CDMA Cellular Network Analysis Software

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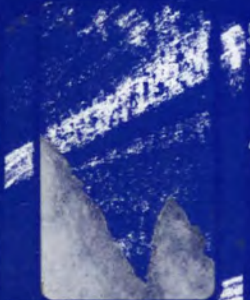

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1 Introduction

Direct sequence (DS) spread spectrum multiple access (SSMA) or code division multiple access (CDMA) has recently enjoyed great popularity in industry. It has been proposed for the next generation of cellular mobile telephones (by Qualcomm in San Diego, CA) [1][2] and personal communications (by MilliCom in New York, which has recently completed a field trial in the U.S. under an F.C.C. experimental licence)[3].

One important reason for industrial interest in spread spectrum is the recent change in regulation, which allows spread spectrum to enjoy a licence-free status over certain frequency bands. In North America, the F.C.C. in the U.S. and the D.O.C. in Canada have strongly encouraged the use of SS radio transmission for up to 1 W in power over three ISM (Instrument Scientific and Medical) bands. In Japan, it is expected that the regulation body will make a similar rule change but with the spectrum allocated at a different frequency. In Europe, the 2.4 GHz ISM band will be allocated for the same usage.

In order to achieve spectral efficiency, almost all large scale wireless communication systems are based presently on the cellular structure. Without exception, the cellular structure is responsible for a very significant increase in system capacity when used with CDMA [1][2].

The recent trend of advocating CDMA is reflected by several industrial proposals from telecommunications manufacturers and operating companies. We have now reached the stage of the design of a CDMA system for wireless communications. There have been some experimental systems [5][6] and products (e.g. by Telesystems [8]) for indoor wireless communications using DS. Qualcomm and other companies have jointly experimented with DS SSMA mobile communications in several countries [4].

For cellular DS-CDMA, the most recent work in the literature pertinent to the proposed research can be found in [1][2][9]. In these works, analyses of the capacity of cellular CDMA are given. The most comprehensive studies known to the authors to date on cellular CDMA capacity can be found in two contract reports by the authors [10][11]. One contract was with MPR Teltech, Ltd., Burnarby, B.C. in 1991. The other one was with the Department of Communications in early 1992. Most of the motivation for the work conducted in this contract came from our work under those two previous contracts. In fact, this work can be viewed as a continuation of the work done under the earlier DOC contract.

In all these works, theoretical analyses have been performed with the aid of numerical computation. Due to the perplexing nature of cellular CDMA, an accurate theoretical analysis is not possible. All analyses have to be simplified with certain assumptions. In fact, due to the co-channel interference nature of CDMA, the overall system performance could be dramatically underestimated or overestimated depending on assumptions made in the simplified analyses. For example, the capacity could differ by a factor of 10 depending on how soft hand-off between cells is modelled [2][11]. This could easily make the difference between a winning system and a loser.

The difficulty in the analysis of a DS-CDMA cellular network is that the network is interference limited and the exact nature of the interference is currently unknown. The problem with modelling the interference at any given receiver is that the interference is dependent on a large number of factors. These factors include (but are not limited to); the transmitters' use of voice activation, the network's use of cell sectorization, the effectiveness of the power control method used, and the effectiveness of the cell-site diversity method used. Voice activation reduces the interference seen in the network as it reduces the power transmitted by the mobile (or network) when there is no voice to transmit. Cell sectorization reduces the interference received at a cell-site by the use of directional antennas. This technique effectively reduces the number of mobiles which interfere with any given mobile, thus increasing the capacity of the network. Major issues in an implementation of a CDMA cellular network are the effect on capacity by power control and cell-site diversity strategies. Analytical approaches have difficulty in addressing the intricacies of the interactions between the channel dynamics, interference, the power control method, and the cell-site diversity. Thus, some of the critical results may be lost in the analytical simplifications.

Therefore, a more credible approach than pure analysis is required. In this contract, we have developed a software tool for analysing CDMA cellular networks through simulation. With this software the effect on capacity can be examined for various implementations of power control and cell-site diversity in a large number of propagation environments. The overall objective of the work was to develop a computer simulation tool for a cellular CDMA communication system. This tool provides more credible results than before and may convincingly solve some outstanding problems surrounding CDMA. While the focus of the research is on the interference analysis, other important issues related to a CDMA system have also been considered such as fading, diversity combining, power control, and soft hand-off. In other words, the simulation tool tends to provide a platform for CDMA analysis where specific details of a CDMA system can be integrated into it for different applications.

The software is comprised of 3 major parts; simulation, forward link analysis and reverse link analysis. The simulation software is capable of simulating a small number of users in a CDMA cellular network. Each user uses identical diversity algorithms and power control algorithms. The simulation software simulates the closed-loop dynamics of the power control and the cell-site diversity for a mobile at an arbitrary location within a cell. The other users were included to accurately model the interference with a small number of users. The forward link and reverse link analysis modules utilize the output of the simulation routine to compute the outages at locations in the cellular network.

1.1 Scope of this Document

This document presents a brief statement of the problem, a discussion of the models used and some results obtained utilizing the software.

Further information about the software can be obtained from the Final Report, which contains more information about methodology and software instructions, and the Source Code listings. In Section 2, an introduction to some of the current problems in CDMA cellular communications is presented. Section 3 presents issues relating to cell-site diversity. In Section 4, the models used and the issues relating to power control are discussed. In Section 5,some of the results that were obtained from the simulation are presented. Recommendations for further work are given in Section 6.

2 Background

In a high capacity cellular network, the network's service region is divided into *cells*. In an idealized cellular model, the shape of the cells is hexagonal and there is one *base station* or *cell-site* at the centre of each cell.[2] The base stations communicate with the mobiles in their respective cells. As the mobile moves through the network, it may be necessary to change to another base station. The process of changing to another base station is known as *hand-off*. To clarify the hierarchy of cellular radio communications, a small cellular network is illustrated in Figure 1. The diagram shows the base stations connected via a back-haul truck to the Mobile Telephony Switching Office (MTSO). The MTSO has various functions, such as interconnecting the cellular network to the Public Switched Telephone Network (PSTN), signalling/paging mobiles, assignment of network resources, and routing of calls to the mobiles. Another of the MTSO responsibilities in interconnecting between the cellular network and the PSTN is to convert between analog voice and digital speech using a *vocoder*. In a digital cellular network, the connection between the MTSO and the base stations would be a digital link and digital information (speech and data) would be carried on this link. The base station then converts the digital information on this link to the radio format required by the mobile (and vice versa). The mobile channel consists of two links: forward and reverse. The forward link is the communication path from the base station to the mobile and the reverse link is the path from the mobile to the base station. Also illustrated in the figure are sources of interference. In a DS-CDMA cellular network, a large number of mobiles use the same radio channel or bandwidth. Thus, any user's communications in the network are subjected to co-channel interference from other users in the network. This interference is known as Multiple Access Interference. It is important to minimize this interference as it is one of the limiting factors in the capacity of the network.

Another factor which makes mobile communication difficult is the fading and shadowing. While the exact modelling of the wide-band channel is currently an area of research, many investigators approximate the channel with Rayleigh fading and Lognormal shadowing [2, 9, 11]. We use a fading model using the channel power gain to approximate the channel characteristics. The block diagram of the fading model is shown in Figure 2. The model includes Rayleigh fading, lognormal shadowing, and the power attenuation, as a function of distance. The parameters of this model can be adjusted to simulate a wide variety of fading environments and vehicle speeds. The lognormal shadowing component is common between the forward and reverse link of a mobile channel and the Rayleigh fading processes are independent for the forward and reverse link. Figure 3 shows a time sequence of channel

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[2] The terms *base station* or *cell-site* are used interchangeably throughout this document.

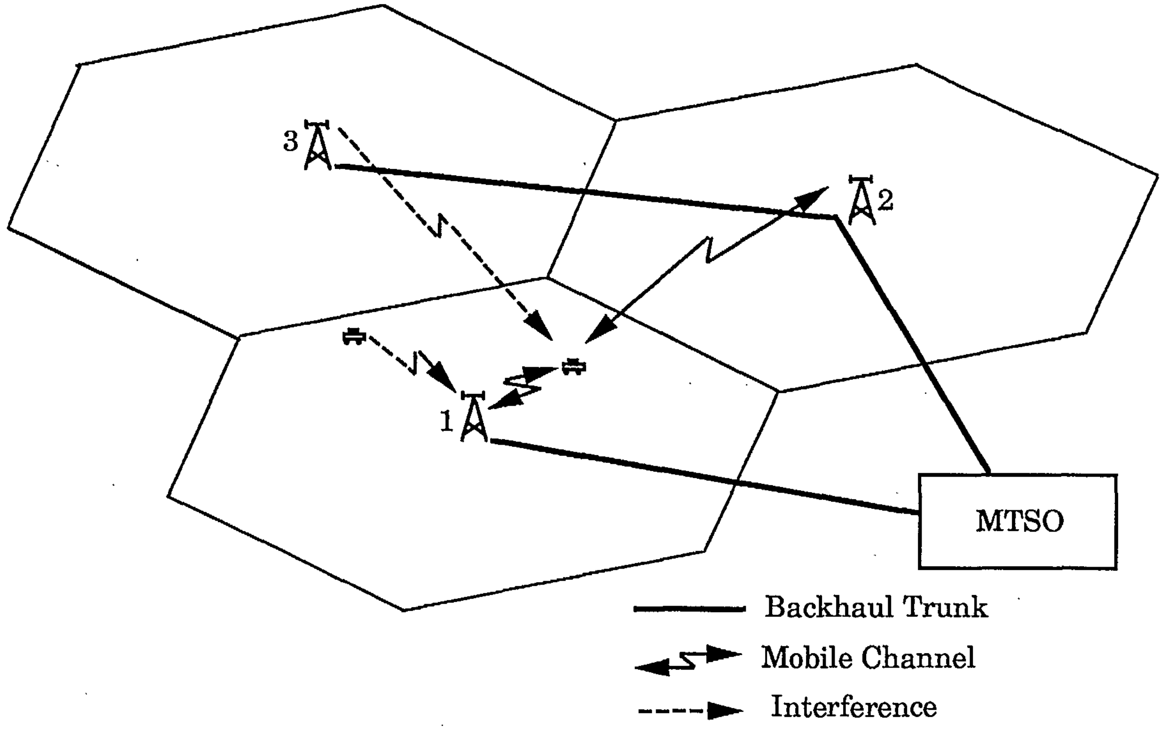

Figure 1: Illustration of a Small Cellular Network

gain between a mobile and two base stations.

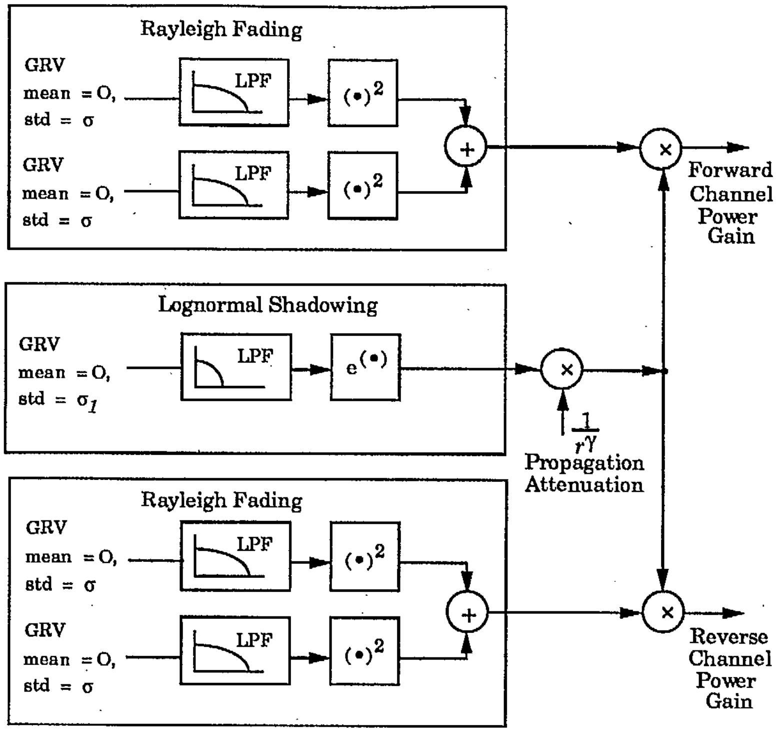

Figure 2: Block Diagram of Fading Channel Model

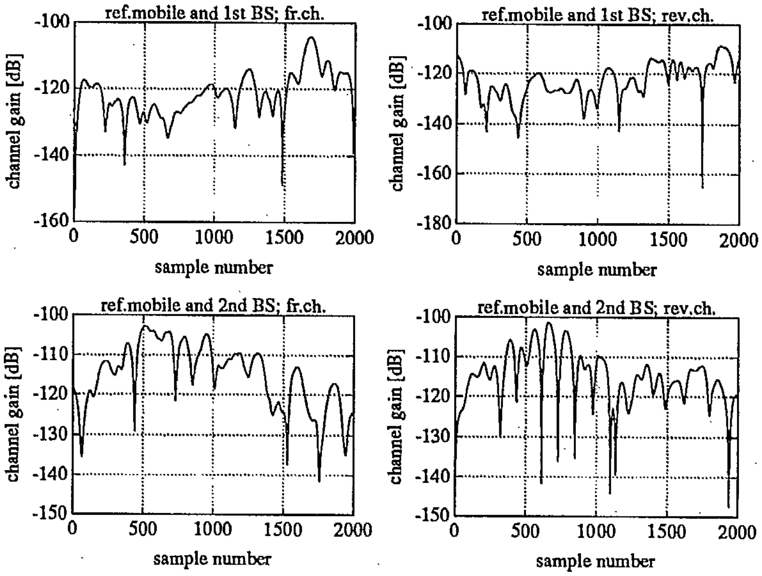

Figure 3: Examples of Channel Gain

3 Handoff Criteria in CDMA Cellular Networks

In the current analog FDMA cellular system it is necessary for the mobiles to briefly halt communications to switch to a new carrier frequency to communicate with the new cell-site. In a DS-CDMA cellular network, a procedure known as "soft hand-off" is possible. With this procedure, two (or more) cell-sites transmit using the mobile's spreading sequence at the same frequency. When the mobile is near the cell-edge of both cells it is possible that, after hand-off, the new cell's signal deteriorates and the original cell-site's signal could actually be better. This ideally requires a handoff back to the original cell-site. The deterioration of the signal may be cause by such things as shadowing or blocking by an obstacle between the mobile and the new cell-site. If a mobile is receiving multiple signals and one of the signal's strength drops below a preset threshold, then the mobile requests that that signal be turned off. The mobile then returns to communicating with only one cell-site. Soft-handoff is also known as cell-site diversity or macroscopic diversity.

Cell-site diversity is employed to improve outage statistics for the mobiles at the edge of a cell. An outage is said to occur when reliable communications can not be maintained with the mobile. However, since the diversity transmissions also increase the overall interference seen by the mobile and require extra equipment and processing in the network, it is essential that the time for cell-site diversity transmissions be kept to a minimum. Thus, it is necessary to obtain the criteria for cell-site diversity to ensure that multiple transmissions to one mobile are sent only when required. The overall objectives are to maximize the network capacity, minimize the use of extra equipment, and minimize network outage (or equivalently ensure a high signal quality to the user). For the special case of soft-handoff, it is important that the need for diversity is detected and request granted quickly to ensure uninterrupted communications. The block diagram of cell-site diversity is shown in Figure 4. The diagram shows only the layout when the diversity system is on. It does not illustrate the control procedures used to switch the diversity on or off. The criteria for having diversity will be discussed in the following sections.

In a real system, the MTSO would transmit the digital signals (along with control information) to the base stations which would then transmit identical signals (both in content and spreading sequence) to the mobile. In the software the power associated with transmitting two signals to the mobile is taken into account. The signal power from each tower is attenuated by the channel power gain from the fading channel simulators and interference is added to the signal. The received signals are then combined using Maximum Ratio Combining (MRC) [23] to form the received signal power at the mobile.[3] For the reverse link,

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[3] The combined signal in a real mobile would then be sent to the demodulator, decoder and vocoder.

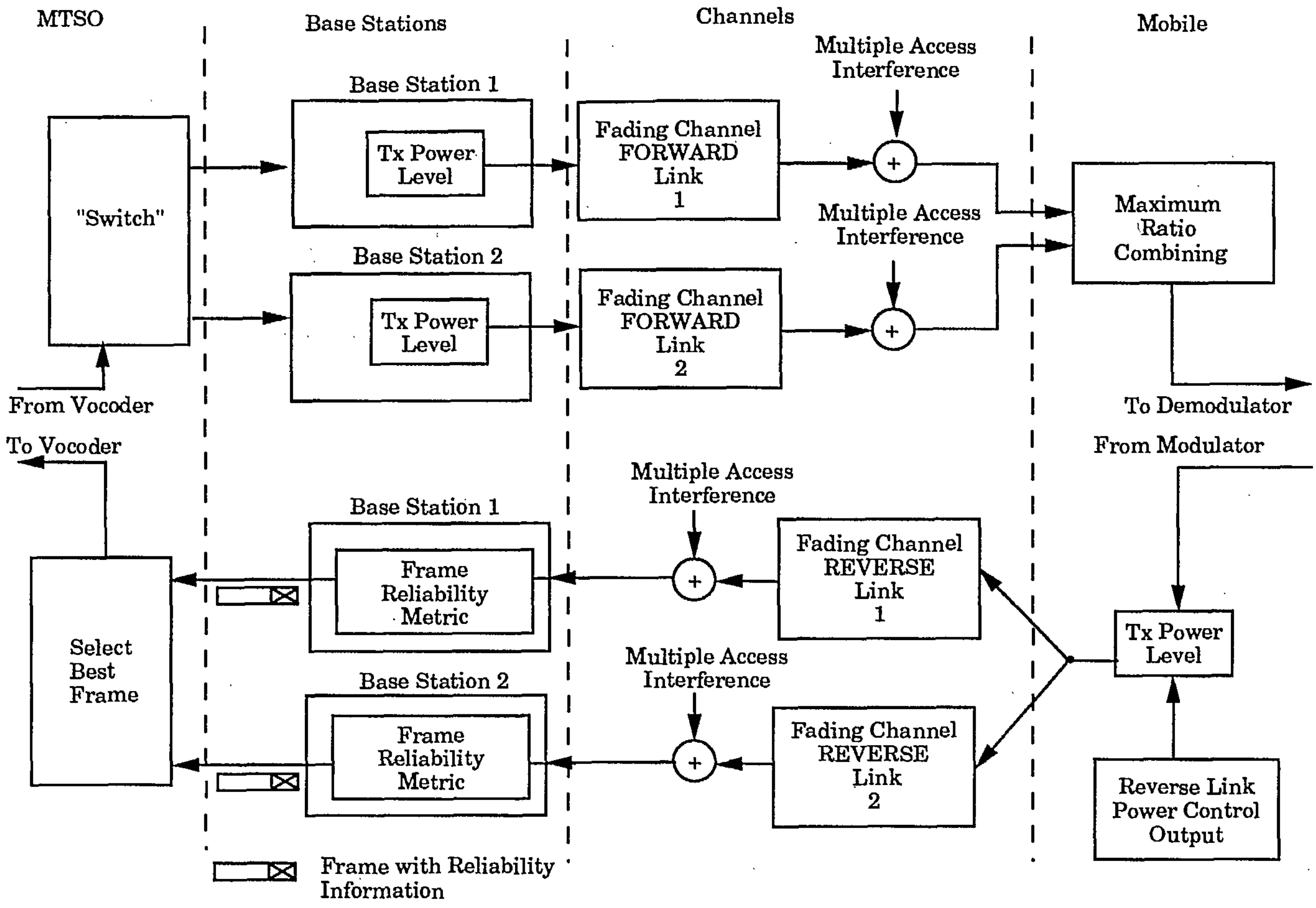

Figure 4: Block Diagram of Two Cell-site Diversity when Diversity is On

frame-wise selection diversity is carried out at the MTSO. The transmit power at the mobile is attenuated by the channel power gain from the respective channels and corrupted with interference. A frame reliability metric (e.g. the average SNR over the frame) is computed and the frame with the best SNR is selected for the decoding. In this study, the implemented combining scheme is based on Qualcomm's frame selective combining [18]. It is assumed here that the cell-sites which are transmitting to the mobile are also the cell-sites processing the signals from the mobile. The mobile decides which cell-sites are being used. The decision process for this aspect is presented in Section 3.

Criteria for Requesting Cell-site Diversity

Determining a request for diversity is a function of the pilot power strength and the prevailing interference. As the mobile approaches the boundary of the cell, the signal quality decreases and the interference experienced by the mobile increases due to the intercell interference. The cell boundary in CDMA cellular networks can be defined as the location between two cell-sites with equal power requirements from both cell-sites [19]. When the

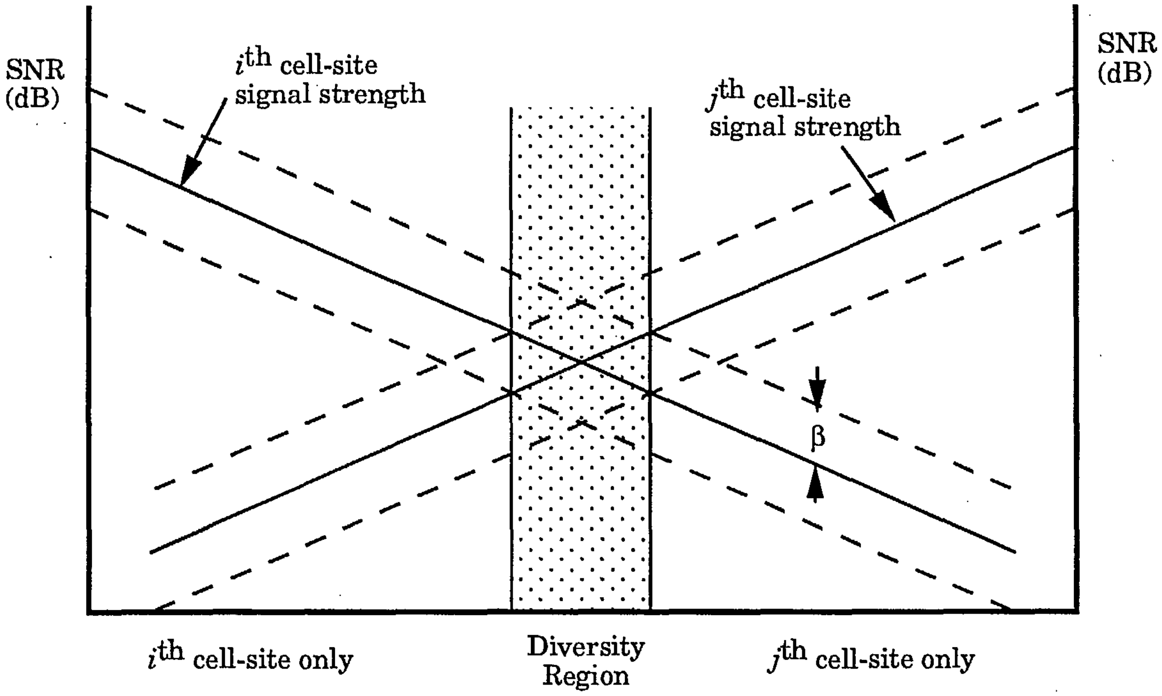

Figure 5: Mobile Cell Membership vs. Signal Strength with the Signal Thresholds Shown.

pilot strength from a neighbouring cell crosses a diversity threshold, the mobile sends a handoff request. As the pilot signal and the communication signal are subject to lognormal shadowing, Rayleigh fading, and interference from users, the pilot's signal power should be averaged over a number of samples to ensure that a reasonable estimate of the mean signal level is obtained.

The estimation is performed by a true average over the last N samples of the pilot and used to form a decision metric Y_n as the average of the last N values of the pilot power X_n.The method averages the pilot power strength to estimate the quality of the signal (the signal level plus multiple access interference).

It monitors the cell-sites' signals for the purposes of requesting additional diversity transmissions (if possible), replacing a cell-site currently transmitting a diversity signal with a better cell-site, and requesting termination of 1 or more of the current diversity transmissions. To avoid confusion, the decision metric regarding the kth cell-site will be denoted as $Y_{k,n}$. The mobile requests transmissions from the ith cell-site alone if the ith cell-site's signal is greater than every cell-site which the mobile is monitoring.

Figure 5 shows the region of soft-handoff using the signal strength to decide handoffs. The margin β and a propagation profile of the signals from the ith and jth cell-sites are shown. As the mobile moves from the ith to the jth cell-site, the received power from the ith cell-site gets weaker. When the received power from the jth cell-site is within β dB of the received power level of the ith signal , the mobile utilizes diversity from both towers. The mobile requests diversity transmissions from the ith and jth cell-site upon entering the region, uses diversity while within the region, and requests that diversity be turned off and receives signals from the better of the two cell-sites upon exiting the region. Figure 5 does not show the effects of shadowing. The mobile would use diversity whenever the signal of another cell-site was within the threshold region defined by β. The mobile would request a change in its diversity state (ie. on/off) when it detects that another cell-site's signal has crossed the threshold.

4 Power Control

In reverse link, power control is essential to alleviate the effects of the near-far problem and to reduce the effects of fading. The objective of the reverse link power control is to ensure that the received signal at the receiving base station is constant for all users. The mobile must vary the level of its transmit power to achieve this objective, due to the varying channel conditions between the mobile and the receiving base station. Figure 6 shows the time sequence of a mobile's transmit power. As can be seen in the figure, the required transmit power varies over a wide range. Since the propagation paths between the mobile and other base stations have independent fading and shadowing, the variations in the mobile's transmit power increases the variance of the interference power at other base stations.

In practice, ideal power control is difficult to achieve. One reason is that the mobile must rapidly vary its transmit power at the rate of the fading process. As there is a finite delay associated with both the estimation of the channel attenuation and the power level adjustment, compensating for fast fading becomes extremely difficult. Also, the estimation of the channel conditions may not be accurate under all conditions, such as very fast fading. Of course, the above two factors depend on the estimation algorithm which is implemented. Mobiles are also limited in the rate at which they can change the output power. One of the main reasons is the fading and shadowing processes can cause a very high channel attenuation which the mobile cannot compensate for due to its limited power supply as well as other design factors.

From the above factors, it is obvious that the effectiveness of any power control algorithm is affected by the delays inherent in the system, the accuracy of the estimate of the channel conditions, the error associated with both discrete and finite steps in power, and the percentage of time in which the mobile can not compensate for a fade due to its maximum power level.

There are several forms of reverse link power control, such as a *slow open loop* which compensates for slow shadowing and the propagation loss due to distance, a *fast open loop* which compensates for sudden improvements in the channel, and a *closed loop* which attempts to compensate for fast Rayleigh fading. The closed loop is necessary as the forward and reverse links are expected to be at different frequencies in a cellular network, thus the Rayleigh fading on the forward and reverse link is expected to be independent. Hence, the mobile is unable to obtain an accurate estimate of the reverse link attenuation by measure from the forward link signal. For this reason, it is necessary for the base station to measure the mobile's received signal and transmit power adjustment commands to the mobile so that it can accurately adjust its transmit power level.

In this study, we considered a closed loop reverse link power control. The model chosen allows various parameters to be changed to investigate the effectiveness of the power control strategy. In Figure 7, the block diagram of the closed loop power control is shown. In the model, the performance measure (eg. average value of the signal power level) for each mobile is evaluated. If the user's performance is lower than the reference value, the base station sends

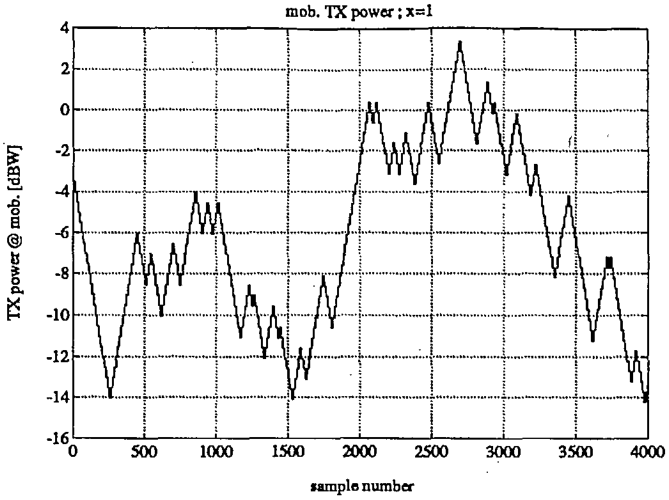

Figure 6: Time Sequence of Transmitted Power of a Mobile Located Equidistant between 3 Base Stations

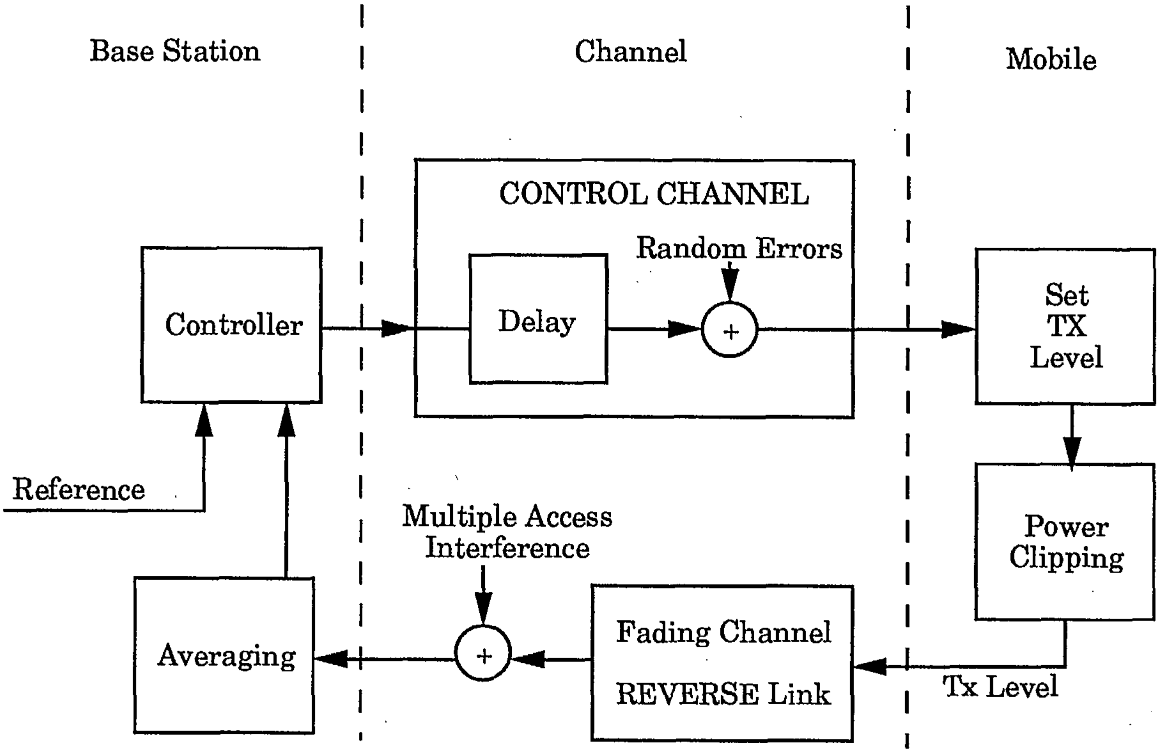

Figure 7: Block Diagram of Closed Loop Reverse Link Power Control without Cell-site Diversity

a power control command to the mobile to increase its transmitted power by a certain fixed step increment (nominally 0.5 dB). The power control is then delayed simulating processing delay (see Section 4.1). It is expected that the command will be subjected to errors due to channel conditions. The model includes a method of adjusting the Bit Error Rate (BER) on this control channel.[4] The mobile receives the command and adjusts the transmit power level accordingly (even if the command is received in error). If the power level is at or above a set maximum power level, the transmit power is *clipped* (eg. set to the maximum power level) otherwise, the power level is unchanged.[5] The power level is then adjusted by the power attenuation from the fading model and the effect of interference is added. This corrupted signal is averaged to obtain the performance measure above.

Since the system's capacity is strongly affected by the cell-site diversity, close interaction of power diversity control is required. In Figure 8, a block diagram of the power control is shown when two cell-site diversity is employed. While more cell-sites can be involved, two cell-site diversity has been implemented in the software. With two cell-site diversity, two cell-sites receive the mobile signals and perform the averaging and decision of the power control command independently. The power control command is sent to the MTSO and the MTSO selects the *best* command. The *best* command is one which lowers the mobile's power the most or has the smallest increase in the mobile's transmit power. This ensures that the cell-site which has the best channel is controlling the mobile's power and thereby minimizing the mobiles transmit power. This strategy also minimizes the contribution to the interference power from the mobile which is seen by other mobiles.

4.1 Delay in Power Control

Two main kinds of delay exist in the power control loop, propagation delay and processing delay. The propagation delay is negligible compared to the processing delay and thus its effect is not considered.

The processing delay arises due to two major factors. The first factor is inherent in the averaging/integrating process of the user's performance at the base station. The second is the action delay between the arrival of a power control command and action resulting from it.

The action delay parameter ranges from zero to the power control command period.

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[4] The noise is modelled by a binomial random variable with the probability of error being p and probability of no error being $1 - p$.

[5] Power clipping also prevents the mobile from excessively interfering with the other users.

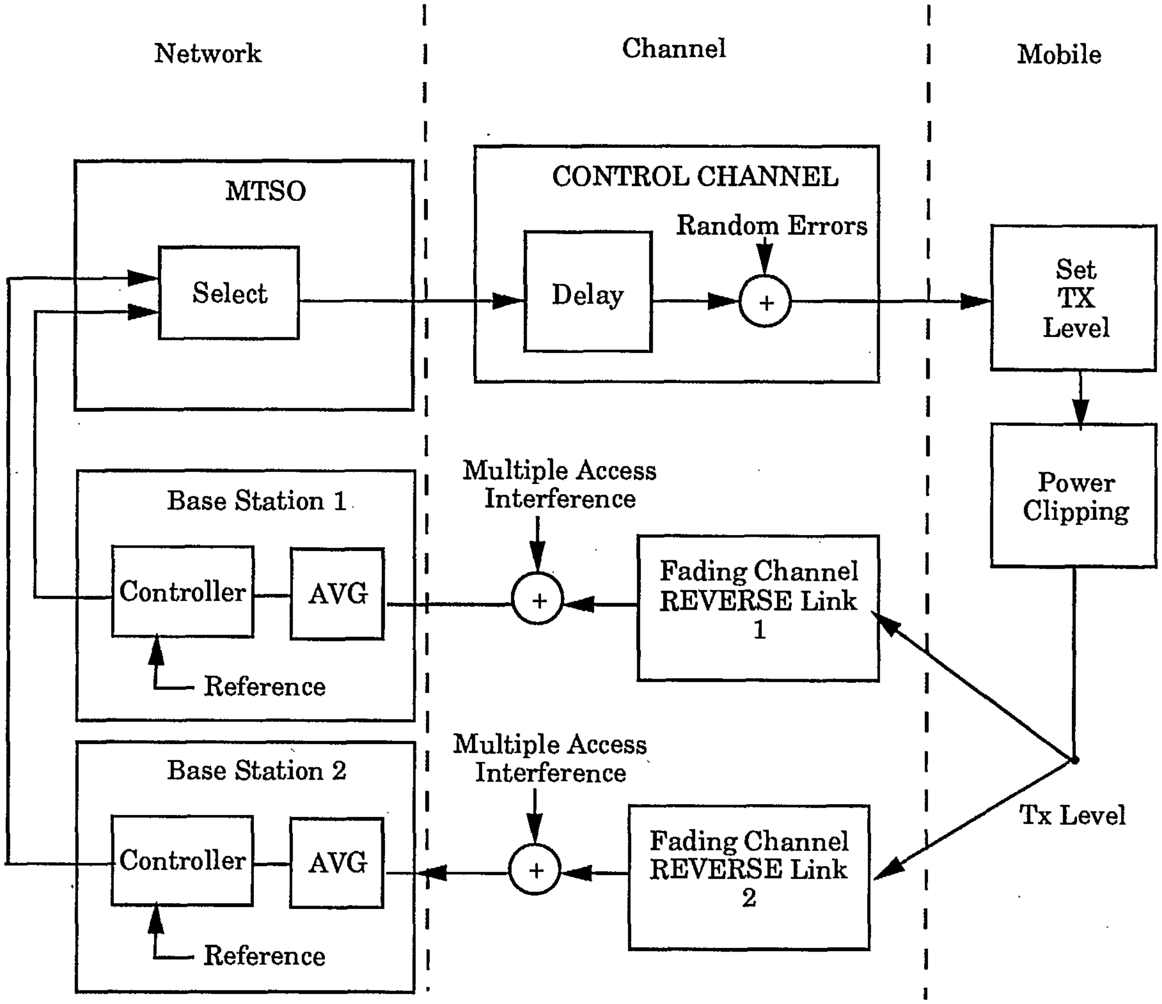

Figure 8: Block Diagram of Closed Loop Reverse Link Power Control when Diversity is Employed

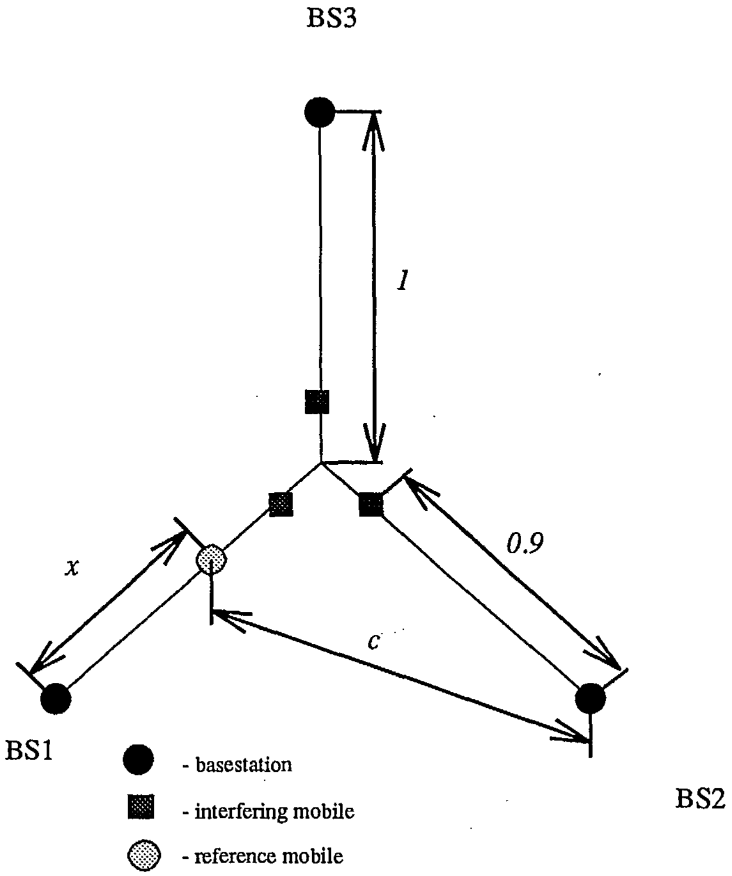

Figure 9: Test System Geometry

5 Numerical Results

In the following section, some simulation results are presented.

The simulation geometry is depicted in Figure 9. This small system has been chosen to study the behaviour of the diversity and power control. This figure shows three base stations arranged as a triangle. Closer to the geometrical center of the triangle are located three interfering mobiles. The reference mobile is located on the line between the center and base station 1. The distance from the closest base station to the reference mobile is denoted as x. All results are parameterized on x.

Figure 10 provides an example of the SNR at the mobile as a function of time. The cell-site diversity order is set to one (only one base station transmits to a particular mobile at a time). The sharp "jumps" in the SNR are due to the frame-wise assigned hard hand-off. We define the *probability of diversity* as a ratio of time that the mobile uses diversity over the total time of the simulation. The probability of diversity as a function of position is shown in Figure 11.

If not otherwise stated, all of the following results were obtained by the simulation based on the following assumptions: Doppler frequency is 50Hz, the normalized distance from the

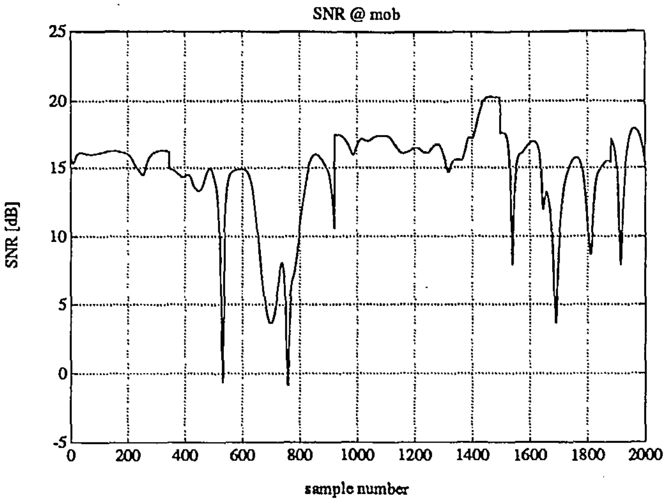

Figure 10: SNR at the Mobile as a Function of Time

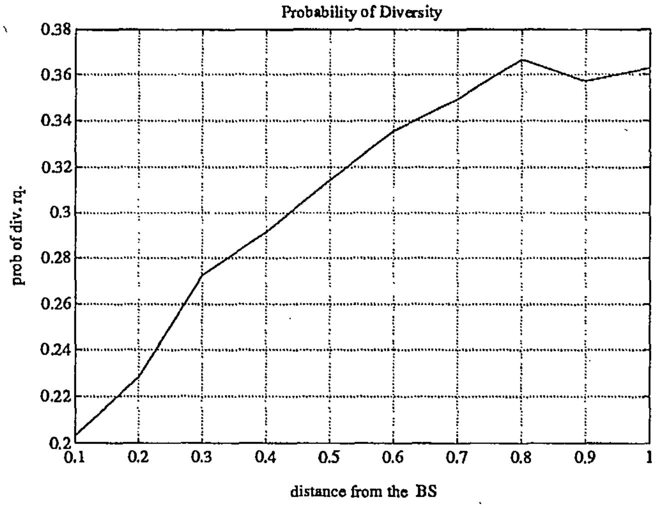

Figure 11: Probability of Forward Cell-site Diversity as a Function of Distance From the Closest Base Station

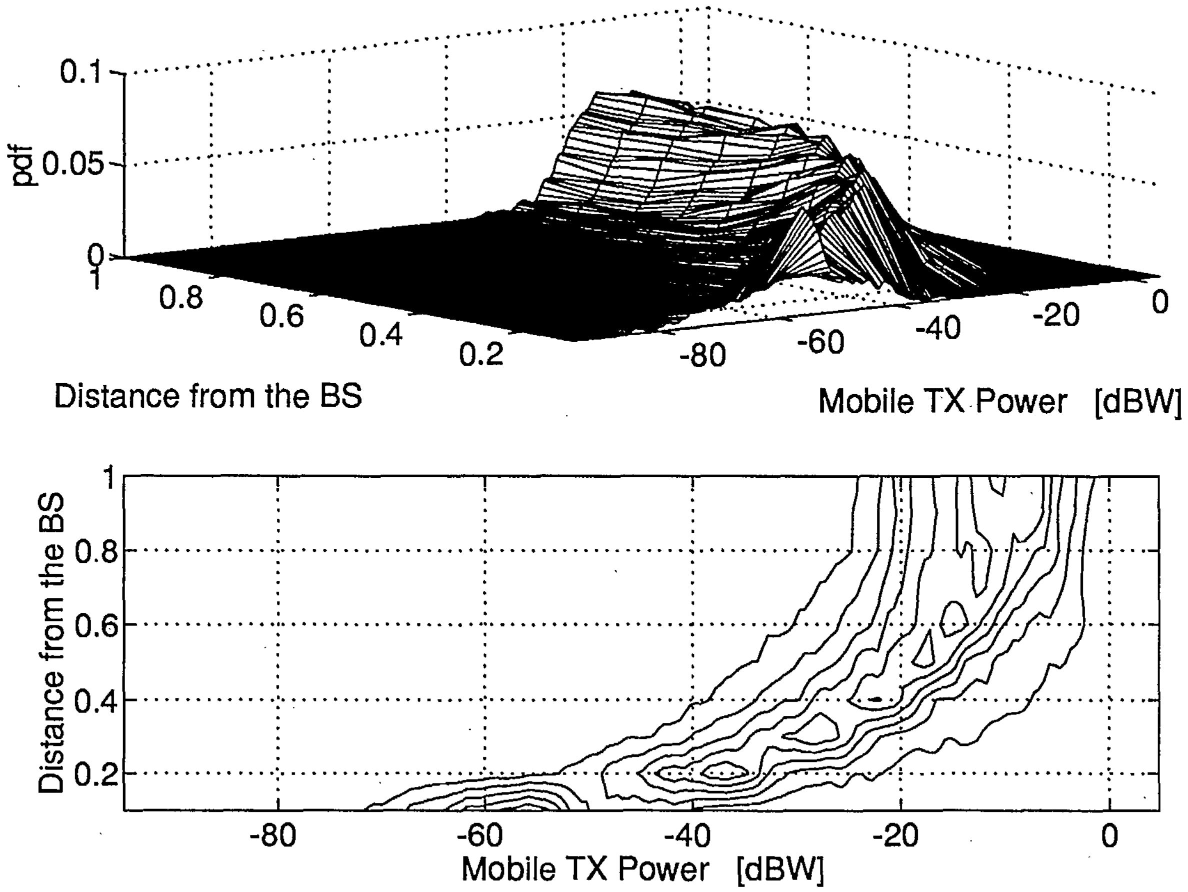

Figure 12: PDF of the Transmitted Power at the Mobile

closest base station is 1, frame-wise diversity (20ms frame length), delay of the power control is 1/16 of the frame length, the power control increment and decrement are equal to 0.5dB, the mobile power clipping is set to 4.7dBW, the propagation exponent is 4, the standard deviation of the shadowing is 8dB and the diversity threshold (ratio) is set to 20dB.

5.1 The Effect of Distance

A typical effect of the distance on the reference mobile's performance is shown in the following figures. In Figure 12, it can be seen that the power control compensates for the decreasing propagation loss as the mobile gets closer to the base station by lowering the transmitted power.

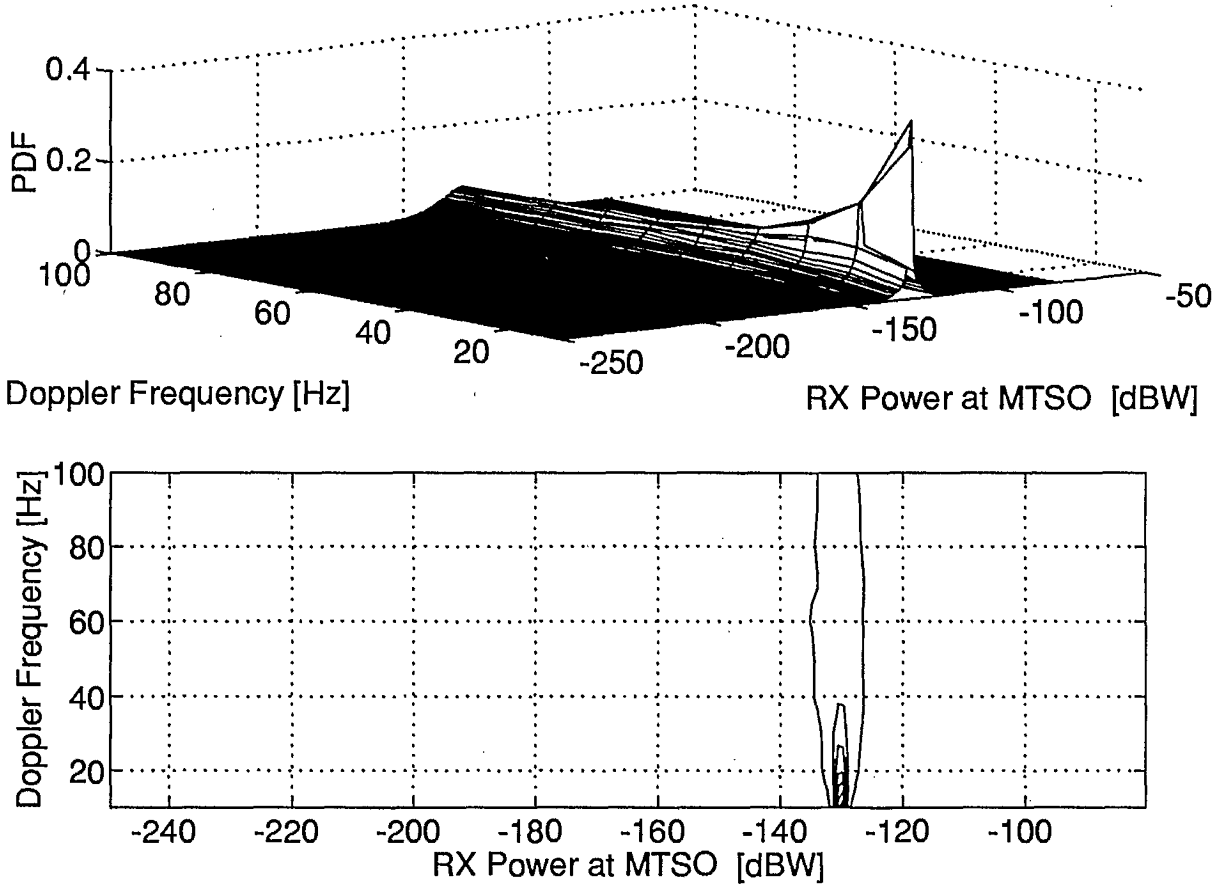

Figure 13: PDF of the Received Power at the MTSO

5.2 The Effect of Doppler Frequency

The Doppler frequency affects the rate of channel fluctuations and thus affects the power control and diversity. The power control is influenced by the rate of fading as the estimation of the signal level depends on the fading environment. The influence of the Doppler frequency on the received power pdf at the MTSO is quite visible as shown in Figure 13. Below a Doppler frequency of 40Hz, the power control works well. Above this limit the power control keeps the mean at the desired level but results show a higher variance of the received power.

5.3 Effect of BER in Power Control Command

Figure 14 shows how the transmitted power of the mobile is affected by the power control error. One can see that this effect is not very strong for error rates below 18%. As for the received power in the reverse link, the effect of the power control error is more obvious as can

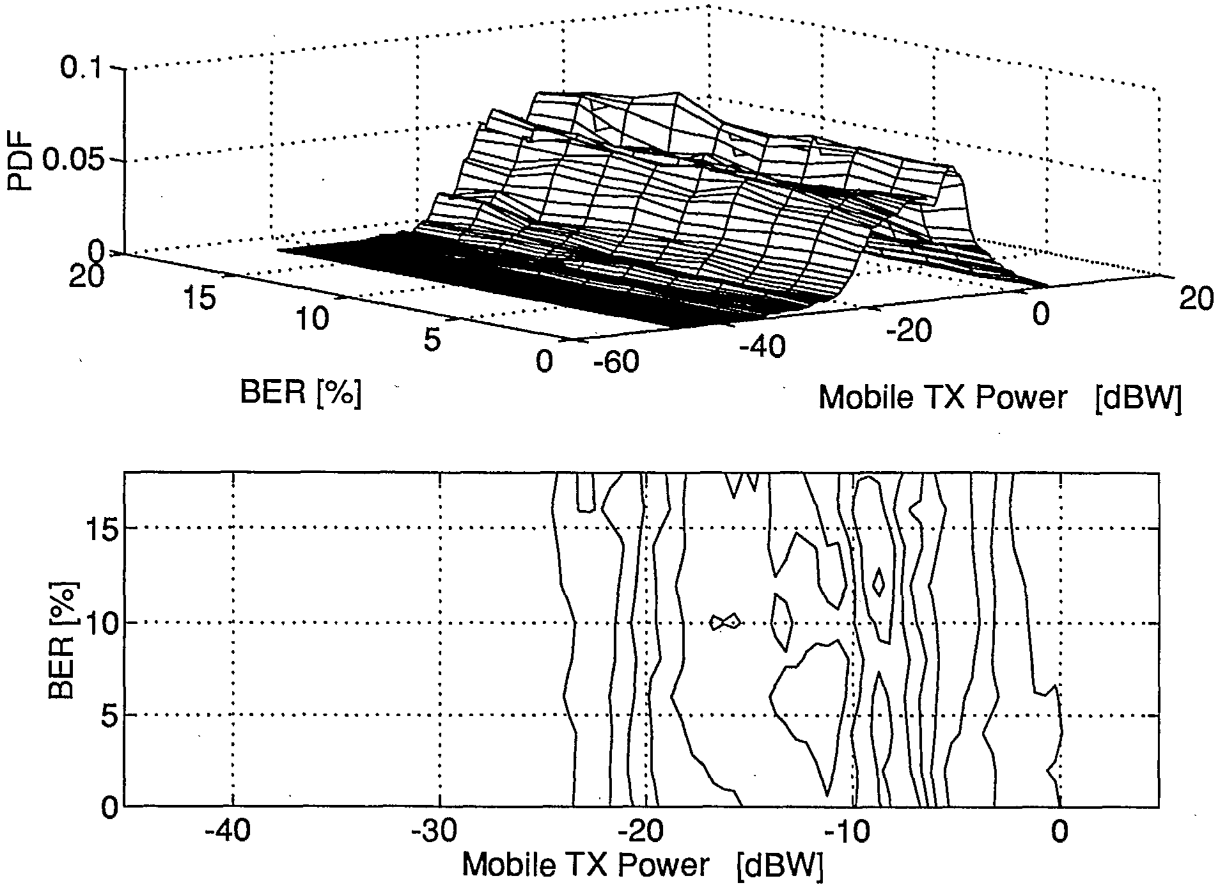

Figure 14: PDF of the Transmitted Power at the Mobile

be seen in Figure 15. In the figure it can be seen that by increasing BER, the pdf becomes "flatter" and the received power has a higher variance.

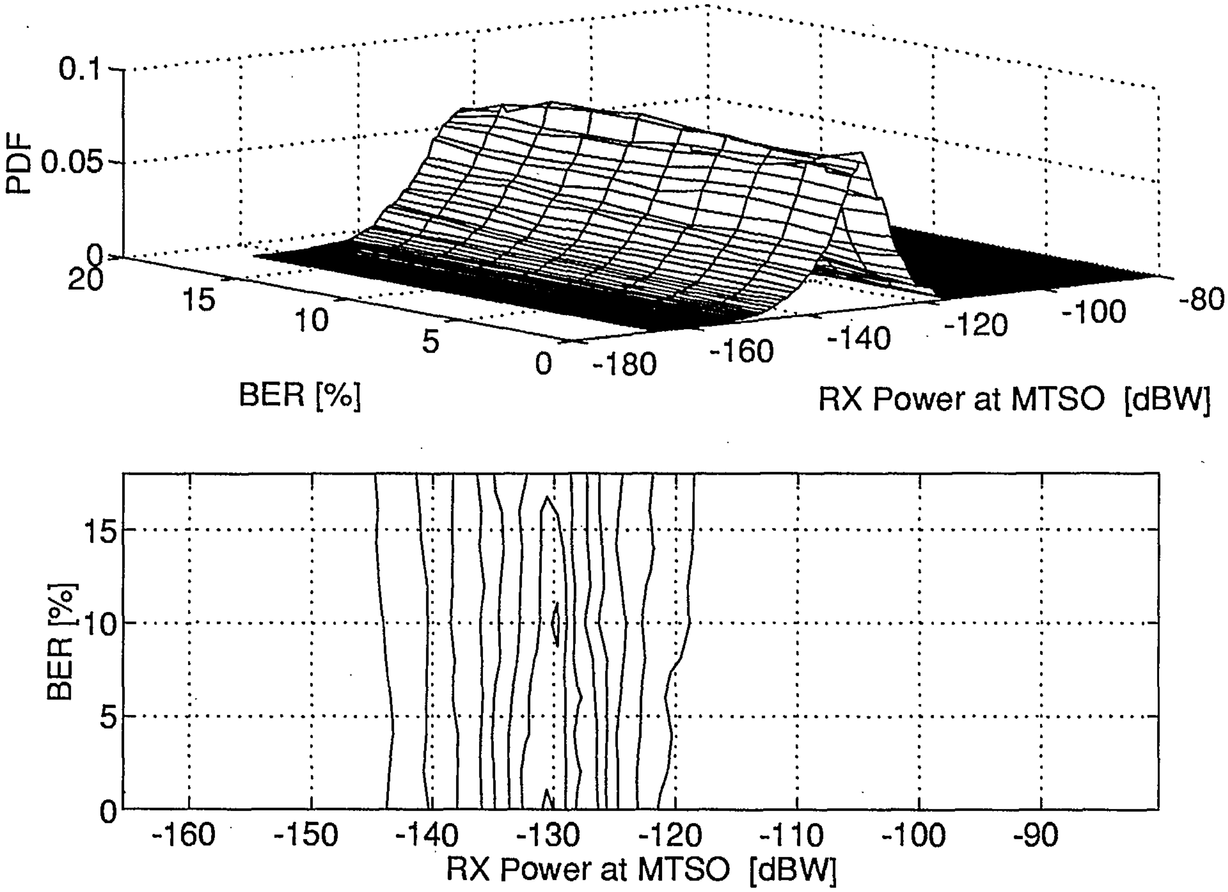

Figure 15: PDF of the Received Power at the MTSO

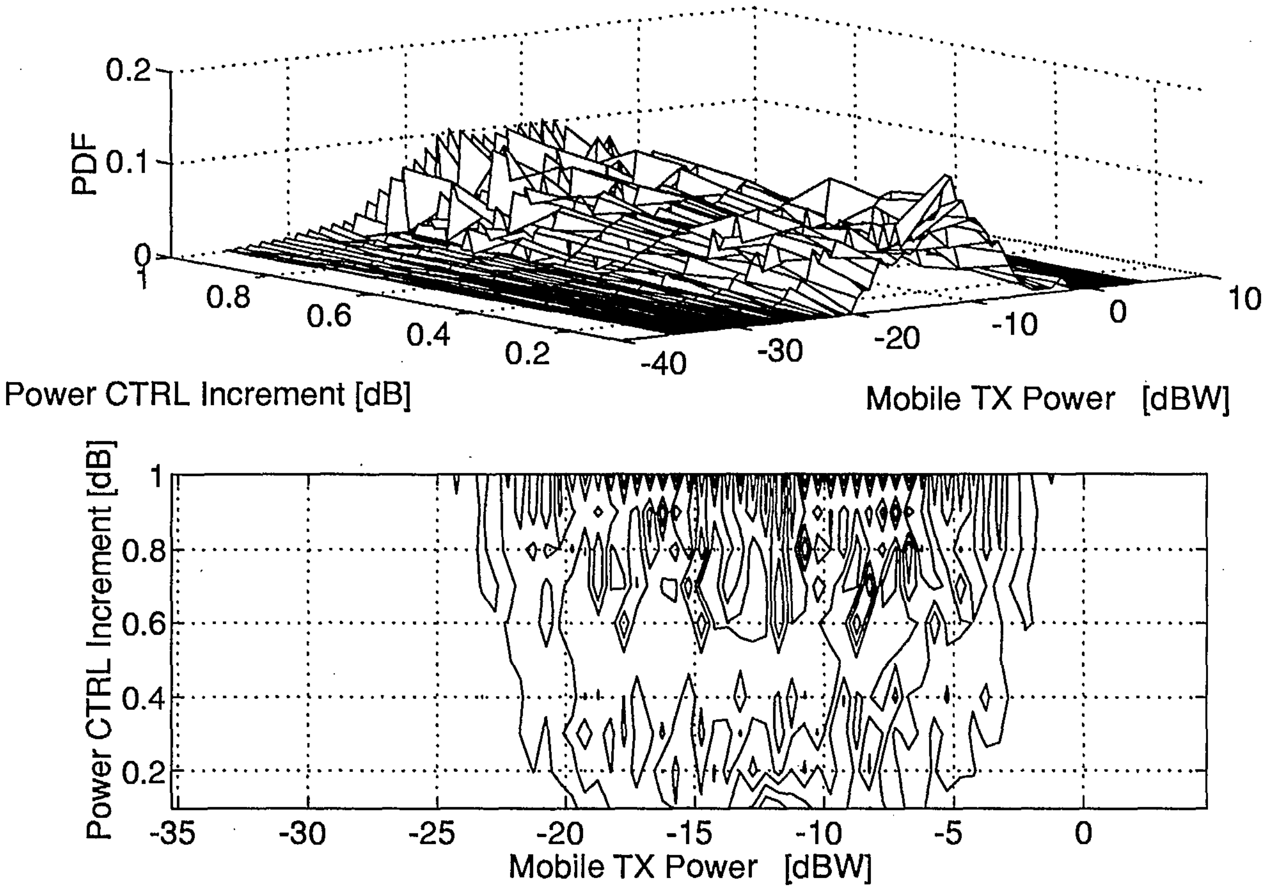

Figure 16: PDF of the Transmitted Power at the Mobile

5.4 Effect of Finite Increment in the Power Control

The same step size is used for both the increment and decrement of the power level. Figure 16 depicts the expected "widening" of the pdf of the transmitted power with the power control step increase. The "ruggedness" of the surface is due to the discrete steps in the transmitted level. However, the fluctuations of the channel introduce additional randomness and smooth out the pdf of the received power in the reverse link as shown in Figure 17. Since with the increasing power control step the power control is able to compensate for deeper fades more quickly, the pdf of the received signal becomes narrower.

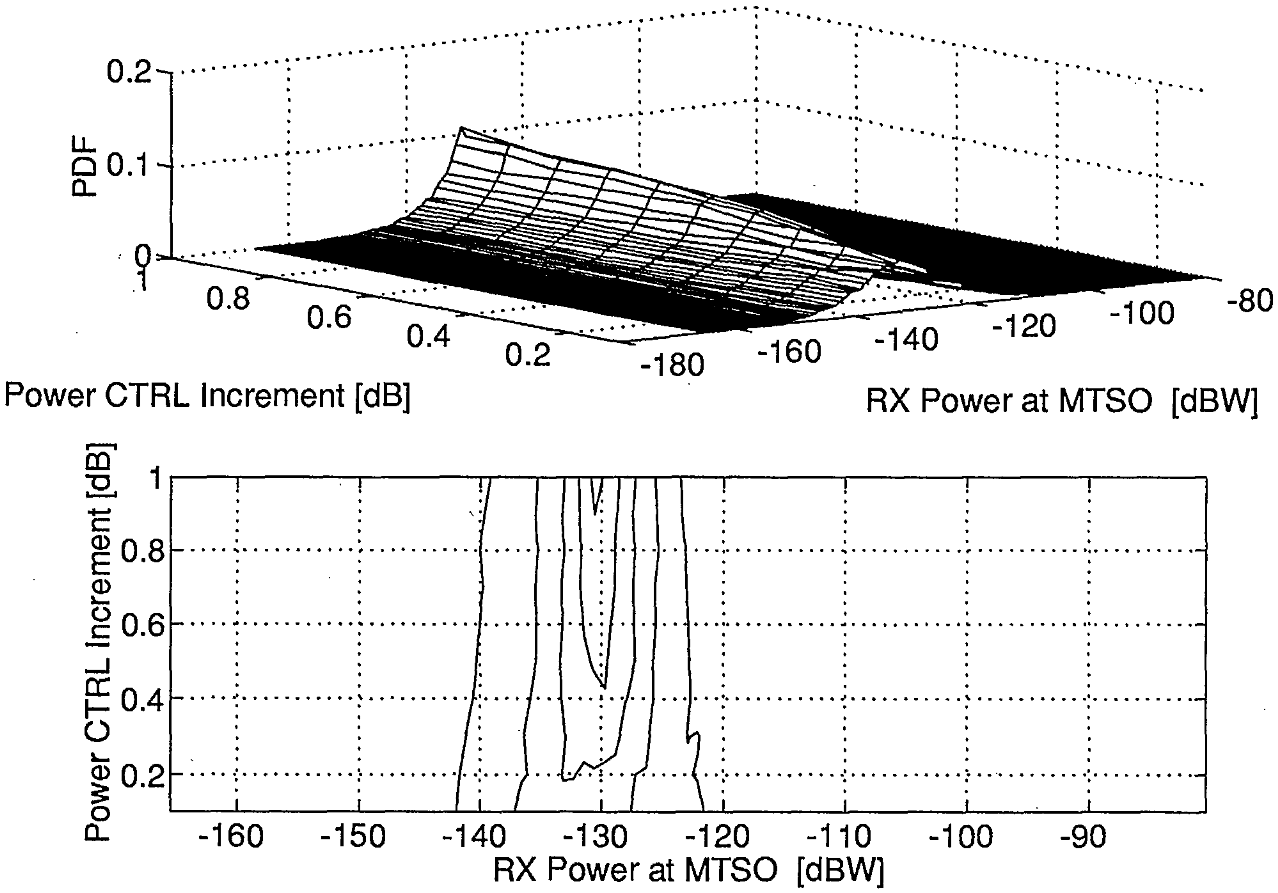

Figure 17: PDF of the Received Power in the Reverse Link

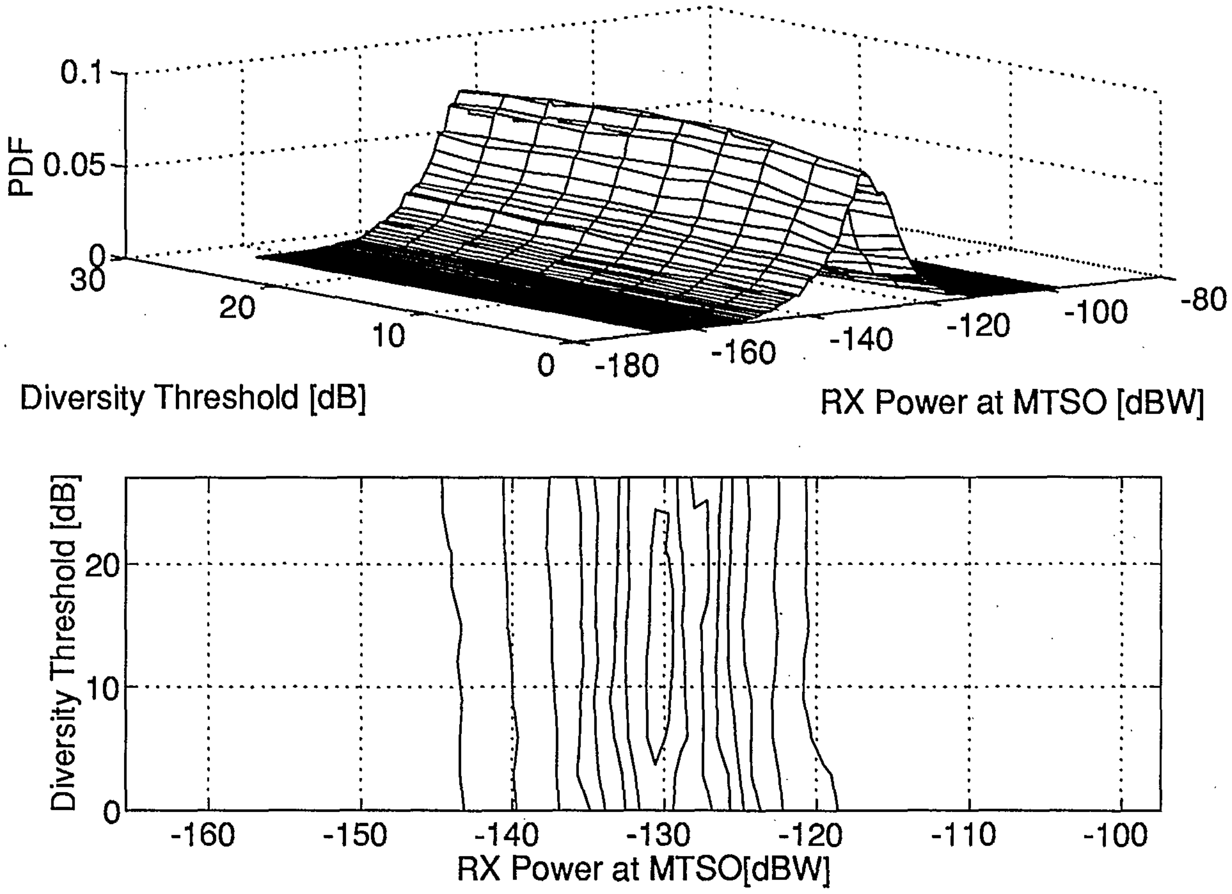

Figure 18: PDF of the Received Power at the MTSO

5.5 Effect of the Diversity Threshold

The diversity threshold is the maximum difference in dB between the strongest pilot level at the mobile and the level of the pilot of a potential diversity transmitting base station. The availability of the diversity increases as the threshold value becomes larger. The reference mobile has been placed close to the center of the three base station triangle since this position is expected to use diversity transmissions most often. . It can be seen, as expected, that a high availability of diversity lowers the probability of high transmitted power levels. The same applies for the received power level in the reverse link as shown in Figure 18. In this figure we note an optimum diversity threshold of approximately 15dB is seen.

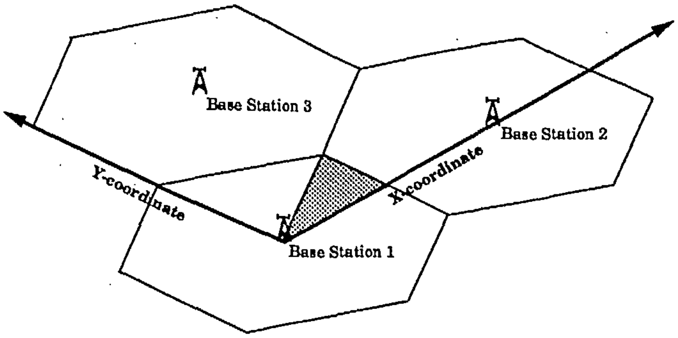

Figure 19: The Location of the Triangular Simulation Test Area

5.6 Forward Link Results

The second stage of the forward link simulation calculates the effects of interference from the three nearest base stations and the effects of diversity on the reference mobile. Some experimental results obtained during the software testing period are described here. The simulation results are obtained for the triangular test area. Based on the simulation results, the forward link outage probabilities are obtained by the analytical method.

In the simulations, we considered a symmetric hexagonal network. As a result of the symmetry, we used a 1/12 sector to represent locations throughout the network, greatly reducing the simulation time required. Figure 19 shows the location within the network of the 1/12 sector as the shaded region. Figure 19 also shows the location of base stations 1, 2, and 3 relative to the shaded region. The results presented in the following figures are positions in the shaded region.

The forward link analysis is based on the simulation results. For this stage, it is assumed that the mobiles are uniformly distributed. The lowest SNR accepted for reliable communications in the forward link is 5 dB, below 5 dB an outage occurs.

Figure 20 illustrates the calculated outage probabilities calculated based on the simulation results. In the figure the outage probabilities for 4 users in the triangular sector is presented.

Figure 21 shows the relationship between the average outage probability and the number of users per sector. After considering the voice activity and sectorization, the actual number of users within a cell area is about 8 times larger than the number shown in Figure 21. From these results, the forward link capacity can be estimated.

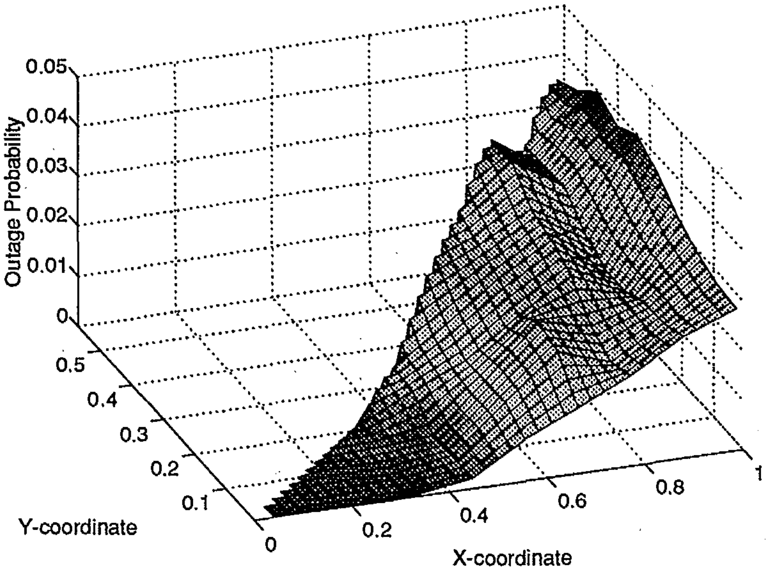

Figure 20: Surface Map of the Outage Probabilities over the Triangular Area for 4 Users in One Sector of the Hexagonal Cell

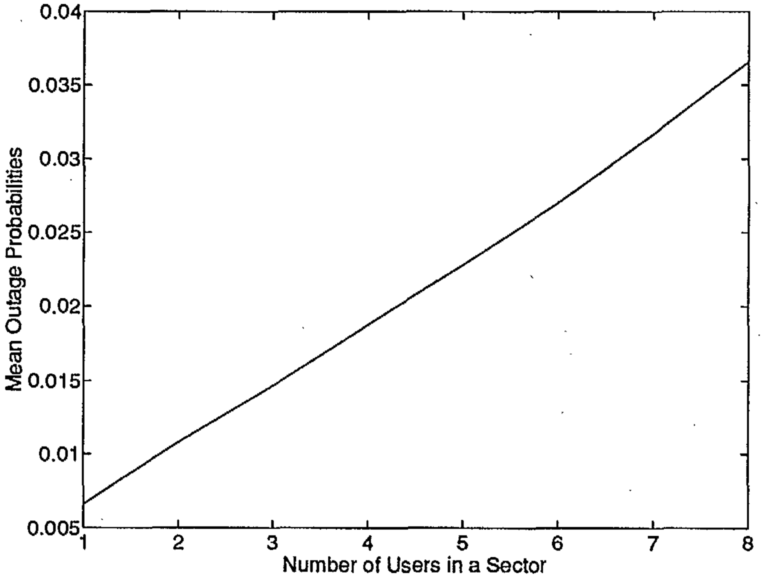

Figure 21: Average Outage Probability Versus the Number of Users in One Sector

6 Future Work

Cellular CDMA is still in its immature stage. There is still much to be done in the both development of evaluation tools such as one the done in this contract and the use of these tools to perform performance analysis and design optimization. More specifically, we propose some future work as follows.

6.1 Enhanced Versatility

Our first-hand experiences and unique insights gained through this contract suggest developing a more versatile simulation software tool or several tools that would encompass simulation features such as the following.

- Sectorization of cells, including overlapping antenna patterns.
- Voice activation process modelling including variable rate transmission.
- Signal (not power) level propagation.
- More detailed modelling of diversity and power control.
- Forward link power control supporting "load sharing" throughout the system.
- Modelling of softer handoff between sectors.
- A channel model for sudden changes of the signal (such as a corner effect)
- Modelling the system at the chip level, thus investigating more closely the spread spectrum phenomena.
- Modelling a particular system with heterogeneous propagation conditions and/or typical irregular cell shapes: highways, congested downtown areas, etc.
- Modelling mutual interference between service providers.
- Addition of a Graphical User Interface (GUI) for the simulation and analysis routines.

6.2 System Analysis and Development of New Techniques

With powerful computational tools in hand, we propose to perform critical analysis of various aspects of cellular CDMA such as testing and optimizing known strategies for the power control and diversity using the existing developed software. We also see clear needs to research and develop new techniques especially in the following areas.

- Reverse link power control with adaptive response.
- Base station diversity.

- The interaction between base station diversity and forward and reverse link power control based on weighted power transmission.
- Power control aided by side information such as the mobile's velocity.
- Strategies for an optimal forward link power control.
- Adaptive RAKE receiver designed for CDMA multi-user interference instead of AWGN as usually assumed at the present.

6.3 Future CDMA Networks

As cellular CDMA evolves to the future generation for universal personal communications, we should extend our work to dealing with multi-media traffic. This traffic may require sophisticated hybrid spread spectrum techniques to combat such interference as that generated by overlaid communications.

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