_k^{-0}, b_k^{0} are the quadrature (Q) and in-phase (I) components previous and current data bits, respectively. They can be either 1 or -1 with equal probability; η and ν are the thermal noise quadrature and in-phase components with power spectral density $N_0/2$.The partial correlation functions and noise components are given by [3]

$$\hat{R}_{1k}(\tau)=\int_{\tau}^{T_b}a_k(t-\tau)a_1(t)dt \qquad R_{1k}(\tau)=\int_{0}^{\tau}a_k(t-\tau)a_1(t)dt \quad (3.6)$$

$$\eta = \int_0^{T_b} a_1(s) n_c(s) ds \qquad\qquad v = \int_0^{T_b} a_1(s) n_s(s) ds \tag{3.7}$$

where g_x, g_y are the inphase and quadrature outputs of the matched filters sampled at T_b. Assuming the receiver selects the j^{th} path of channel 1, implying $\tau_{j1} = \phi_{j1} = 0$, then the complex envelope of matched filters output z = $g_x + j\, g_y$ is given by,

$$z = A\beta_{j1}T_b b_1^0 + \sum_{k=1}^{K} A(b_k^{-1}X_k + b_k^0\hat{X}_k) + j\sum_{k=1}^{K} A(d_k^{-1}Y_k + d_k^0\widehat{Y}_k) + (\eta + jv) \tag{3.8}$$

with $$X_1 = \sum_{\substack{l=1 \\ l\neq j}}^{L} R_{11}(\tau_{l1})\beta_{l1}\cos(\varphi_{l1}) \qquad \hat{X}_1 = \sum_{\substack{l=1 \\ l\neq j}}^{L} \hat{R}_{11}(\tau_{l1})\beta_{l1}\cos(\varphi_{l1})$$

$$Y_1 = \sum_{\substack{l=1 \\ l\neq j}}^{L} R_{11}(\tau_{l1})\beta_{l1}\sin(\varphi_{l1}) \qquad \widehat{Y}_1 = \sum_{\substack{l=1 \\ l\neq j}}^{L} \hat{R}_{11}(\tau_{l1})\beta_{l1}\sin(\varphi_{l1})$$

and for $k \geq 2$ $$X_k = \sum_{l=1}^{L} R_{1k}(\tau_{l1})\beta_{lk}\cos(\varphi_{lk}) \qquad \hat{X}_k = \sum_{l=1}^{L} \hat{R}_{1k}(\tau_{lk})\beta_{lk}\cos(\varphi_{lk})$$

$$Y_k = \sum_{l=1}^{L} R_{1k}(\tau_{l1})\beta_{lk}\sin(\varphi_{lk}) \qquad \widehat{Y}_k = \sum_{l=1}^{L} \hat{R}_{1k}(\tau_{lk})\beta_{lk}\sin(\varphi_{lk})$$

The QPSK demodulator computes the phase estimate $\hat{\phi} = \arctan(\mathrm{Re}(z)/\mathrm{Im}(z))$, which is compared with each of the stored prototype phase angles ϕ_i. The demodulator selects ϕ_i that is closed to the noisy estimate computed. The next section discusses the bit error probability of these models in AWGN, and multipath channels.

4 TERRESTRIAL RADIO PERFORMANCE EVALUATION

4.1 BER Performance Analysis

4.1.1 BER of CDMA in AWGN

The spreading-despreading 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 [9].

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_o}}\right) = Q\left(\sqrt{2\frac{E_b}{N_o}}\right) \tag{4.1}$$

Total noise into the system for CDMA comes as thermal noise and multi-user interference (MAI). When multi-user interference is taken into account, the BER has been shown in [15] to be given by

$$P_b = Q(\overline{SNR}),$$

where

$$\overline{SNR} = \sqrt{\frac{P_i}{\operatorname{var}\{MAI\} + Var\{AWGN\}}}$$

$$= \sqrt{\frac{1}{\frac{(K-1)}{3G_p}\left(1 - \frac{1}{4G_p}\right) + \frac{N_0}{2E_b}}} \tag{4.2}$$

K is the number of subscribers, G_p is the processing gain and E_b/N_0 is the AWGN value. The plots of equation 4.2 given in figure 6.1, with Gp =64, clearly show the effect of multi-user interference on CDMA system. The curves show that as K the number of active remote stations decreases for a given BER, the required *Eb/No* is reduced.

For the purpose of distance education in rural environment, the subscribers are few, sparse and scattered. The result is reduced value of K. This feature can be used to compensate for increased coverage or decrease in *Eb/No* requirements for the same BER for the proposed distance education system.

It is also observed that as *Eb/No* is increased, the improvements rate in the BER decreases as K increases. This is because in CDMA, increasing the transmitted power results in increment of the MAI, since one has to also raise the powers of the other channels to achieve proper detection levels.

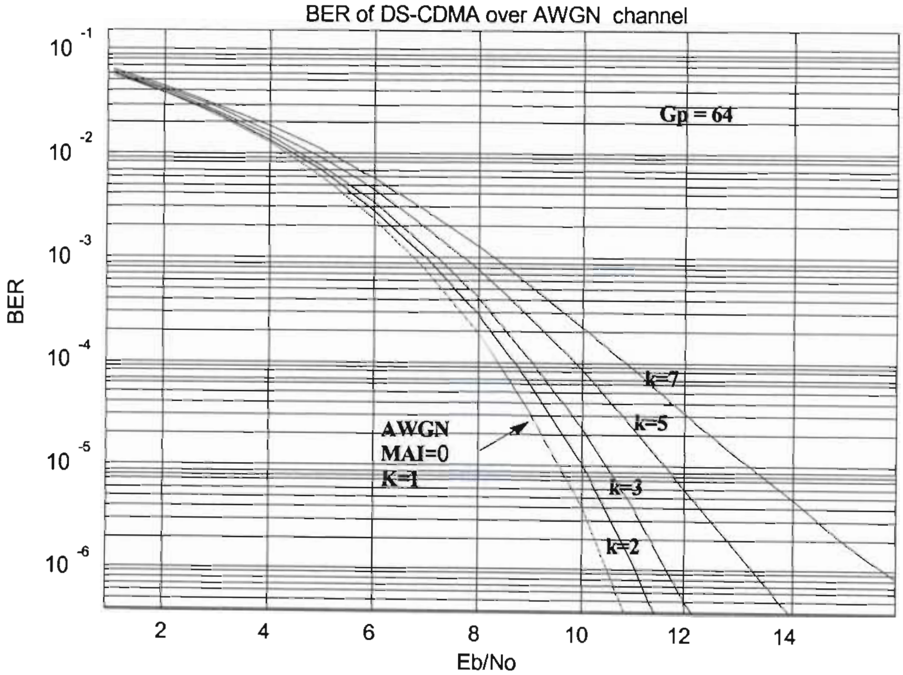

Figure 4.1: BER v/s Eb/No of DS-CDMA in AWGN. K=1, K=2, K=3 ,K=5 and K=7

4.1.2 BER of CDMA over Multipath Channel

For a multipath channel, the total received power is the sum of the L multipath signal powers received [20]. If the multipaths can be resolved, then the rake receiver employing time diversity can be used to constructively add the individual multipaths. Diversity implies combining a number of signals carrying the same information in order to improve the performance.

For most rural areas, it is safe to assume that about three significant multiple paths can be resolved [21]. The average resultant power in the multipath channel P_r, is always less than or equal to the power seen in an AWGN channel P_i. The average resultant power in a multipath channel can be expressed as the sum of the powers of the individual multipaths.

$$P_r = \sum_{l=1}^{L} P_l = \sum_{l=1}^{L} \operatorname{var}\{s(t)\beta_l \exp(j\gamma_l)\} = P_i \sum_{l=1}^{L} E\{\beta_l^2\} \tag{4.3}$$

where $\sum_{l=1}^{L} \beta_l \leq 1$

β_l is the signal amplitude weights of the multipath components and $s(t)$ the transmitted signal. The equation 4.2 above changes to

$$\overline{SNR} = \sqrt{\frac{P_i \sum_{l=1}^{L} E\{\beta_l^2\}}{\operatorname{var}\{MAI\} + Var\{AWGN\}}} = \sqrt{\frac{\sum_{l=1}^{L} E\{\beta_l^2\}}{\frac{(K-1)}{3G_p}\left(1 - \frac{1}{4G_p}\right) + \frac{N_0}{2E_b}}} \tag{4.4}$$

For a light multipath channel, one of the resolvable multipath components caries most of the received power. The β_l for this path is much larger compared to the rest of the signal amplitude weights of the other multipath components. In a heavy multipath channel, all the resolvable multipath components contribute fairly equally to the total received power and thus all the β_l values are approximately equal. The simulation results are plotted in figure 4.2. The effect of a multipath channel causing power level reduction and resulting in the system BER performance degradation can be observed. The figure 4.2 shows results for AWGN K=1, 3, 5, light multipath K=1, 3, 5 and heavy multipath K=1, 3, 5. The simulation considered L=3 significant resolvable multipaths. A minimum degradation of about 1 dB for K=1 light multipath and about 5,5 dB for K=1 heavy multipath compared to K=1 in AWGN.

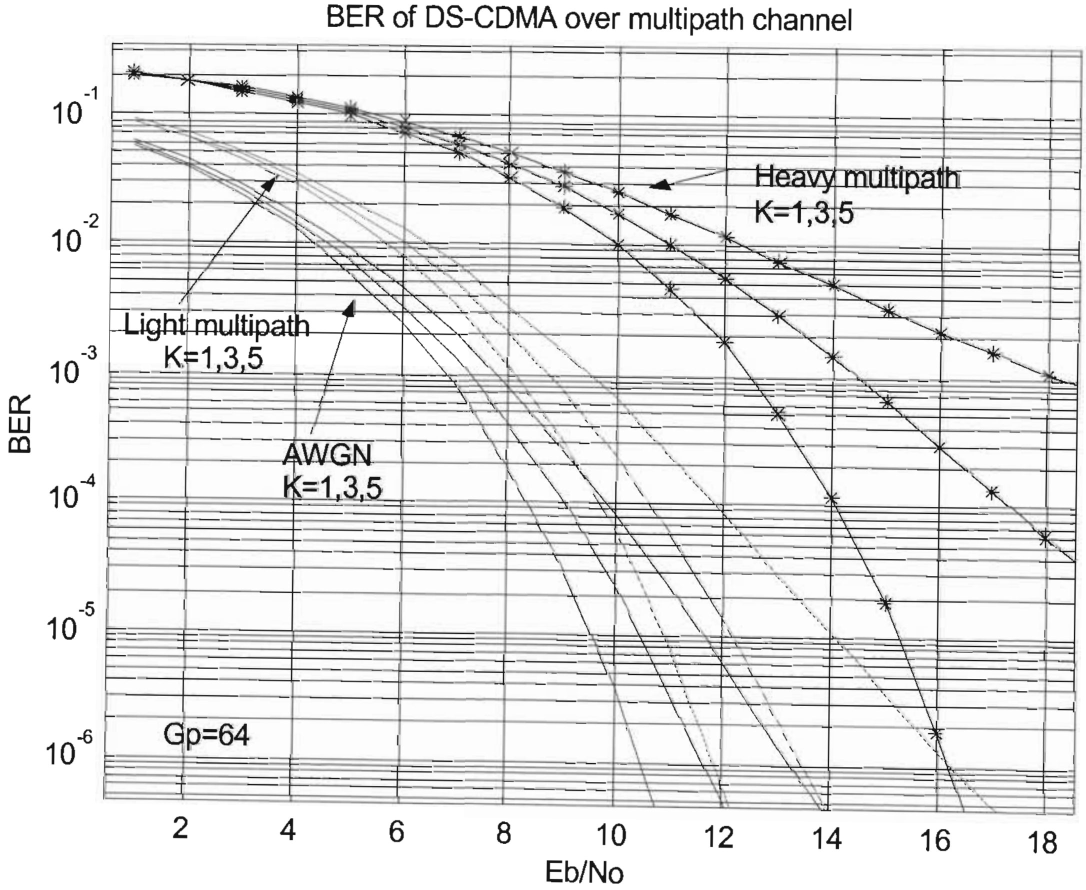

Figure 4.2: BER v/so Eb/No of DS-CDMA in AWGN, Light and Heavy multipath channels (K=1, 3,5)

It is also observed that for a given BER a higher *Eb/No* is required with increase in K and the severity or the intensity of multipath channel. The results show the worst case, since the simulation does not take into account the degradation of MAI due to the multipath characteristics of the channel. There is still a need to improve the performance shown in figure 4.2, by implementing strategies to reduce MAI and multipath effects.

4.2 Improvements on BER Performance

There are numerous ways and modifications that can be implemented to improve the BER performance of the proposed system. These improvements come because of extensive studies that have been and are still undertaken by many CDMA researchers.

The research efforts aimed at mitigating the effects of MAI on a conventional receiver have focused on spreading code waveform design, power control, FEC codes design, sectored/adaptive antennas, and multi-user detection [18].

Code waveform design involves the design of spreading codes with good cross-correlation properties. If the spreading codes were perfectly orthogonal there will be no MAI in CDMA, but this is not the case. In practice, nearly orthogonal or very low cross-correlation exhibiting codes like Orthogonal Walsh are used to minimise MAI.

Power control mechanisms can be used to assign certain channels higher transmission power compared to other channels in order to achieve required BER on those channels. This process must be done with caution since it may very well worsen MAI seen by weaker channel receivers. For this reason power control mechanisms are mostly used to equal the power levels of the channels seen by a receiver.

Voice activity factor: there is a reduction in MAI due to the ability of the CDMA technology to take advantage of the low human voice activity. The reduction in the interference due to the voice activity results in the *Eb/No* improvement ranging between 0 and 3.46 dB or equivalently, a capacity increase by factor of up to 2.22 [9]. The maximum improvement can be achieved when all the traffic channels carry only voice and there will be no improvement if all traffic channels only carry data.

4.2.1 Multi-user Detection Methods

Multi-user detection methods use code, timing, phase and amplitude information of multiple channels or users to jointly better the detection of each individual channel or user. It is assumed that the unique codes of the multiple channels are known to the receivers in advance [18], which is the case for the proposed system at the base station. An optimum multi-user sequential detector is known, but it is too complex for practical DS-CDMA systems [18].

The sub-optimal multi-user detectors can be categorised into linear detectors that apply linear transformations to the outputs of the matched receiver bank to reduce the MAI seen by the detector, and subtractive detectors that attempt to estimate and subtract the MAI. Although the multi-user detection concepts are still in the investigation stage, their implementation have been restricted to the uplink or base station, due to weight, size, and cost concerns for mobiles and remote terminals.

For the proposed system it might be worthwhile to consider multi-user detectors, but with such few users one also has to consider performance and capacity improvement as a result of these methods versus their cost and complexity.

One such method worth looking at, is the one proposed in [21] consisting of the combined Rake receiver/MAI Canceller. A simplified block diagram for a single channel receiver is shown in figure 4.3. The details of operation can be obtained from the reference. The receiver is simple, combines the capabilities of the MAI Canceller to reduce co-channel interference and those of the Rake receiver in using multipath diversity.

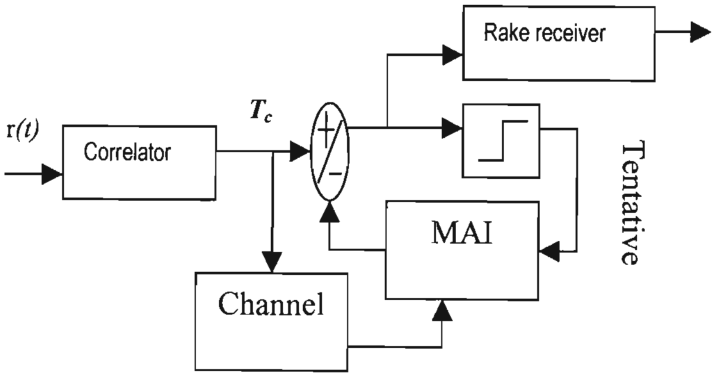

Figure 4.3: Block diagram of the Combined RAKE/MAI Canceller receiver

The receiver relies on channel parameters and time delay estimates. For a fixed receiver position there is no significant change on channel parameters. The simulation results obtained show that the proposed receiver structure has better BER performance than either the MAI Canceller or the Rake receiver when operated alone in a multipath channel environment, figure 4.4.

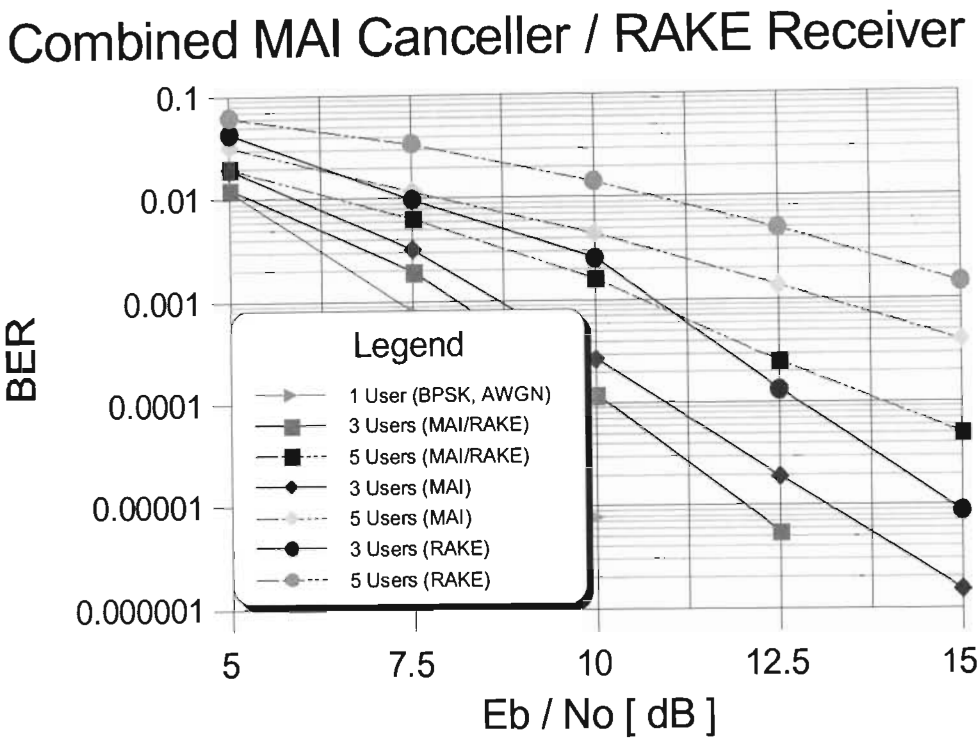

Figure 4.4: BER performance of a Combined MAI Canceller / Rake receiver [21]

At a 10^{-3} BER, K=3, a reduction of about 2.5 dB and less than 1 dB over the Rake receiver and the MAI Canceller, respectively, can be achieved on the required *Eb/No*. For the same BER and K=5 a reduction of about 4.4 dB and about 2.4 dB over Rake receiver and MAI Canceller respectively can be achieved on the required *Eb/No*. The reduction is even greater for the case of heavy multipath.

4.2.2 Coding Gain

Error coding using FEC codes is one of the most trusted, extensively studied and successfully implemented ways of improving the performance of a radio communication system. The performance results shown in section 4.1 are for uncoded DS-CDMA system and convolutional codes can be employed to improve performance.

The reduction on required E_b/N_0 for a given BER brought by the convolutional codes depends very largely on the rate, the constraint length K, transfer function of the convolutional encoder and the BER. This reduction is called coding gain. Table 4.1 shows the simulation results of the short constraint lengths soft-decision Viterbi decoding coding gain values for ½ rate codes [14].

	Uncoded	**Coding gain (dB)**		
P_e	E_b/N_o	K=5	K=6	K=7
10^{-3}	6.8	**3.3**	**3.5**	**3.8**
10^{-5}	9.6	**4.3**	**4.6**	**5.1**
10^{-7}	11.3	**4.9**	**5.3**	**5.8**

Table 4.1 Coding gain for soft-decision Viterbi decoding, rate 1/2

It is observed that the coding gain increases with increase in K and the reduction in BER. A 3.3 dB gain achieved on a ½ rate encoder with length of K=5 might be satisfactory to operate at about 6dB E_b/N_0 with BER of 10^{-3} on the light to medium multipath channel cases, see figure 4.2.

A gain not less than 6.5 dB is needed in the case of a heavy multipath channel to operate at about 6dB E_b/N_0 with BER of 10^{-3}, see figure 4.2. It takes a much more complex ½ rate K=41 length sequential decoder to provide a gain of 7.5 dB at 10^{-3} BER [14]. In this case we need extremely complex decoders to achieve the required gain, thus some other methods should explored to provide additional gain and keep decoder complexity as low as possible.

If we have on average the coding gain of about 3.3 dB, and 2.5 dB of the average voice activity factor gain, we can achieve an average gain of about 5.8 dB. The result is the same as shifting the simulation curves in figure 4.2 by 5.8 dB to the left on *Eb/No* axis. Depending on system design environment, it is clear that a good performance can be obtained for the light to medium multipath channel case, with just coding gain and voice activity factor gain.

In the worst case (heavy multipath) the required *Eb/No* for 10^{-3} BER is greater than 5.8 dB. The following can be implemented:

- Combined MAI/Rake receiver Canceller and MAI mitigation techniques mentioned can be used in order to provide additional gain while keeping the decoder complexity low at ½ rate and K=5,
- Alternatively, with the same combined coding and voice activity gain of 5.8 dB, increase the transmitted power to achieve operational *Eb/No* to give acceptable BER performance. To achieve BER performance of 10^{-3} would require *Eb/No* about 12.2 dB in this case.

Combined MAI/Rake receiver Canceller and MAI mitigation techniques mentioned can be used for the light to medium multipath to increase coverage area for a given BER and *Eb/No* operating point. In the next subsection, we look at performance estimation using link budget estimations for both the forward and reverse links.

4.3 Link Budget Computation

For a given bit error probability, the actual E_b/N_0 ratio depends on the radio system design and the error correction codes. If we know the performance of the coding methods used, the tolerance of digitised voice and the data errors, we can find the minimum E_b/N_0 ratio for proper system operation. The link budget calculation is then used to predict the operational E_b/N_0 ratio since it takes into account the radio system design components.

The predicted operational E_b/N_0 value should preferably be higher compared to the required minimum value. If not then, system design parameters (coverage, capacity, and transmitted power) are adjusted or traded off in the link budget calculation, until a satisfactory E_b/N_0 ratio above minimum value is obtainable. For Link budget calculation equations and terms see appendix C.

The frequency reuse factor is not used for this application, assuming we have good separation between the base stations. The voice activity factor is taken to be 0.6. For a coverage distance of about 3 to 30 km from base station, the Hata-Okumura model estimation of average propagation loss is about -95 to -140 dB. We specified a nominal traffic channel rate of 64 kbits/s, and 16 kbits/s for sync channel and the paging channel.

The FCC standards require the total EIRP for the base station not to exceed 1640 W (32dBW) in any direction per 1.25 MHz for heights above average terrain less than 300 m [9]. No range for the nominal power is specified for the wideband CDMA; its value is to be obtained from the forward overhead channel parameters. We will use the 1.25 MHz specifications as a guide for our 5 MHz wideband channel. The FCC standards define three power classes of remote or personal mobile stations. It is specified that the EIRP of one of the classes at maximum shall exceed 3 dBm. Typical values for IS-95 standard are assumed for the rest of the parameters [9].

The minimum value on *Eb/No* specified by required bit error performance of system is to be satisfied by the traffic channel. The pilot channel does not require large *Eb/No* since it is a known sequence. The sync channel requires a large value of *Eb/No* to achieve low bit error rates, since correct and accurate sync has to be maintained between base station and remote terminals for proper timing of the received message.

4.3.1 Forward Link Budget Computation

The forward link is from the base station to the remote station. The following can be derived from the predictions given by the forward link budget computations

i. Trading coverage distance

If all the remote stations are very close to the base station, the reduced propagation loss can be traded in for reduced ERP of the traffic channels or improve received Eb/*N.*

Trading coverage distance for reduced ERP (fixed traffic channel Eb/No): A saving of 20 dB on the base station ERP (Effective Radiated Power) of the forward traffic channels is achieved when the propagation loss is reduced by an equivalent value of 20 dB for a given *Eb/No*, see table 4.2 columns 1 and 2. The same results are obtained with gain of 30 dB in table 6.2 column 1 and 4 when propagation loss is reduced by 30 dB.

Trading coverage distance for reduced traffic channel Eb/No(fixed ERP): A gain of about 5.9 dB on the received traffic channel *Eb/No* is observed, as propagation loss is reduced form -120 to -110 dB for a given forward link channel ERP values, table 4.2 columns 2 and 3.

ii. Trading capacity

When the total number of active remote stations is small, the reduced capacity can be traded in for reduced ERP or improved coverage distance depending on the need.

Trading capacity for coverage distance (fixed ERP): Reducing the number of active users from 25 to 5, results in the received traffic channels *Eb/No* gain of about 7 dB for given ERP values of the channels of the forward link, table 4.3 column 1, 2 and 3. The sync, and pilot channels received *Eb/No* did not change as significantly as the traffic channel. This improvement can be used to compensate for the increase in propagation loss as the coverage distance is increased.

Trading capacity for reduced ERP (fixed Eb/No): for a given received traffic channels *Eb/N* at the user stations, a saving of about 7 dB is achieved on the ERP of the total base station traffic channels when the number of active users are reduced from 25 to 5, table 4.3 column 1 and 4.

iii. Base station ERP Limits

When the total base station traffic channel ERP is reduced from maximum of 60 dBm to 44 dBm, a good performance (without degrading the received Eb/No to unacceptable values) can still be maintained, table 4.3 column 4.

Table 4.2 Forward Link wideband CDMA channel Budget Calculations

Quantity	Column 1	Column 2	Column 3	Column 4	Units
Total traffic ERP	**50**	**30**	30	20	dBm
Number of users	20	20	20	20	
Sync channel ERP	**37**	**17**	17	7	dBm
Pilot channel ERP	**41**	**21**	21	11	dBm
Total channel activity factor	0.6	0.6	0.6	0.6	
Cell transmit Antenna gain	14	14	14	14	dB
Transmit filter & cable losses	-2.5	-2.5	-2.5	-2.5	dB
Mean propagation losses	**-140**	**-120**	-110	-110	dB
Lognormal shadow/fade Allowance	-6.2	-6.2	-6.2	-6.2	dB
Receive gain of remote station antenna	0	0	0	0	dB
RS receive cable and body losses	-3	-3	-3	-3	dB
BW	4.10	4.10	4.10	4.10	MHz
Noise Figure	8	8	8	8	dB
Channel Rate					
traffic channel	64000	64000	64000	64000	bps
Sync channel	16000	16000	16000	16000	bps
Power					
Pt	39.21	19.21	19.21	9.21	dBm
Pc	44.14	24.14	24.14	14.14	dBm
Pu	27.71	7.71	7.71	-2.29	dBm
Pa	32.64	12.64	12.64	2.64	dBm
Pm	-105.06	-105.06	-95.06	-105.06	dBm
Ptr	-109.99	-109.99	-99.99	-109.99	dBm
Ppr	-108.20	-108.20	-98.20	-108.20	dBm
Psr	-112.20	-112.20	-102.20	-112.20	dBm
Interference					
It	-169.975	-169.975	-159.975	-169.975	dBm/Hz
Ip	-171.185	-171.185	-161.185	-171.185	dBm/Hz
Is	-170.418	-170.418	-160.418	-170.418	dBm/Hz
Ig	-66.124	-66.124	-66.124	-66.124	dBm/Hz
Thermal Noise N	-165.977	-165.977	-165.977	-165.977	dBm
Eb/No					
Traffic	7.12	7.12	13.09	7.12	dB
Pilot	-9.49	-9.49	-4.38	-9.49	dB
Sync	10.79	10.79	16.38	10.79	dB

Table 4.3 Forward Link wideband CDMA channel Budget Calculations

Quantity	Column 1	Column 2	Column 3	Column 4	Units
Total traffic ERP	51	51	51	44	dBm
Number of users	25	15	5	5	
Sync channel ERP	37	37	37	37	dBm
Pilot channel ERP	41	41	41	41	dBm
Total channel activity factor	0.6	0.6	0.6	0.6	
Cell transmit Antenna gain	14	14	14	14	dB
Transmit filter & cable losses	-2.5	-2.5	-2.5	-2.5	dB
Mean propagation losses	-140	-140	-140	-140	dB
Lognormal shadow/fade Allowance	-6.2	-6.2	-6.2	-6.2	dB
Receive gain of remote station antenna	0	0	0	0	dB
RS receive cable and body losses	-3	-3	-3	-3	dB
BW	4.096	4.096	4.096	4.096	MHz
Noise Figure	8	8	8	8	dB
Channel Bit Rates					
Traffic channel	64000	64000	64000	64000	bps
Sync channel	16000	16000	16000	16000	bps
Power					
Pt	39.24	41.46	46.23	39.23	dBm
Pc	44.15	45.00	47.75	44.15	dBm
Pu	27.74	29.96	34.73	27.73	dBm
Pa	32.65	33.50	36.25	32.65	dBm
Pm	-105.05	-104.20	-101.45	-105.05	dBm
Ptr	-109.96	-107.74	-102.97	-109.97	dBm
Ppr	-108.20	-108.20	-108.20	-108.20	dBm
Psr	-112.20	-112.20	-112.20	-112.20	dBm
Interference					
It	-169.96	-168.736	-165.258	-169.965	dBm/Hz
Ip	-171.175	-170.328	-167.574	-171.178	dBm/Hz
Is	-170.409	-169.689	-167.223	-170.412	dBm/Hz
Thermal Noise N	-165.977	-165.977	-165.977	-165.977	dBm
Eb/No					
Traffic	7.15	9.36	14.14	7.14	dB
Pilot	-9.49	-9.70	-10.63	-9.49	dB
Sync	10.79	10.57	9.60	10.79	dB

4.3.2 Reverse Channel Link Budget Computation

The reverse link is from the remote stations to the base station. There are different classes of remote terminals defined in [9], with the maximum ERP for all the classes being 23 dBm. The following can be deduced from the prediction for the reverse traffic link budget computation

i. Trading propagation coverage distance for reduced ERP

Table 4.4 columns 1 and 4. : A saving of about 26 dB on the remote station's reverse traffic channel ERP is achieved when the propagation loss is reduced to –110 dB from –140 (this equivalent to reducing the distance between the base station and the remote station from more than 30km to about 5km) for a given *Eb/No.*

Table 4.4, column 1 and 5: the propagation loss becomes dominant as the distance increases. At propagation loss of –140 dB, a minimum traffic channel ERP of about 23 dB is required for acceptable *Eb/No*. At lower propagation loss values, far less traffic channel ERP values are required to achieve an acceptable base station received *Eb/No* value, table 4.4 columns 3 and 4.

ii. Trading capacity for reduced ERP

Reducing number of active users from 25 to 5 results in significant *Eb/No* gain of the traffic channels at the base station. This gain can be traded for reduced traffic channel ERP, as shown in table 4.5 comparing column 1 and 2, and comparing column 3 and 4.

Table 4.4 Reverse Link wideband CDMA channel Budget Calculations

Quantity	**Column 1**	**Column 2**	**Column 3**	**Column 4**	**Column 5**	**Units**
Remote station ERP	**23**	**23**	**5**	**-5**	10	dBm
Number of users	**20**	**20**	**20**	**20**	**20**	
traffic channel	64000	64000	64000	64000	64000	bits/s
Total channel activity factor	0.60	0.60	0.60	0.60	0.60	
Cell transmit Antenna gain	14.00	14.00	14.00	14.00	14.00	dB
Transmit filter & cable losses	-2.50	-2.50	-2.50	-2.50	-2.50	dB
Mean propagation losses	**-140.00**	-110.00	-110.00	-110.00	-140.00	dB
Lognormal shadow/fade Allowance	-6.20	-6.20	-6.20	-6.20	-6.20	dB
RS receive cable and body losses	-3.00	-3.00	-3.00	-3.00	-3.00	dB
Bandwidth	4.096	4.096	4.096	4.096	4.096	MHz
Base station Noise Figure	5	5	5	5	5	dB
Power						
Pma	**26.00**	**26.00**	**8.00**	**-2.00**	**13.00**	dBm
Pcu	-111.70	-81.70	-99.70	-109.70	-124.70	dBm
Iutr	-167.25	-137.25	-155.25	-165.25	-180.25	dBm/Hz
Thermal noise N	-168.98	-168.98	-168.98	-168.98	-168.98	dBm
Reverse traffic channel ***Eb/No***	**5.26**	**7.49**	**7.31**	**5.96**	**-4.10**	dB

Table 4.5 Reverse Link wideband CDMA channel Budget Calculations

Quantity	**Column 1**	**Column 2**	**Column 3**	**Column 4**	**Units**
Remote station ERP	20	20	12	12	dBm
Number of users	**25**	**10**	**10**	**5**	
traffic channel	64000	64000	64000	64000	bits/s
Total channel activity factor	0.60	0.60	0.60	0.60	
Cell transmit Antenna gain	14.00	14.00	14.00	14.00	dB
Transmit filter & cable losses	-2.50	-2.50	-2.50	-2.50	dB
Mean propagation losses	-130.00	-130.00	-130.00	-130.00	dB
Lognormal shadow/fade Allowance	-6.20	-6.20	-6.20	-6.20	dB
RS receive cable and body losses	-3.00	-3.00	-3.00	-3.00	dB
Bandwidth	4.096	4.096	4.096	4.096	MHz
Base station Noise Figure	5	5	5	5	dB
Power					
Pma	23.00	23.00	15.00	15.00	dBm
Pcu	-104.70	-104.70	-112.70	-112.70	dBm
Iutr	-159.24	-163.50	-171.50	-175.02	dBm/Hz
Thermal noise N	-168.98	-168.98	-168.98	-168.98	dBm
Reverse traffic channel ***Eb/No***	6.04	9.65	6.29	7.25	dB

5 CONCLUSIONS

The distance education services described, ranges from narrowband to broadband, from real to non-real time and from broadcast to fully interactive services. Due to the large bandwidth demands, the large coverage distances, and the cost involved it is more economically feasible not to provide broadband services. All video material would have to be downloaded from the base station stored and played back at the remote station.

The satellite links are ideal since even broadband services can be provided over very large coverage distances. Unfortunately, satellite links are very expensive to operate. Terrestrial wireline solutions are not cost effective for rural areas. The proposed network for distance education services is a hybrid of the satellite and terrestrial wireless links.

The satellite links are to provide a means by which national centres can transport information to the base stations of the terrestrial system. The cost can be reduced further if the satellite link becomes just a broadcast link. The terrestrial part of the network provides subscriber access to the network. This system makes interaction possible up to the base stations. The terrestrial system model, description and specification are all based on a fixed cellular DS-CDMA wireless system. Some of the reasons for choosing of CDMA over TDMA and FDMA relevant for this particular application are: CDMA provides increased capacity and coverage range, improved protection against multipath interference, reduced average required transmitted power, high narrowband interference rejection capability, enhanced privacy and security, and the ability to provide variable data rates with out changing the transmission and detection systems.

The terrestrial rural channel propagation characteristics depend very much on the terrain and line of sight. When shadowing occurs, the radio signal gets around obstacles by diffraction, reflection and scattering, resulting in small-scale fading and large-scale propagation loss at the receiver location. For a non-mobile or fixed links, small scale fading is a spatial phenomenon.

The large-scale propagation losses depend on carrier frequency and transmitter-receiver separation. Lower carrier frequencies, unlike the much higher carrier frequencies, cover longer distances, do not require line of sight, and they are not affected by rain scattering and atmospheric absorption. The higher frequencies have an advantage of availability of much wider bandwidth.

In other countries there exists radio frequency bands for which no license is required to operate radio links and are free for all to use called unlicensed radio frequency bands. The disadvantage of operating in these bands is the uncertainty about the performance of the system with time since there is no knowledge or control over interfering systems being deployed within the same frequency band and operational area. Telkom SA currently has exclusive rights to all the unlicensed radio frequency bands in South Africa. South African National table of frequency allocations is current being revised by SABRE. We propose the use of PCS frequency band in the 1800MHz for the terrestrial radio links.

The simulation results show a minimum degradation of about 1dB in light multipath and about 5.5 dB in heavy multipath compared to in AWGN for the number of active channels K=1. The results also show that as K decreases for a given BER, the required *Eb/No* is reduced. The results also show that as *Eb/No* is increased, improvements rate in BER decreases. This is due to the fact that in CDMA, increasing transmitted power results in increment of the MAI.

It is observed that for a given BER a higher *Eb/No* is required with the severity or the intensity of the multipath channel. The results represent the worst-case scenario, since the degradation of MAI due to the multipath characteristics of the channel is not considered. The reduction of the MAI and the multipath effects in order to improve performance are discussed. The discussions include spreading codes, power control, FEC codes, sectored/adaptive antennas, and multi-user detection. Depending on system design environment, it is shown in section 4.2.2 that with just coding gain, diversity processing and voice activity factor gain, acceptable performance levels can be obtained.

The link budget estimations have been computed and the system performance explained for various systems parameters in section 4.2. The results show predictions within the acceptable range for the system operation to comply with the radio regulations. The results also show the limiting effect of propagation loss on the coverage distance for a given bit error rate performance. From these results we therefore can draw a conclusion that the proposed system is feasible.

APPENDIX A

CDMA Review

Spread spectrum signals for digital communications were originally developed and used for military communications. The developers aimed at providing a multiple access technique that would use the same channel, provide hostile jamming resistance, and hide signals by transmitting it at low power, thus make it difficult for the unintended listener to detect its presence in noise.

CDMA or spread spectrum technology has been implemented under various schemes such as [3,6,7]

Direct sequence (DS-CDMA): In this technique, the information-bearing signal is multiplied directly by fast code signal.

Frequency hopping *(*FH-CDMA): Here, carrier frequency at witch the information-bearing signal is transmitted is rapidly changed according to the code signal.

Time hopping (TH-CDMA): The information-bearing signal is not transmitted continuously; instead, the signal is transmitted in short bursts where the times of the burst are decided by the code.

Hybrid modulation: Two or more of the above-mentioned spread spectrum modulations techniques can used together to combine the advantages.

Wideband CDMA is a direct sequence CDMA where the transmission bandwidth is 5, 10 and 20 MHz and can support a minimum of at least 64 kbits/s. Narrowband CDMA has a spreading bandwidth of 1.228 MHz and maximum data rate of 9.6 kbits/s.

CDMA has recently found application in variety of both commercial mobile and fixed communication systems. CDMA has also experienced the most rapid deployment and rise in subscriber of any wireless technology [16]. It has been shown by many from a technological and commercial perspective that CDMA is an excellent technology choice and provides superior solutions for WLL systems [16,17].

In a mobile environment the wide ranging unique features and benefits of CDMA has resulted in rapidly growing acceptance and preference over its competitors within the cellular industry. The North American CDMA standard called IS-95 has already been successfully implemented in many countries. The largest CDMA networks exits mainly in Asian countries.

A.1 Direct Sequence CDMA

We introduce briefly DS-CDMA, as it has been extensively referred to in most of the chapters. In DS-CDMA a narrowband PSK information signal is directly modulated or multiplied by a digital code signal. The digital code signal is often called pseudo-random/pseudo-noise (PN) sequence. The PN code is a stream of binary ones (+1) and zeros (-1) referred to as chips. The word bits usually refer to the elements of the information signal.

For binary data, the data modulation is omitted and information signal bits $b(t)$ is directly multiplied by the PN sequence $c(t)$. The resulting code is modulated signal by a carrier using one of the phase shift keying (PSK) techniques figure A.1. For spreading the chip interval T_c is much smaller than the bit interval, T_b.

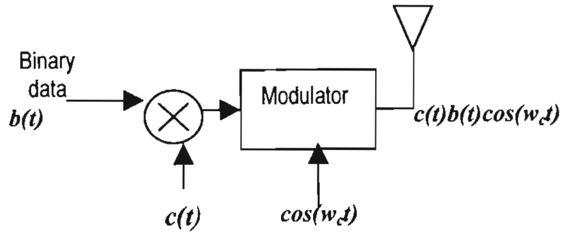

Figure A.1: B lock diagram of a BPSK DS-CDMA transmitter

The DS-CDMA receiver uses coherent detection to despread the received signal, using locally generated replica of the PN code sequence and a receiver correlator to extract from all possible signals the desired signals. The correlator responds only to a DS-CDMA signal that are encoded with a PN code sequence that matches its own code and thus can be tuned to different code by simply changing its local code. Apart from the known properties of CDMA, DS-CDMA has specific properties as listed below in table A.1 [3]:

Table A.1 DS-CDMA Advantages and disadvantages

• **Advantages of DS-CDMA**	• **Disadvantages of DS-CDMA**
• DS-CDMA code signal generation is easy, done by simple multiplication. • Frequency synthesiser(carrier generator) is simple, since only one carrier frequency is needed • Coherent demodulation of spread spectrum signal is possible. • There is no user-to-user synchronisation needed.	• Synchronisation between locally generated PN code and received signal is not easy and must be achieved within a fraction of chip time T_c. • Difficulty of controlling measures to solve the near-far effect. This is not an issue for a broadcast system.

A.2 Wideband CDMA and 3G Networks

The first Generation wireless systems were analogue, followed by (2G) second-generation digital wireless. Most current existing networks are 2G networks. Standard organisations around the world have recently been and are currently still working on the standards for what is called the "Third Generation mobile Communication Networks" (3G). Increased demand for higher data rates services and better spectral efficiency drives the emergence these new standards.

The European ETSI 3G networks standard is called UMTS and the ITU networks standard is called the IMT-2000.The 3G networks are to provide multimedia services and high rate packet data services. In summary the IMT-2000 main objectives are [6]:

Full coverage and mobility for 144 Kbps,386 kbps
Limited coverage and mobility for 2Mb/s
High spectral efficiency compared to existing systems
High flexibility to introduce new services

Wideband CDMA is a direct sequence CDMA where the transmission bandwidth is 5, 10 and 20 MHz. Wideband CDMA has been proposed as air interfaced for most of the 3G networks. The air interface standards based on CDMA are classified depending on whether the base stations are synchronised or not. The network asynchronous schemes consist of WCDMA jointly proposed by the European ETSI and Japanese ARIB, and the Korean standard called TTA II, with same parameters as WCDMA. The network synchronous consist of the adapted CDMA2000 form USA, and one similar to it called TTA I from Korea.

APPENDIX B

Terrestrial Channel Characteristics Overview

Channel propagation characteristics are important for modelling and designing of an efficient radio communication system. There is often no line of sight between a transmitter and receiver in rural environment because of vegetation, hills, mountains and sometimes, high buildings. This results in shadowing and the radio signal gets around these obstacles by diffraction, reflection and scattering.

The multipaths arrive at the receiver with different amplitudes and phases. These reflections add up and cause signal peaks or dips. The interaction of the multipaths affects the received power as a function of distance and introduces small scale fading.

B.1 Large Scale Path Loss

Propagation models are used to predict propagation path losses between a transmitter and a receiver. The accuracy of each model depends on its the ability to account for irregular terrain and buildings. The model outputs are used for coverage, path loss and interference prediction. This makes accuracy of these models is very important, as it affects the performance of the system.

Inaccurate prediction would for example: either raise prediction of required Eb/No level witch would affect financial feasibility or reduce prediction of Eb/No leading to degradation of quality of services. The imperical propagation models only provide general guidelines and average values [28]. For proper design, accurate field measurements should be done to provide information on radio coverage in the specific area where the system is to be deployed.

One of the most extensively used imperical channel models is called *Hata-Okumura Model* and is given by [9,20, 23, 26-29]

$$L_{50}(urban) = 69.55 + 26.16 \log f_c - 13.82 \log h_b - a(h_n) + (44.9 - 6.55 \log h_b) \log(R) \quad dB$$
$$L_{50}(rural) = L_{50}(urban) - 4.78(\log f_c)^2 + 18.33(\log f_c) - 40.94 \quad dB$$
$$\text{(B.1)}$$

where $a(h_m) = 3.2(\log 11.75 h_m)^2 - 4.97 \quad dB$

$150 \leq f_c \leq 1{,}500$ MHz;	transmission frequency (MHz)
h_m	mobile antenna height
$30 \leq h_b \leq 200$ m,	base station antenna height
$1 \leq h_m \leq 10$ m;	$a(h_m)$ = correction factor for RS antenna height (dB)
$1 \leq R \leq 20$ km;	distance from BS (km) to receiver

The L_{50} gives us the average propagation loss due to both path loss and large scale fading characteristics that would be experienced by a signal 50% of the time for given values of R, f_c, h_b and h_m. Typical values of propagation losses are plotted in figure B.1. One would certainly require a better value for specification of a communication system. For example, it would be better to design a system using a propagation loss that would be experienced by a signal 80-90% or even 95% of the time.

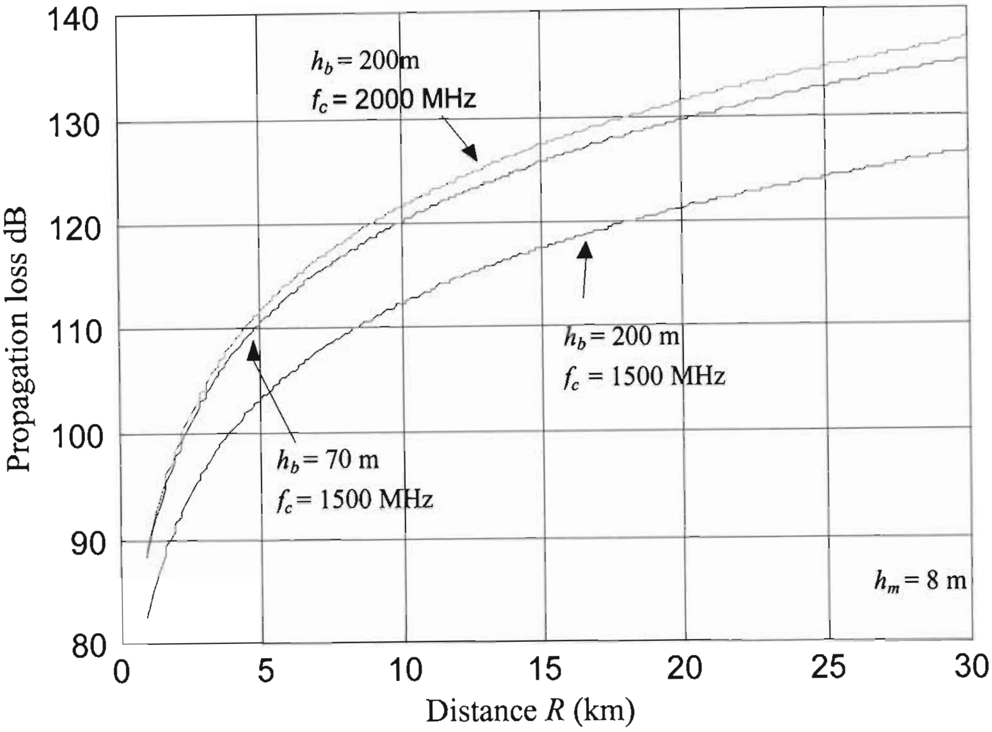

Figure B.2: Propagation loss using Hata-Okumura model

If we approximate propagation loss as a Gaussian variable with mean L_{50}, and variance σ = 6dB for rural areas [9]. About 84% of probability curve is covered within the range (-∞,σ). That is for L_{84} there is a gain in propagation loss over L_{50}. Therefore $L_{84} = L_{50} + \sigma$ dB, gives us the estimate of the average propagation loss for 84% of the time that a signal will experience.

If average propagation loss for x% of the time is required, one would have to find a corresponding point α in the Gaussian curve, for which x% of curve is covered form -∞ to α point in terms of the variance σ (e.g. $p\sigma$) as an offset from L_{50}. Thus $L_x = L_{50} \pm p\sigma$ dB gives the estimate propagation loss experienced for x% of the time;

B.2 Small Scale Fading and Multipath

Multipath propagation causes fast signal fluctuations called *small-scale fading*, *short-term fading* or just fading. Fading is observed when two or more multipaths arrive at the receiver at slightly different times [28]. The result is amplitude and phase variation of a received signal. In a mobile environment the effects of multipath propagation are; rapid changes in signal strength over small travel distance or time, random frequency modulation due to Doppler shifts on different multipaths and time dispersion caused by multipaths propagation delays [20].

In a rural environment, most of the obstacles causing multipaths are stationary relative to a fixed receiver and fixed transmitter for a fixed radio access system. The effects of multipath for a fixed radio environment compared to mobile are:-

a) no rapid signal strength changes over small time intervals for a fixed receiver location
b) no random frequency modulation since the multipaths will not experience any Doppler shifts
c) relatively constant time dispersion caused by multipaths propagation delays

In a fixed radio environment fading is then seen to be a purely spatial phenomenon. The advantage is that receiver antennas can be positioned at locations where multipaths add up to give signal peaks. The Raleigh probability density function for heavy multipath channel; and Rician probability density function for light multipath channel can characterise the envelope of the received signal, r, at different locations or distances. Unlike in mobile environment the envelope is relatively constant for a fixed location.

A **multipath channel** can be represented by multiple paths having, a real positive gain β_l, propagation delay τ_l, and phase shift γ_l, where l is the path index. In a fixed radio environment, the complex response of lth path is time invariant and is given as [20]

$$h_l(\tau) = \beta_l \exp\{j\gamma_l\}\delta(\tau - \tau_l), \tag{B.2}$$

and the total complex impulse response is modelled as

$$h(\tau) = \sum_{l=1}^{L} \beta_l \exp\{j\gamma_l\}\delta(\tau - \tau_l), \tag{B.3}$$

where $\delta(\,)$ is the direc delta function, $h(\tau)$ is the time domain response. An important quantity is the *delay spread* T_m, defined as the variance of the power delay profile. And is given by

$$T_m \equiv \sqrt{E\left[\tau^2\right] - E^2[\tau]} \tag{B.4}$$

with $$E[\tau] \equiv \frac{\sum_l \tau_l \beta_l}{\sum_l \beta_l^2} \quad \text{and} \quad E\left[\tau^2\right] \equiv \frac{\sum_l \tau_l^2 \beta_l}{\sum_l \beta_l^2}$$

If the data bit is larger than the delay spread $T_{m,}$ then the channel introduces a negligible intersymbol interference. Typical value for delay spread is 0.8 μs macrocells [3].

The inverse of T_m is the measure of *coherence bandwidth* $\{(\Delta f)_c\}$ of the channel, which is the bandwidth over which the propagation characteristics are correlated. If the coherence bandwidth is small compared to the transmitted signal bandwidth W, the channel is frequency selective. Generally CDMA systems are frequency selective, since they have $W >> (\Delta f)_c$. In a non-mobile environment, the channel will still be frequency selective but its gain and phase will not vary with time.

APPENDIX C

Link Budget Calculations Equations

C.1 Forward CDMA channel equations [9]

1.Traffic channel effective radiated power (ERP)

$$p_t = P_t - 10\log N_t - 10\log C_f \qquad (dBm)$$

P_t	ERP of all traffic channels from transmit antenna of cell site *(dBm)*
C_f	the channel voice activity factor (typical value 0.4 to 0.6)
N_t	number of traffic channels supported by the sector or cell

2. Transmitted Power per user:

$$p_u = P_t - G_t - L_c \qquad (dBm)$$

G_t	the gain of the cell transmit antenna *(dB)*
L_c	transmit filter and cable loss between the output of the linear amplifier circuit and the input of the transmit antenna filter & cable losses

3. Total base station ERP:

$$P_c = 10\ \log[\ 10^{\,0.1 p_t} + 10^{\,0.1 p_s} + 10^{\,0.1 p_p}\ ] \qquad (dBm)$$

p_s , p_p the ERP of sync, and pilot channels respectively *(dBm)*

4. Base station amplifier power:

$$p_a = P_c - G_t - L_c \qquad (dBm)$$

5. Total remote station received power:

$$p_m = P_t + L_p + A_l + G_m - L_m \qquad (dBm)$$

L_m the remote station receiver cable and connector losses *(dB)*

L_p the average path loss between the base station and the remote station *(dB)*

A_l Lognormal shadow/fade allowance

G_m the (receive) gain of remote station antenna

6. Received power for each of the channels by the remote station from the serving base station *(dBm)*:

$$p_{tr} = p_t + L_p + A_l + G_m - L_m \qquad p_{pr} = p_p + L_p + A_l + G_m - L_m$$

$$p_{sr} = p_s + L_p + A_l + G_m - L_m$$

where p_{tr}, p_{pr} ,p_{sr} are the received powers of the traffic, pilot, and sync channels respectively.

7. Interference from other users (same base station) on each channel *(dBm/Hz)*:

$$I_{up} = p_m - 10 \log B_w$$

$$I_{ut} = 10 \log[10^{0.1 p_m} - 10^{0.1 p_{tr}}] - 10 \log B_w$$

$$I_{us} = 10 \log[10^{0.1 p_{pm}} - 10^{0.1 p_{sr}}] - 10 \log B_w$$

where I_{ut}, I_{up} ,I_{us} are the interferences on the traffic, pilot, and sync channels respectively from other users on same base station.

8. Interference by users from other base station on each channel *(dBm/Hz)*:

$$I_{ct} = I_{ut} + 10 \log\left[\frac{1}{f_r} - 1\right] \qquad I_{cs} = I_{us} + 10 \log\left[\frac{1}{f_r} - 1\right]$$

$$I_{cp} = I_{up} + 10 \log \left[\frac{1}{f_r} - 1 \right]$$

f_r frequency reuse factor(typical value 0.65)

where I_{ct}, I_{cp}, I_{cs} are the interferences on the traffic, pilot, and sync channels respectively by users from other base station.

9. Interference density for each channel *(dBm/Hz)*:

$$I_t = 10 \log[\, 10^{0.1 I_{ut}} - 10^{0.1 I_{ct}} \,] \qquad I_s = 10 \log[\, 10^{0.1 I_{us}} - 10^{0.1 I_{cs}} \,]$$

$$I_p = 10 \log[\, 10^{0.1 I_{up}} - 10^{0.1 I_{cp}} \,]$$

where I_t, I_p, I_s are the interferences density of the traffic, pilot, and sync channels respectively.

10. Thermal noise density at the reference thermal noise temperature of 290 K:

$$N_o = 10 \log(290 \times 1.38 \times 10^{-23}) + N_f + 30 \qquad (dBm / Hz)$$

N_f mobile noise figure *(dB)*

11. Signal-to-noise plus interference ratio of the channels *(dB)*

$$\frac{E_b}{N_o + I_t} = p_{tr} - 10 \log b_{rt} - 10 \log[\, 10^{0.1 I_t} - 10^{0.1 N_o} \,]$$

$$\frac{E_b}{N_o + I_p} = p_{pr} - 10 \log B_w - 10 \log[\, 10^{0.1 I_p} - 10^{0.1 N_o} \,]$$

$$\frac{E_b}{N_o + I_s} = p_{sr} - 10 \log b_{rs} - 10 \log[\, 10^{0.1 I_s} - 10^{0.1 N_o} \,]$$

C.2 Reverse CDMA channel equations [9]

1. Remote station power amplifier:

$$P_{ma} = P_{me} + L_m + G_m \qquad (dBm)$$

P_{ma}	the power output of the remote station power *(dBm)*
P_{me}	the ERP from the transmit antenna of the remote station *(dBm)*
L_m	the transmit filter and cable loss between the output of the power amplifier and input of the transmit antenna of the remote station *(dB)*
G_m	gain of the remote station transmit antenna *(dB)*

2. Base station received power per user:

$$P_{cu} = P_{me} + L_p + A_l + G_t - L_t \qquad (dBm)$$

G_t	the (receive) gain of the base station antenna *(dB)*
L_t	the base station receiver cable and connector losses *(dB)*
L_p	the mean propagation losses between the remote and the base station *(dB)*
P_{cu}	received power from each remote station by the serving base station *(dBm)*
A_l	Lognormal shadow/fade allowance due to local terrain for a given coverage *(dB)*

3. Interference density of other remote stations in the serving base station:

$$I_{utr} = P_{cu} + 10 \log[N_t - 1] + 10 \log C_a - 10 \log B_w \qquad (dBm/Hz)$$

I_{utr}	received power from each remote station by the serving base station *(dBm)*
C_f	total channel activity factor(0.4-0.6)
N_t	number of users traffic channels supported per sector/base station.

B_W the bandwidth (Hz)

4. Interference density from users in other base stations:

$$I_{ctr} = I_{utr} + 10 \log \left[\frac{1}{f_r} - 1 \right] \qquad (dBm / Hz)$$

f_r frequency reuse factor(typical value 0.65)

5. Interference density from other users in the serving base station and other base station (dBm/Hz)

$$I_{tr} = 10 \log[10^{0.1 I_{utr}} - 10^{0.1 I_{ctr}}] \qquad (dBm / Hz)$$

10. Thermal noise density at the reference thermal noise temperature of 290 K:

$$N_o = 10 \log(290 \times 1.38 \times 10^{-23}) + N_f + 30 \qquad (dBm / Hz)$$

N_f remote station noise figure (dB)

11. Reverse traffic signal-to-noise plus interference Ratio:

$$\frac{E_b}{N_o + I_{tr}} = p_{cu} - 10 \log b_{rr} - 10 \log[10^{0.1 I_{tr}} - 10^{0.1 N_o}]$$

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