NETWORK CONFIGURATIONS FOR SEAMLESS SUPPORT OF CDMA SOFT HANDOFFS BETWEEN CELL-CLUSTERS

by

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ABSTRACT

Current CDMA networks do not support soft handoffs between adjacent cell-clusters serviced by different mobile switching centers (MSCs). Three novel network configurations are proposed here to overcome this limitation. To allow diversity combining of signals, configurations I and II employ cross links from boundary cells to MSCs serving opposite cell-clusters. On the other hand, configuration III directly connects the MSCs of adjacent cell-clusters together to accomplish this objective. A channel assignment scheme associated with configuration I is proposed to reduce the handoff blocking probability by lengthening the handoff transition time. Configuration II expands each cell-cluster by some layers of cells which overlap with adjacent cell-clusters, thus enabling the use of different inter-cluster handoff regions for different handoff directions, an innovation which prevents handoff oscillations which may occur in configuration I while also reducing the necessary number of inter-cluster handoffs. Configuration III accommodates the highest number of calls of the three configurations by allowing the handoff and new calls to fully share the channels linking each cell to the respective MSC. A secondary contribution of this thesis is the development of a mobility model which enables dimensioning of trunk groups for each configuration. In configurations I and II, the optimal partitioning of trunk groups serving a boundary cell into direct and cross links is determined by mathematical analysis and computer simulation. For configuration III, the optimal number of trunks required to interconnect adjacent MSCs is investigated by computer simulation. Both vehicle and pedestrian traffic is examined and the performance in all three configurations is compared. Each configuration has its own distinct features: scheme I, configuration I is the simplest; scheme II, configuration I produces the lowest handoff blocking probability by trading off the new call blocking probability; configuration II eliminates the handoff oscillations and reduces the number of inter-cluster handoffs; configuration III provides the best trunking efficiency to accommodate the highest number of calls.
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Chapter 1 INTRODUCTION

In this introductory chapter, the first section introduces a North American standardized code division multiple access (CDMA) system and its soft handoff. The objectives of this thesis appear in the second section while the last section provides an outline of the thesis.

1.1 Background and Previous Work

CDMA is an emerging air interface standard for digital cellular systems and future personal communication networks (PCN) [1]. Compared to its competitors (e.g. TDMA and FDMA), CDMA offers many advantages, such as high spectrum efficiency, soft capacity, soft handoff, simplified frequency reuse planning and easy system deployment [2–4]. Because of these advantages, CDMA has been standardized for development of the third generation mobile and personal telecommunication systems.

1.1.1 The IS-95 Standard

A North American digital cellular system based on CDMA, “Mobile Station-Base Station Compatibility Standard for Dual Mode Wideband Spread Spectrum Cellular System,” was standardized as Interim Standard 95 (IS-95) by the U.S. Telecommunications Industry Association (TIA) in 1993 [5]. An IS-95 system operates in the 869–894 MHz for its forward links which are used to transfer signals and data from base station (BS) to mobile terminal (MT) and 824–849 MHz for its reverse links which are used to transfer signals and data from MT to BS. A forward and reverse channel pair is separated by 45 MHz. IS-95 has been described in detail in [6–10]. Here, it is summarized as follows:

IS-95 specifies a forward link CDMA waveform design which uses a combination of frequency division, pseudo-random code division and orthogonal signal multiple access techniques. Frequency division divides the available cellular spectrum into nominal 1.23 MHz bandwidth channels. Pseudo-random noise (PN) binary codes are used to distinguish signals received at a MT from different BSs. All CDMA signals in the system share a
quadrature pair of PN codes. Signals from different cells are distinguished by time offsets from the basic code. The PN codes are generated by linear shift registers that produce a code with a period of 32768 chips. The PN chip rate is 1.2288 MHz, or exactly 128 times the 9600 bps information transmission rate. Two codes are generated, one for each of two quadrature carriers, resulting in quadriphase PN modulations. Signals transmitted from a single antenna in a particular CDMA radio channel share a common PN code phase. They are distinguished at a MT receiver by a binary orthogonal code based on Walsh functions (also known as Hadamard matrices). The Walsh function is 64 PN code chips long, providing 64 different orthogonal codes called code channels. The convolutional forward error correction (FEC) code transmitted has a code rate of 1/2 and a constraint length of 9.

The forward CDMA channel consists of a pilot channel, a synchronization channel, up to 7 paging channels, and up to 63 forward traffic channels. The pilot channel, code channel 0, allows a MT to acquire the timing of the forward CDMA channel. Operating at 19.2 kbps, it provides a phase reference for coherent demodulation and provides a means of comparing signal strength between BSs so as to determine when to handoff. The synchronization channel is code channel 32 which transports the synchronization message to the MT. It operates at 1200 bps. The paging channels, which can be code channels 1 through 7, are used to send control information and paging messages from a BS to MTs. They operate at 9600, 4800, or 2400 bps and they can be replaced, one by one, with forward traffic channels. The forward traffic channels, the remaining code channels, support variable user data rates at 9600, 4800, 2400 or 1200 bps.

The CDMA reverse link also employs PN modulation using the same 32768 length binary sequences which are used for the forward link. However, the modulation characteristics for the forward and reverse channel are different because a MT does not establish a system time as a BS does. Therefore, the reverse channel signal received at the BS cannot use coherent detection. Signals from different MTs are distinguished by the use of
a very long \(2^{42} - 1\) PN sequence with a user address determined time offset. The transmitted digital information is convolutionally encoded using a rate 1/3 code (three encoded binary symbols per information bit) of constraint length 9. The encoded information is grouped in six symbol groups (or code words). These code words are used to select one of 64 different orthogonal Walsh functions for transmission. In the reverse link, the Walsh function, which is determined by the information being transmitted, is different from the Walsh function in the forward link. The use of Walsh function modulation on the reverse link simply obtains 64-ary modulation with coherence over two information bit times. This is the best way to provide a high quality link in a fading channel with low \(E_b/N_o\) where a pilot phase reference channel cannot be provided.

The reverse CDMA channels are made up of access channels and reverse traffic channels. The reverse CDMA channel can have up to 62 traffic channels and up to 32 access channels per supported paging channel.

The CDMA system examined in this thesis is based on the above specifications. There are at most 62 reverse traffic channels and 63 forward traffic channels available at each BS. The number of forward and reverse channels slightly differs because of different modulation and coding schemes. For simplicity, this thesis assumes a maximum of 62 reverse and forward traffic channels at each BS in the process of determining the optimal partitioning of trunk groups.

### 1.1.2 Soft Handoffs in CDMA

One of the many distinct features of CDMA is its support of soft handoffs between adjacent cells for MTs crossing cell boundaries. Soft handoffs allow MTs in handoff regions to communicate with both old and new BSs simultaneously, enabling coherent diversity combining of signals using RAKE receivers to minimize signal degradations and disruptions. Because of the “make before break” switching function of the radio links, the soft handoffs are inherently seamless, avoiding the undesirable “ping-pong” phenomenon occurring in conventional hard handoffs.
In PCNs employing microcells, soft handoffs between two microcells within a cluster of microcells connected to the same mobile switching center (MSC) are readily achieved by diversity combining reverse signals from the two adjacent BSs at the common MSC and coherently combining the corresponding forward signals by a RAKE receiver at the MT [6, 7, 11-14]. A cell-cluster is a collection of cellular BSs which are controlled by a MSC. This handoff process is managed entirely by the common MSC without the involvement of the backbone intelligent network (IN); it does not require the setting up and switching of network connections during the handoff. For example, in the cellular Asynchronous Transfer Mode (ATM) network, the handoff within the same cell-cluster is achieved by assigning to the call with virtual circuit numbers (VCNs) which define a path between the source and target BSs, therefore not involving the backbone IN as described in [15, 16].

As personal communication networks (PCNs) become ubiquitous, it is necessary to extend the same handoff service between microcell clusters connected to different MSCs. Seamless handoffs between different cell-clusters would be much more complicated because signaling would need to be transferred between MSCs, probably through the backbone IN. Recently, attempts have been made to provide seamless handoffs of ATM/BISDN network connections between different MSCs while avoiding the involvement of IN during handoffs between cell-clusters [17]. On the other hand, the configuration and the partitioning of trunk groups for the support of soft handoffs between adjacent cell-clusters have not received much consideration in the literature. New configurations means to evaluating their performance, such as their traffic capacities. Consequently, this thesis proposes three novel network configurations and evaluates their performance for CDMA soft handoffs between cell-clusters over BS-MSC links.

### 1.2 Objectives

This thesis attempts to investigate soft handoffs over the BS-MSC links between
cell-clusters connected to different MSCs. Because soft handoffs between MSCs require new connections and trunk groups, this thesis suggests three novel network configurations for CDMA soft handoffs between cell-clusters. The operations of soft handoffs in these configurations are described in detail and the traffic capacities of these configurations are examined.

In order to analyze the traffic capacities of these configurations, traffic statistics for microcells are needed. This thesis develops a new mobility model for vehicle and pedestrian traffic in microcells serving a city center. The mobility model includes go-and-stop probabilities which simulate the movement of vehicles and pedestrians in a city center. The mobility model provides data of channel holding time, ratios of handoff calls and handoff transition time for various size of microcells and traffic condition.

With the traffic statistics provided by the mobility model, the optimal partitioning of trunk groups under the constraint of 62 channels in direct and cross links of each microcell is investigated by mathematical analysis and computer simulation for both vehicle and pedestrian traffic. The blocking probability of each channel and the new call and handoff blocking probabilities and optimal channel dimensions are also determined with various new call arrival rate. Because the first channel assignment scheme of configuration I produces some undesirable handoff blocking probabilities from MT user’s point of view, another channel assignment scheme is developed for configuration I to provide lower handoff blocking probability by lengthening the handoff transition time of MTs.

The total number of 62 channels in direct and cross links of each microcell is a minimum constraint. By adding extra channels to direct and cross links, the blocking probabilities can be further reduced and the optimal partitioning of trunk groups in this case is investigated. According to the mobility model, different cell sizes and traffic conditions provide different traffic statistics. The maximum new call arrival rate to keep new call blocking probability, $P_{Bn} < 0.01$, with optimal channel dimensions is analyzed in all these cases. It is expected that the maximum new call arrival rate increases with
the decrease of cell size. Finally, the sensitivity of optimal channel dimensions to the new call arrival rate and handoff transition time is examined. Throughout this thesis, the results obtained for these three configurations are compared with each other.

1.3 Structure of the Thesis

The following chapters of this thesis are structured as follows: In chapter 2, a mobility model with stop-and-go probabilities is developed for vehicle and pedestrian traffic. Mean channel holding time, handoff call ratios and handoff transition time are investigated. Chapter 3 describes network configuration I, the simplest of the three configurations. This chapter proposes two channel assignment schemes so as to compare the new call and handoff blocking probabilities. Chapter 4 describes network configuration II, which prevents the problem of oscillations and reduces the number of unnecessary handoffs between cell-clusters. The performance of configuration II is evaluated by mathematical analysis and computer simulation. Chapter 5 describes network configuration III, which provides the most efficient trunk utilization compared to the other two configurations, thus potentially accommodating the most calls of the three configurations. Its performance is investigated by computer simulation. Chapter 6 compares all three configurations in terms of their handoff procedures and blocking probabilities. Finally, Chapter 7 draws conclusions.
Chapter 2 MOBILITY MODEL

This chapter develops a mobility model for vehicle traffic moving through microcells within a city center. The mobility model is also modified for pedestrian traffic. Before the channel dimensions of the BS-MSC links can be determined, the mobility pattern of MTs in microcells needs to be known. Traffic and mobility models have a major impact on PCNs. A huge amount of traffic will load the PCNs far more than is the case of the current systems and thus a study of traffic mobility helps to design PCNs. Whereas traffic statistics and mobility models for macrocells have been widely discussed in the literature [18–20], mobility models for microcells have received less attention [21]. The following mobility model to facilitate traffic analysis in subsequent chapters is newly developed.

The mobility model developed in this thesis simulates the vehicle and pedestrian traffic in microcells serving in a city center. As cars in a city center often stop because of traffic congestion and pedestrians often sit down when they are talking on MTs, the mobility model introduces stop-and-go probabilities for vehicle and pedestrian traffic. The traffic parameters are chosen for the situation of an urban city. From the mobility model of this urban city, the channel holding time, ratios of handoff calls and handoff transition time are investigated.

Figure 2.1 shows a hexagonal microcell with radius $R$ having a BS located at its center. MTs are assumed to be uniformly distributed over a circular region with radius $7R$ around the BS. The hexagonal cell is surrounded by three circular rings of neighboring cells with the following radii: $R$ to $3R$, $3R$ to $5R$ and $5R$ to $7R$. The hexagonal cell is assumed to be surrounded by six other microcells which constitute the first layer of the circular ring. The circular rings are approximations for hexagonal microcells surrounding the center hexagonal cell. The original location of a MT is represented by its distance $r$ and angle $\theta$ from the BS. The mobility pattern of the MT is as follows. The movement of the MT consists of moving and stopping intervals, consistent with the traffic in a
city center where the microcell is likely located. If $p$ is the probability that the MT enters a stopping interval, the probability of the MT entering a moving interval after a stopping or moving interval will be $1-p$. Random variables $T_m$ and $T_s$ represent the duration of each moving and stopping interval, uniformly distributed in $[0, T_{m_{\max}}]$ and $[0, T_{s_{\max}}]$, respectively. Random variable $V$ represents the speed of the MT in a moving interval, assumed to be uniformly distributed in $[0, V_{\max}]$. The direction of the travel is assumed to change before each moving interval with its angle uniformly distributed between $\pm \phi$ relative to the MT’s travelling direction in the previous moving interval. Finally, random variable $T$ stands for the unencumbered message duration, which is negatively exponential distributed with mean $1/\mu$. The following equations shows the
probability density functions of the above random variables:

\[
f_r(r) = \begin{cases} 
2r/(7R)^2, & \text{for } 0 \leq r \leq 7R \\
0, & \text{elsewhere}
\end{cases} \tag{1}
\]

\[
f_\theta(\theta) = \begin{cases} 
1/2\pi, & \text{for } 0 \leq \theta \leq 2\pi \\
0, & \text{elsewhere}
\end{cases}
\]

\[
f_{T_m}(t) = \begin{cases} 
1/T_{m_{\text{max}}}, & \text{for } 0 \leq t \leq T_{m_{\text{max}}} \\
0, & \text{elsewhere}
\end{cases} \tag{3}
\]

\[
f_{T_s}(t) = \begin{cases} 
1/T_{s_{\text{max}}}, & \text{for } 0 \leq t \leq T_{s_{\text{max}}} \\
0, & \text{elsewhere}
\end{cases} \tag{4}
\]

\[
f_V(v) = \begin{cases} 
1/V_{\text{max}}, & \text{for } 0 \leq v \leq V_{\text{max}} \\
0, & \text{elsewhere.}
\end{cases}
\]

\[
f_T(t) = \begin{cases} 
\mu e^{-\mu t}, & \text{for } t \geq 0 \\
0, & \text{elsewhere.}
\end{cases} \tag{6}
\]

Let \( \alpha, \beta \) and \( \gamma \) be the ratios of the number of MTs which originate calls from \( R < r < 3R, 3R \leq r < 5R \) and \( 5R \leq r < 7R \), respectively, and they move into the center cell before call termination, to the number of new calls originating in the center cell, over a given time interval. Let \( \delta \) be the ratio of the number of MTs originating call from the center cell, going out of it, and returning to the center cell before call termination, to the number of new calls originating in the center cell, over a given time interval. These values of \( \alpha, \beta, \gamma \) and \( \delta \) correspond to the ratios of handoff calls from the corresponding layers of neighboring cells into the center cell to the new calls originating from the center cell.

Apart from handoff call ratios, the handoff transition time of MTs during soft handoffs needs to be investigated so that the number of channels required in cross links can be determined. The handoff transition time of a MT is the period between the detection of a reduction of the quality of the received signal strength requiring a change of channel and the completion of establishing a new channel. It usually happens when MTs are
near the boundary of microcells. Figure 2.2 shows the handoff transition region. The circular microcell is assumed to be surrounded by six other microcells, so the handoff transition region is one-sixth of the circular ring with inner radius of \( r_1 \) and outer radius of \( R \). The handoff transition region depends on the signal strength received by MTs at a distance \( r_1 \) from the BS at the center of the circular microcell. In turn, the signal strength depends on the pathloss, Rayleigh fading, and shadowing effect. The following equation describes the pathloss curve [8, 9]:

\[
P_r(dBm) = P_t(dBm) - \kappa \log \frac{r_1}{r_o}
\]  

In this equation, \( P_t(dBm) \) is the transmitted power at the BS, \( P_r(dBm) \) is the received power at the MT, \( r_1 \) is the distance between the MT and the BS, \( r_o \) is a scaling factor and \( \kappa \) is the pathloss slope. From [22], the handoff transition region begins when the median signal strength drops to \(-90\) dBm. From [23], the hysteresis of a handoff is between \( 3 \) dB and \( 6 \) dB. This thesis assumes the hysteresis to be \( 5 \) dB. Because signals are diversity combined at receivers during soft handoffs, Rayleigh fading is eliminated. If BSs are
installed on lamp posts in microcells, most MTs on the street will have a line of sight to the BSs and thus shadowing effect is not very important. Therefore, only the pathloss curve is accounted for in the calculation of the area of the handoff transition region in this thesis. The previously described mobility pattern is employed to investigate the mean handoff transition time $1/\mu_2$ by computer simulation.

2.1 Vehicle Traffic

The system parameters chosen for vehicular MTs traveling through a city center are as follows: $T_{m\_max} = 40$ s, $T_{s\_max} = 40$ s, $V_{max} = 70$ km/hr, $1/\mu = 120$ s and $\phi = 100^\circ$. $T_{m\_max}$ is about the time required for a MT to travel through two city blocks, and $T_{s\_max}$ is about the time interval of a red traffic light in a city. $V_{max}$ is approximately the maximum speed of a MT traveling in a city. The value $1/\mu$ is representative of the average duration of calls over MTs in rush hours. The value $\phi$ reflects the fact that vehicular MTs are unlikely to reverse direction on the road. Various traffic conditions are simulated: $p = 0.0$ for light traffic, $p = 0.25$ for moderate traffic, and $p = 0.5$ for heavy traffic, with $R$ ranging from 300 m to 1000 m.

Simulations with a model written in C programming language indicate that the mean channel holding time $1/\mu_1$ increases with cell size and road traffic as shown in Figure 2.3. It also shows that the channel holding time probability density function is approximately negatively exponential, the approximation getting closer to the theoretical value with larger cells. Figures 2.4, 2.5, 2.6 and 2.7 show the values of $\alpha$, $\beta$, $\gamma$ and $\delta$ respectively. They show that except for the values of $\delta$, the handoff call ratios in the microcell decrease with increasing cell size and road traffic. Figure 2.6 shows that relatively few calls originating from MTs located at $5R \leq r < 7R$ eventually go into the center cell before being terminated, especially when $R > 500$ m. In contrast, the values of $\alpha$ are much greater than the corresponding values of $\beta$ and $\gamma$, showing that most handoff calls originate from immediately adjacent cells. The values of $\delta$ are the next largest values to
the corresponding values of $\alpha$ and therefore they cannot be neglected. Table 2.1 shows the 99\% confidence level of the results at $R = 500$ m and $p = 0.25$ in 20 trials. Because the ranges of confidence intervals of these results are very narrow, the results for other values of $R$ and $p$ are also expected to be close to mean values.

Figure 2.3 Mean channel holding time $1/\mu_i$ vs. cell size for various vehicle traffic
Figure 2.4 Values of $\alpha$ vs. cell size for various vehicle traffic

Figure 2.5 Values of $\beta$ vs. cell size for various vehicle traffic
Figure 2.6 Values of $\gamma$ vs. cell size for various vehicle traffic

Figure 2.7 Values of $\delta$ vs. cell size for various vehicle traffic
Table 2.1 Confidence interval of the mobility model at $R = 500$ m and $p = 0.25$ for vehicle traffic

<table>
<thead>
<tr>
<th>Traffic parameters</th>
<th>Mean value</th>
<th>99 % confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1/\mu_I$ (s)</td>
<td>52.994</td>
<td>[52.973, 53.015]</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.33057</td>
<td>[0.33030, 0.33084]</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.01481</td>
<td>[0.01468, 0.01494]</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.000992</td>
<td>[0.000969, 0.001015]</td>
</tr>
<tr>
<td>$\delta$</td>
<td>0.07391</td>
<td>[0.07366, 0.07416]</td>
</tr>
</tbody>
</table>

For the handoff transition time, the value of $\kappa$ is chosen to be 40 for vehicle traffic according to the fourth power rule for signal propagation in microcells [24, 25, 8]. From equation (7), the handoff transition region appears to be 44% of the area of microcells, and this value is consistent with the value suggested in [23] to keep the probability of handoff termination less than 0.01. Figure 2.8 shows that the handoff transition time increases with cell sizes and road traffic.

The results for $R = 500$ m and $p = 0.25$ (moderate traffic) are chosen for channel dimensions of the BS-MSC links in the three network configurations, and the data are shown in Appendix B.
2.2 Pedestrian Traffic

As PCNs become ubiquitous, it is necessary to consider pedestrian traffic. Therefore, this thesis proposes a pedestrian traffic modification of the above mobility model of vehicle traffic. The random variables are the same except that the numerical values of the traffic parameters are different. The microcells serving pedestrians are smaller than those serving vehicles, and the movements of pedestrians are slower and more random than those of vehicles. Consequently, the system parameters chosen for pedestrians are as follows: $100 \leq R \leq 300$ m, $T_{m_{\text{max}}}=60$ s, $T_{s_{\text{max}}}=60$ s, $V_{\text{max}}=8$ km/hr, $1/\mu=120$ s and $\phi=180^\circ$. The range of $R$ gives the size of a microcell in a park or a mall. $T_{m_{\text{max}}}$ is about the time required for a pedestrian to walk the length of two blocks in a mall and $T_{s_{\text{max}}}$ is about the time interval required by a pedestrian to find a place to sit down and talk on the phone. $V_{\text{max}}$ is approximately the maximum speed of a pedestrian who is in a hurry. The value $1/\mu$ for pedestrian calls is assumed to be the same as vehicle
calls. The chosen value $\phi$ for pedestrians is larger than that for vehicles, showing that the movements of pedestrians are more random than those of vehicles.

Figure 2.9 shows the mean channel holding time $1/\mu_1$ versus cell sizes with various pedestrian traffic conditions. The mean channel holding time for pedestrians is longer than that for vehicles since the mobility of pedestrians is slower than that of vehicles. Figure 2.10 shows handoff call ratio $\alpha$ versus cell size under various pedestrian traffic conditions. The values of $\alpha$ for pedestrians are smaller than those for vehicles, showing that most pedestrians stay in the same cell during their calls. The values of $\beta$ and $\gamma$ are too small to have any effect on pedestrian traffic, showing that it is very rare for a pedestrian to pass through more than one cell during a call. Figure 2.11 shows the values of $\delta$ in pedestrian traffic where the trend is different from the trend of vehicles because of different values of $\phi$ chosen.

Figure 2.9 Mean channel holding time $1/\mu_1$ vs. cell size for various pedestrian traffic
Figure 2.10 Values of $\alpha$ vs. cell size for various pedestrian traffic

Figure 2.11 Values of $\delta$ vs. cell size for various pedestrian traffic
The value of $\kappa$ is chosen to be 20 for evaluation of the handoff transition time of pedestrian traffic, according to the square rule for signal propagation in smaller microcells [23, 24]. The microcells for vehicle traffic are bigger and the MT is usually out of sight of the BS; furthermore, signal strength from the BS is greatly attenuated by the surrounding buildings. On the other hand, the microcells for pedestrians traffic are smaller, and the MT tends to be in the line of sight of the BS. The value of pathloss slope $\kappa$ for pedestrians is therefore smaller than that for vehicles. The pathloss slope $\kappa$ for pedestrians is close to the pathloss slope value of free space [8]. By putting the chosen value of $\kappa$ into equation (7), the handoff transition region for pedestrians is about 68% of the area of the microcells, a value which is consistent with that suggested in [23] for keeping the probability of handoff termination less than 0.01. The handoff transition region for pedestrians occupies a larger percentage of the area of the microcells than that for vehicles because the cell size for pedestrians is smaller than that for vehicles. Figure 2.12 shows the mean handoff transition time $1/\mu_2$ verses different cell sizes with various pedestrian traffic conditions. The mean handoff transition time in pedestrian traffic is longer than that in vehicle traffic because the movement of pedestrians is slower than that of vehicles.

The results for $R = 150$ m and $p = 0.25$ (moderate traffic) are chosen for channel dimensions of the BS-MSC links in the network configurations, and the data are shown in Appendix B.
Figure 2.12 Mean handoff transition time $1/\mu_2$ vs. cell size for various pedestrian traffic
Chapter 3 NETWORK CONFIGURATION I

This chapter describes the first proposed network configuration, the simplest of the three network configurations. The available 62 channels from each BS are partitioned into direct links and cross links for the minimum handoff blocking probability. Two channel assignment schemes are proposed, one of them lengthening the handoff transition time so as to lower the handoff blocking probability.

3.1 Description and Operation

In configuration I, each pair of microcells at the edge of two adjacent cell-clusters are cross-linked with the MSCs serving the opposing cell-clusters. This linkage is illustrated in Figure 3.1, where microcells 1 and 2 are adjacent at the boundary of two neighboring cell-clusters; direct links $L_{A1}$ and $L_{B2}$ connect MSCs A and B to microcells 1 and 2, respectively, and cross links of $L_{A2}$ and $L_{B1}$ interconnect microcells 2 and 1 to MSCs A and B, respectively. The addition of the cross links enables soft handoffs between the two microcells by allowing diversity combining of received signals at the MSCs and MTs during the handoff process. The soft handoff operation between microcells 1 and 2 is described below.

Consider a MT moving from microcell 1 to 2. When the MT enters the handoff region, a CDMA channel is assigned in microcell 2 to enable the MT to communicate simultaneously with both BSs 1 and 2. Initially, the MT's call is routed through MSC A and its connections to BSs 1 and 2 via direct link $L_{A1}$ and cross link $L_{A2}$, respectively; diversity combining occurs at MSC A for the reverse channel and at the MT for the forward channel. At the same time, network signaling is invoked, possibly through the IN, to set up a new network connection to MSC B for the handoff between the cell-clusters. When a successful connection occurs, an alternate route for the call exists, through MSC B and its connections to BSs 1 and 2 via cross link $L_{B1}$ and direct link $L_{B2}$.
At this point, the forward signal for the MT is available at MSC B from the network but is not yet forwarded to the MT over the air interface via $L_{B1}$ and $L_{B2}$; likewise, the reverse signal from the MT is available at MSC B via $L_{B1}$ and $L_{B2}$ but is not yet forwarded to the network. A seamless handoff between the network connections now occurs (either through the connection architecture and protocols proposed in [17], or through IN services) to switch the network connection from MSC A to MSC B. This process completes the new connection for the reverse traffic over the network and for the forward traffic over BSs 1 and 2 via $L_{B1}$ and $L_{B2}$, respectively. When the new connection is in full operation, the old network connection to MSC A and the connections from MSC A to BSs 1 and 2 via $L_{A1}$ and $L_{A2}$ are dropped. As soon as the signal strength for the MT has fallen below a certain threshold in microcell 1, cross link $L_{B1}$ and the corresponding
CDMA channel in microcell 1 are dropped. This concludes the handoff operation: the MT now communicates exclusively through BS 2 and MSC B.

In the above handoff operation, as long as the MT which has moved from microcell 1 to 2 stays in microcell 2, communications will not be disrupted regardless of any delay in completing the new handoff connection to MSC B over the network. It is therefore expected that the IN will be quite capable of handling the network portion of the handoff between MSC A and MSC B. In fact, if the completion of the handoff from MSC A to B is delayed, possible oscillations between the handoff connections due to the MT moving back and forth across the boundary of cell-clusters will be reduced. However, the delay in the handoff completion reduces the traffic capacity of each microcell while increasing the cross-link capacity required. Due to these trade-offs, a certain degree of oscillations is unavoidable. This oscillations may increase the signalling traffic in the network. However, configuration II, to be presented in the next chapter, completely prevents oscillations from occurring.

### 3.2 Channel Dimensions

The objective is to determine the number of channels required for direct link $L_{A1}$ and cross link $L_{A2}$ as illustrated in Figure 3.1. By symmetry, links $L_{B2}$ and $L_{B1}$ require the same number of channels as links $L_{A1}$ and $L_{A2}$, respectively. Let $\lambda_0$ be the rate at which new calls arrive in a microcell. Assume all arrival processes are Poisson. The total arrival rate at direct link $L_{A1}$ is $(1+\alpha+\delta)\lambda_0$ which is contributed by originating calls, $\lambda_o$, and handoff calls, $(\alpha+\delta)\lambda_0$. The total arrival rate at cross link $L_{A2}$ is $(2/3)(\alpha+\delta)\lambda_0$ which is contributed solely by handoff calls, $(\alpha+\delta)\lambda_0$. These handoff calls come from two sides of a six-sided hexagonal cell and these handoff calls in either directions from microcell 1 to 2 and from microcell 2 to 1 are taken into account. Therefore, there is a factor $(2/3)$ in the arrival rate of cross link $L_{A2}$. Because the values of $\beta$ and $\gamma$ are relatively small compared to the value of $(1+\alpha+\delta)$, the factors $\beta$ and $\gamma$ are neglected.
For cross link $L_{A2}$, assume the channel holding time for the MTs passing through the handoff region (the handoff transition time) is exponentially distributed with mean $1/\mu_2$.

In all the following mathematical analyses, link blocking probabilities have been taken into the account; however, for the sake of simplicity, they will not be shown in subsequent equations. For example, the arrival rate at direct link $L_{A1}$ is shown to be $(1+\alpha+\delta)\lambda_0$. More precisely, the arrival rate at direct link $L_{A1}$ should be $(1+[\frac{1}{3}(1-P_B(L_{B2})\cdot(1-P_B(L_{B1}))+\frac{2}{3}(1-P_B(L))\cdot\alpha]+[(\frac{1}{3})^2(1-P_B(L_{A1})\cdot(1-P_B(L_{A2}))(1-P_B(L_{B2})\cdot(1-P_B(L_{B1}))+\frac{2}{3}(1-P_B(L_{A1})\cdot(1-P_B(L))\cdot\delta)\cdot\lambda_0\)\], a formula which takes into the account of the fact that some calls have already been blocked in other links during call originating before they may contribute to handoff arrivals in link $L_{A1}$, where $P_B(L_x)$s are the blocking probabilities of the respective links $L_x$. The factor, $(\frac{1}{3})(1-P_B(L_{B2})(1-P_B(L_{B1}))+\frac{2}{3}(1-P_B(L))$, is multiplied to the value $\alpha$ to show that a portion of $\alpha\lambda_0$ handoff calls are blocked because these handoff calls have utilized links $L_{B2}$, $L_{B1}$ and other direct links before they handoff to link $L_{A1}$. The new call and handoff blocking probabilities are then obtained by the equations derived with these link blocking probabilities by iteration.

There are two possible channel assignment schemes, according to the amount of channel holding time over cross links during the soft handoffs. The two assignment schemes are described as follows:

### 3.2.1 Channel Assignment Scheme I

The first channel assignment scheme provides a simple algorithm for CDMA soft handoffs between cell-clusters in network configuration I. Its description is as follows:

#### 3.2.1.1 Description

In channel assignment scheme I, when a MT handoffs from microcell 1 to 2, the handoff is successful when a channel in direct link $L_{B2}$ is available. However, if no channel is available in direct link $L_{B2}$, the handoff call is blocked and dropped.
immediately. The blocking probability $P_B$ of each link is given by the Erlang B formula [26]:

$$P_B = \frac{\rho^m / m!}{\sum_{n=0}^{m} \rho^n / n!}$$

(8)

where $\rho = \lambda / \mu$ is the Erlang load, and $m$ is the number of channels in the corresponding link. Let $P_B(L_{A2})$ and $P_B(L_{B2})$ be the blocking probabilities of cross link $L_{A2}$ and direct link $L_{B2}$, respectively. The following equation shows the handoff blocking probability $P_{BhII}$ between the two cell-clusters:

$$P_{BhII} = P_B(L_{A2}) + [1 - P_B(L_{A2})]P_B(L_{B2}).$$

(9)

3.2.1.2 Results for Vehicle Traffic

Subject to the constraint that the total number of channels in links $L_{A2}$ and $L_{B2}$ equals 62, the cell-cluster handoff blocking probability $P_{BhII}$ can be minimized with respect to the channel dimensions of links $L_{A2}$ and $L_{B2}$. When $\lambda_o = 2000/hr/cell$, Figure 3.2 shows that in order to minimize $P_{BhII}$, 53 channels should be assigned to direct link $L_{B2}$ and the remaining 9 channels to cross link $L_{A2}$. Table 3.1 shows the vehicle traffic parameters for scheme I, configuration I, and the channel dimensions minimizing $P_{BhII}$ at $1800 \leq \lambda_o \leq 2300/hr/cell$. Figure 3.3 shows the blocking probability $P_B$ of direct and cross links for optimal channel dimensions at $\lambda_o = 2000/hr/cell$. The blocking probability $P_B(L_{A1})$ of direct link $L_{A1}$ is more susceptible to the new call arrival rate $\lambda_o$ than that $P_B(L_{A2})$ of cross link $L_{A2}$ because the handoff call arrival rate for cross link $L_{A2}$ is only a small proportion of the new call arrival rate. Figure 3.4 shows the new call and handoff blocking probabilities with optimal channel dimensions at $1800 \leq \lambda_o \leq 2300/hr/cell$. The handoff blocking probability is higher than the new call blocking probability because both direct and cross links are required for a successful handoff call. From the MT user’s point of view, the termination of an ongoing call is less desirable than the blocking of a new call. Consequently, the results of the new call and handoff blocking probabilities in channel
assignment scheme I are not so desirable; therefore, a second channel assignment scheme is developed in Section 3.2.2 and it will lower the handoff blocking probability.

Figure 3.2 Inter-cluster handoff blocking probability for channel assignment scheme I in configuration I, $P_{BhII}$, vs.
number of channels in $L_{A2}$ at $\lambda_o = 2000/hr/cell$ for vehicle traffic

Table 3.1 Vehicle traffic parameters of channel assignment scheme I in configuration I

<table>
<thead>
<tr>
<th>Connecting links</th>
<th>Arrival rate</th>
<th>Channel holding time</th>
<th>Channel dimensions to minimize $P_{BhII}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{A1}, L_{B2}$</td>
<td>$(1+\alpha+\delta)\lambda_o$</td>
<td>$1/\mu_1$</td>
<td>$1800 \leq \lambda_o \leq 2000$</td>
</tr>
<tr>
<td>$L_{A2}, L_{B1}$</td>
<td>$(2/3)(\alpha+\delta)\lambda_o$</td>
<td>$1/\mu_2$</td>
<td>$2100 \leq \lambda_o \leq 2300$</td>
</tr>
</tbody>
</table>
Figure 3.3 Blocking probability $P_B$ of direct and cross links with optimal channel dimensions at $\lambda_o = 2000$/hr/cell of scheme I in configuration I for vehicle traffic.

Figure 3.4 New call and handoff blocking probability of scheme I in configuration I with optimal channel dimensions for vehicle traffic.
The previous paragraph has assumed that 62 forward/reverse channels are at each BS; in fact, this number is the minimum total number of channels in the direct and cross links. The blocking probabilities can be reduced by increasing the total number of direct-link-and-cross-link channels to more than 62. Figure 3.5 shows optimal dimensions of cross links at $\lambda_o = 2000/\text{hr/cell}$, when there are more than 62 channels available for direct and cross links. This result is obtained by the Erlang B equation (8) and equation (9) with increased values of $m$. Figure 3.6 shows that adding extra channels to the present 62 channels significantly reduces the new call and handoff blocking probabilities.

Figure 3.5 Channel dimensions of scheme I in configuration I at $\lambda_o = 2000/\text{hr/cell}$ for vehicle traffic
Figure 3.6 New call and handoff blocking probability of scheme I in configuration I vs. total no. of channels in direct and cross links at $\lambda_o = 2000$/hr/cell for vehicle traffic

According to the mobility model in Chapter 2, different cell sizes and traffic conditions have different channel holding times, handoff call ratios and handoff transition times. The optimal channel dimensions to minimize handoff blocking probability, $P_{BhII}$, with new call blocking probability, $P_{Bn} < 0.01$, for different parameters in the mobility model have been investigated and the results are tabulated in Table 3.2. This table shows that more channels in cross links are required when cells are smaller and the mobility is higher (light traffic). Figure 3.7 shows the maximum new call arrival rate $\lambda_o$ that scheme I, configuration I, can accommodate in these situations. As expected, the traffic capacity increases when the cell size decreases. The handoff blocking probability $P_{BhII}$ in the mobility model ranges from 0.011 to 0.014.
Table 3.2 Effects of mobility parameter and cell size on channel dimensions of scheme I in configuration I with $P_{Bn} < 0.01$ for vehicle traffic

<table>
<thead>
<tr>
<th>$L_{A1}, L_{A2}$</th>
<th>Probability of entering stopping interval $p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell radius (m)</td>
<td>0.0</td>
</tr>
<tr>
<td>300</td>
<td>53, 9</td>
</tr>
<tr>
<td>400</td>
<td>53, 9</td>
</tr>
<tr>
<td>500</td>
<td>53, 9</td>
</tr>
<tr>
<td>600</td>
<td>53, 9</td>
</tr>
<tr>
<td>700</td>
<td>53, 9</td>
</tr>
<tr>
<td>800</td>
<td>53, 9</td>
</tr>
<tr>
<td>900</td>
<td>53, 9</td>
</tr>
<tr>
<td>1000</td>
<td>54, 8</td>
</tr>
</tbody>
</table>

Figure 3.7 Max. new call arrival rate of scheme I in configuration I with $P_{Bn} < 0.01$ and optimal channel dimensions for vehicle traffic

3.2.1.3 Results for Pedestrian Traffic

The performance of pedestrian traffic in scheme I, configuration I, is investigated in the same manner as the performance of vehicle traffic. The total number of channels for direct and cross links is still capped at 62. Figure 3.8 shows that 54 channels should
be assigned to direct link $L_{B2}$ and the remaining 8 channels to cross link $L_{A2}$ so as to minimize $P_{B\text{II}}$ at $\lambda_0 = 1400/\text{hr/cell}$. Table 3.3 shows the pedestrian traffic parameters for scheme I, configuration I, and the channel dimensions minimizing $P_{B\text{II}}$ at $1200 \leq \lambda_0 \leq 1700/\text{hr/cell}$. Figure 3.9 shows the blocking probability $P_B$ of the corresponding link for optimal channel dimensions at $\lambda_0 = 1400/\text{hr/cell}$. The blocking probability $P_B(L_{A1})$ of direct link $L_{A1}$ increases at a larger rate with respect to the new call arrival rate $\lambda_0$ than $P_B(L_{A2})$ of cross link $L_{A2}$ for pedestrian traffic due to the same reason as in vehicle traffic. The new call and handoff blocking probabilities when the optimal channel dimensions are employed at $1200 \leq \lambda_0 \leq 1700/\text{hr/cell}$ are shown in Figure 3.10. The handoff blocking probability is higher than the new call blocking probability for pedestrian traffic due to the same reason for vehicle traffic. The relatively high handoff blocking probability can be reduced by channel assignment scheme II in Section 3.2.2.

![Figure 3.8](image-url)

Figure 3.8 Inter-cluster handoff blocking probability for channel assignment scheme I in configuration I, $P_{B\text{II}}$, vs. number of channels in $L_{A2}$ at $\lambda_0 = 1400/\text{hr/cell}$ for pedestrian traffic
Table 3.3 Pedestrian traffic parameters of channel assignment scheme I in configuration I

<table>
<thead>
<tr>
<th>Connecting links</th>
<th>Arrival rate</th>
<th>Channel holding time</th>
<th>Channel dimensions to minimize</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{A1}, L_{B2}$</td>
<td>$(1+\alpha+\delta)\lambda_o$</td>
<td>$1/\mu_1$</td>
<td>$P_{Bhl}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$1200 \leq \lambda_o \leq 1300$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$1400 \leq \lambda_o \leq 1700$</td>
</tr>
<tr>
<td>$L_{A2}, L_{B1}$</td>
<td>$(2/3)(\alpha+\delta)\lambda_o$</td>
<td>$1/\mu_2$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.9. Blocking probability $P_B$ of direct and cross links of scheme I in configuration I with optimal channel dimensions at $\lambda_o = 1400$/hr/cell for pedestrian traffic.
Figure 3.10 New call and handoff blocking probability of scheme I in configuration I with optimal channel dimensions for pedestrian traffic.

Figure 3.11 shows optimal channel dimensions of cross links at $\lambda_o = 2000$/hr/cell when more than 62 channels are available for direct and cross links. Similar to the performance of vehicle traffic, Figure 3.12 shows that adding extra channels to the existing 62 channels for direct and cross links significantly reduces new call and handoff blocking probabilities for pedestrian traffic.
Figure 3.11 Channel dimensions of scheme I in configuration I at $\lambda_o = 2000/hr/cell$ for pedestrian traffic.

Figure 3.12 New call and handoff blocking probability of scheme I in configuration I vs. total no. of channels in direct and cross links at $\lambda_o = 1400/hr/cell$ for pedestrian traffic.
In regard to pedestrian mobility, the optimal channel dimensions to minimize handoff blocking probability \( P_{BHII} \) with new call blocking probability, \( P_{BN} < 0.01 \), have been investigated and the results are tabulated in Table 3.4. This table shows that similar to the performance of vehicle traffic, more channels in cross links are required when cells shrink and mobility increases (light traffic) for pedestrian traffic. Figure 3.13 shows the maximum new call arrival rate \( \lambda_o \) that scheme I, configuration I, can accommodate under these situations. Figures 3.7 and 3.13 show the same behavior for both vehicle and pedestrian traffic: the traffic capacity in the microcell increases as the cell size decreases. The handoff blocking probability \( P_{BHII} \) for pedestrian traffic in all these cases ranges from 0.011 to 0.014, the same range as for vehicle traffic.

Table 3.4 Effect of mobility parameter and cell size on channel dimensions of scheme I in configuration I with \( P_{BN} < 0.01 \) according to the mobility model for pedestrian traffic

<table>
<thead>
<tr>
<th>( L_{A1}, L_{A2} )</th>
<th>Probability of entering stopping interval ( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0</td>
</tr>
<tr>
<td>Cell radius (m)</td>
<td></td>
</tr>
<tr>
<td>( R )</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>52, 10</td>
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<tr>
<td>150</td>
<td>53, 9</td>
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<tr>
<td>200</td>
<td>53, 9</td>
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<tr>
<td>250</td>
<td>54, 8</td>
</tr>
<tr>
<td>300</td>
<td>54, 8</td>
</tr>
</tbody>
</table>
3.2.2 Channel Assignment Scheme II

Channel assignment scheme II is an alternative handoff procedure which lengthens the handoff transition time in cross links. The handoff blocking probability in scheme II is much lower than that in scheme I, a feature that is more desirable from the MT user’s point of view.

3.2.2.1 Description

In channel assignment scheme II, if no channel is available in direct link $L_{B2}$ when a MT handoffs from microcell 1 to 2, the handoff call is maintained by the existing channel in cross link $L_{A2}$ until either the MT leaves microcell 2 or a channel in direct link $L_{B2}$ becomes available. The MT can still maintain the call through cross link $L_{A2}$ even if no channel is available in direct link $L_{B2}$ as long as it stays in microcell 2. If the MT moves away from microcell 2 when the call is still being handled by cross link $L_{A2}$, the call will have to be dropped, however. This scheme helps to reduce the handoff blocking probability between cell-clusters.
Several schemes have been proposed to reduce the handoff blocking probability [18, 27–31]. The derivation of blocking probabilities in channel assignment scheme II is similar to the derivation of those of the priority scheme II without any guard channel in [18]. The size of queue is infinite in [18], but the size of queue is finite in this channel assignment scheme. Assume that \( C \) and \( C_q \) channels are in direct link \( L_{A1} \) and cross link \( L_{A2} \), respectively. By symmetry, links \( L_{B2} \) and \( L_{B1} \) require the same number of channels as links \( L_{A1} \) and \( L_{A2} \), respectively. A new call in microcell 2 is blocked when all the \( C \) channels in direct link \( L_{B2} \) are fully occupied. At this moment, if a handoff call arrives from cross link \( L_{A2} \), cross link \( L_{A2} \) will try to maintain this call for as long as the MT is in microcell 2. Effectively, the handoff call is in a queue, waiting for an available channel in direct link \( L_{B2} \). If a channel becomes available in direct link \( L_{B2} \), the available channel will be assigned to the first handoff call waiting in the queue in cross link \( L_{A2} \). If more than one handoff calls are waiting in the queue in cross link \( L_{A2} \), the principle of “first come first served” (FCFS) applies. That is, the handoff calls in cross link \( L_{A2} \) are allowed to queue with a buffer size equal to the number of channels \( C_q \) available in cross link \( L_{A2} \). The buffers are not real. Therefore, there are no physical limitations on buffer size except the number of channels \( C_q \) in cross links.

When all the channels in direct link \( L_{B2} \) are fully occupied, the waiting time for the completion of handoff calls in the channels of cross link \( L_{A2} \) depends on the channel holding time of MTs in microcell 2, which is exponentially distributed with mean \( 1/\mu_I \), as defined in the mobility model of Chapter 2. Let \( X \) be the random variable that the time period beginning at the instant that a handoff call joins the queue in cross link \( L_{A2} \) and ending at the instant that a channel in direct link \( L_{B2} \) is released. Because \( C \) channels serving in direct link \( L_{B2} \) have a service time of \( 1/\mu_I \) each, the probability density function of the random variable \( X \) is given by the following equation:

\[
f_X(t) = \begin{cases} 
C\mu_I e^{-C\mu_I t}, & \text{for } t \geq 0 \text{ and there is a queue} \\
0, & \text{elsewhere}
\end{cases}
\]  

(10)
Let $T_i$ be the time remaining for the handoff call in the $i$th queue position before the MT moves out of microcell 2. Given the memoryless property, the random variable $T_i$ is same as the random variable of channel holding time with mean $1/\mu_1$, which has been defined in the mobility model of Chapter 2. Let $N(t)$ be the state or occupancy of the queue at time $t$. From the description of this scheme and the independence of $X, T_1, T_2, \cdots, T_k$, the probability that a queued handoff call will advance by one position or be lost after a time interval $h$ is described as follows:

$$
\Pr\{N(t+h) = C + k - 1 \mid N(t) = C + k\} = \Pr\{X \leq h \text{ or } T_1 \leq h \text{ or } \cdots \text{ or } T_k \leq h\} = 1 - \Pr\{X > h\} \Pr\{T_1 > h\} \cdots \Pr\{T_k > h\} = 1 - e^{-(C+k)\mu_1 h} \tag{11}
$$

Any new arrival during the time interval $h$ does not change the above condition because only the handoff call already in the queue is considered and its position will not be changed by the new arrival. From (11), it follows the birth and death process and the resulting state transition diagram is shown in Figure 3.14. Let the state variable represent the number of calls trying to get a channel in direct link $L_{A1}$. For the first $C$ calls, they simply get a channel in direct link $L_{A1}$, and the arrival rate is $(1+\alpha+\delta)\lambda_o$ which includes the originating and handoff calls. Beyond this number of calls, only handoff calls may get a channel in direct link $L_{A1}$ by queueing at the $C_q$ channels in cross link $L_{B2}$ and thus the arrival rate is $(2/3)(\alpha+\delta)\lambda_o$. Solving the Markov chain equations [26], the state

![State transition diagram for channel assignment scheme II in configuration I](image)

Figure 3.14 State transition diagram for channel assignment scheme II in configuration I
probabilities $P_n$ of direct link $L_{B_2}$ can easily be found as follows:

$$P_n = \begin{cases} \frac{(1+\alpha+\delta)\lambda_o}{\mu_1} P_{n-1}, & n = 1, 2, \ldots, C \\ \frac{1}{3}(\alpha+\delta)\lambda_o}{\mu_1} P_{n-1}, & n = C + 1, \ldots, C + C_q \end{cases}$$  \quad (12)

$$\sum_{n=0}^{C+C_q} P_n = 1$$  \quad (13)

The following equations are obtained by solving (12) and (13):

$$P_0 = \left\{ \begin{array}{c} \sum_{n=0}^{C} \left[ \frac{(1+\alpha+\delta)\lambda_o}{\mu_1} \right]^n \frac{1}{n!} P_0, \\ \sum_{n=C+1}^{C+C_q} \left[ \frac{(1+\alpha+\delta)\lambda_o}{\mu_1} \right]^n \frac{1}{n!} P_0 \end{array} \right\}^{-1}$$  \quad (14)

$$P_n = \left\{ \begin{array}{c} \frac{(1+\alpha+\delta)\lambda_o}{\mu_1} \frac{1}{n!} P_0, \\ \frac{1}{3}(\alpha+\delta)\lambda_o}{\mu_1} \frac{1}{n!} P_0 \end{array} \right\}^{n-C} \quad n = 1, 2, \ldots, C$$

$$n = C + 1, \ldots, C + C_q$$  \quad (15)

The following equation gives the blocking probability $P_{Bo}$ of an originating call blocked in direct link $L_{B_2}$:

$$P_{Bo} = \sum_{n=C}^{C+C_q} P_n$$  \quad (16)

The following equation gives the average queue length $N_Q$ for the handoff calls:

$$N_Q = \frac{\sum_{n=0}^{C_2} n P_{C+n}}{P_{Bo}}$$  \quad (17)

By the application of Little’s theorem, the average waiting time $w$ in the queue is found by the following equation:

$$w = \frac{N_Q}{\frac{1}{3}(\alpha+\delta)\lambda_o}$$  \quad (18)

From [18], the following equations can be used to find the blocking probability of handoffs between cell-clusters in direct link $L_{B_2}$. Let $P_{fh}$ be the probability of a failed handoff attempt occurring after a MT has entered the queue; that is, the MT leaves
microcell 2 and prior to its coming into the first queue position and getting a channel. Let \( P_{fh|k} \) be the probability that the attempt fails given that it enters the queue in position \( k+1 \).

\[
P_{fh} = \sum_{k=0}^{C_q-1} P_{C+k} P_{fh|k}
\]

Let \( P(i | i+1) \) represents the probability that a handoff queued in position \( i+1 \) moves to position \( i \) before the corresponding MT moves away from microcell 2. Given the memoryless property, the following equation is obtained:

\[
1 - P_{fh|k} = \prod_{i=1}^{k} P(i | i + 1) \cdot \Pr\{\text{get channel in first position}\}
\]

A handoff call in position \( i+1 \) will advance if the remaining time in microcell 2 of the MT exceeds either at least one of the remaining times \( T_j \) of calls queued ahead of the referenced call, \( j = 1, 2, \ldots, i \), or the minimum remaining holding time, \( X \), of those calls in progress in microcell 2 through link \( L_{B2} \). A handoff attempt in position \( i+1 \) will not advance if both the above two conditions are not satisfied. Consequently, the following equation is produced:

\[
1 - P(i | i + 1) = \Pr\{T_{i+1} \leq X, T_{i+1} \leq T_j, j = 1, 2, \ldots, i\} \quad i = 1, 2, \ldots, k.
\]

Because the MTs move independently of each other and of the channel holding time, the joint probability can be expressed as a product. Given the memoryless property, the following equation is obtained.

\[
1 - P(i | i + 1) = \int_{0}^{\tau_2} \int_{0}^{\tau_2} \mu_1 e^{-\mu_1 \tau_1} C_{1} e^{-C_{2} \mu_1 \tau_2} d\tau_1 d\tau_2.
\]

\[
= \frac{1}{C + 1} \left( \frac{1}{2} \right)^i
\]
The MT at the head of the queue will get a channel if its remaining time, \( T_1 \), in microcell 2 exceeds \( X \).

\[
\Pr\{\text{get channel in first position}\} = \Pr\{T_1 > X\}
\]

\[
= \int_{0}^{\infty} \int_{0}^{T_2} C\mu_1 e^{-C\mu_1 T_1} \mu_2 e^{-\mu_2 T_2} d\tau_1 d\tau_2
\]

\[
= \frac{C}{C+1}
\]

(23)

From equations (19)-(23), the probability \( P_{fh} \) can be calculated.

The following equation gives the blocking probability \( P_h(L_{B2}) \) that a handoff call will be blocked in direct link \( L_{B2} \):

\[
P_h(L_{B2}) = P_{fh} + P_{C+C_q}\]

(24)

The weighted blocking probability \( P_B(L_{B2}) \) of direct link \( L_{B2} \) is as follows:

\[
P_B(L_{B2}) = \frac{\left\{(1 + \frac{2}{3}(\alpha + \delta))\lambda_o\right\} P_{B_0} + \left[\frac{1}{3}(\alpha + \delta)\lambda_o\right] P_h(L_{B2})}{(1 + \alpha + \delta)\lambda_o}
\]

(25)

The probability that cross link \( L_{A2} \) will be blocked given that direct link \( L_{B2} \) is not blocked is given by equation (7), with the arrival rate = \((2/3)(\alpha+\delta)\lambda_o\), the mean service time = \(1/\mu_2\) and \( m = C_q \). The probability that cross link \( L_{A2} \) will be blocked given that direct link \( L_{B2} \) is blocked is given by the following equation derived from the two dimensional Markov chain [26]:

\[
\Pr\{L_{B1}\text{blocked} \mid L_{A1}\text{blocked}\} = \frac{\sum_{n=0}^{C_q} \frac{\rho_1^{i_n} \rho_2^{q-n}}{n!(C_q-n)!}}{\sum_{i=0}^{C_q} \sum_{j=0}^{C_q-i} \frac{\rho_1^i \rho_2^j}{i!j!}}
\]

(26)

where the arrival rate and the mean service time for \( \rho_1 \) are \((1/3)(\alpha+\delta)\lambda_o\) and \(1/\mu_2\) respectively, and the arrival rate and the mean service time for \( \rho_2 \) are \((1/3)(\alpha+\delta)\lambda_o\).
and $1/\mu_2+w$, respectively. Appendix C shows the derive of equation (26). The blocking probability $P_B(L_{A2})$ for cross link $L_{A2}$ is as follows:

$$P_B(L_{A2}) = \Pr\{L_{A2} \text{ blocked} \mid L_{B2} \text{ blocked}\} \cdot P_{B_0} + \Pr\{L_{A2} \text{ blocked} \mid L_{B2} \text{ not blocked}\} \cdot (1 - P_{B_0})$$

(27)

Finally, the following equation gives the handoff blocking probability $P_{B_{hIII}}$ between cell-clusters:

$$P_{B_{hIII}} = P_B(L_{A2}) + (1 - P_B(L_{A2})) \cdot P_{fh}$$

(28)

3.2.2.2 Results for Vehicle Traffic

Again, when the total number of channels in $L_{A2}$ and $L_{B2}$ equals 62, the cell-cluster handoff blocking probability $P_{B_{hIII}}$ can be minimized with respect to channel dimensions of links $L_{A2}$ and $L_{B2}$. When $\lambda_o = 2000/hr/cell$, 51 channels should be assigned to direct link $L_{B2}$ and the remaining 11 channels should be assigned to cross link $L_{A2}$ in order to minimize $P_{B_{hIII}}$, as Figure 3.15 details. Table 3.5 shows the vehicle traffic parameters for scheme II, configuration I and the channel dimensions that minimize $P_{B_{hIII}}$ at $1800 \leq \lambda_o \leq 2300/hr/cell$. Note that $P_{B_{hIII}}$ in Table 3.5 is less sensitive to the channel partitioning than $P_{B_{hII}}$ in Table 3.1. More channels are assigned to cross link $L_{B1}$ in scheme II than in scheme I because in scheme II, channels in cross link $L_{B1}$ having longer holding times to service the prolonged handoff calls. Figure 3.16 shows the blocking probability $P_B(L_{B2})$ in direct link $L_{B2}$. Here, the blocking probability in direct link $L_{B2}$ is taken as the new call blocking probability. The blocking probability $P_B(L_{A2})$ in cross link $L_{A2}$ is too low to be shown for any interest: for example, it is less than 0.0001 for $\lambda_o = 2000/hr/cell$, one-hundredth of the blocking probability $P_B(L_{B2})$ of direct link $L_{B2}$. Comparison of Figures 3.2 and 3.15 shows that the handoff blocking probability $P_{B_{hIII}}$ in scheme II is much lower than the handoff blocking probability $P_{B_{hII}}$ in scheme I. The new call
probability and handoff blocking probability \( P_{BHIII} \) with optimal channel dimensions at \( 1800 \leq \lambda_o \leq 2300/\text{hr/call} \) are shown in Figure 3.17. The handoff blocking probability is lower by at least one tenth in scheme II than that in scheme I when Figures 3.17 and 3.4 are compared. However, the new call blocking probability in scheme II is higher than that in scheme I. These results show that scheme II can accommodate more handoff calls than scheme I, but only by sacrificing its ability to accommodate some new calls. The average waiting time \( w \) in the queue of cross link \( L_{A2} \) is 1.1 s.

![Figure 3.15 Inter-cluster handoff blocking probability for channel assignment scheme II in configuration I, \( P_{BHIII} \), vs. number of channels in L_{A2} at \( \lambda_o = 2000/\text{hr/cell} \) for vehicle traffic](image-url)
Table 3.5 Vehicle traffic parameters of channel assignment scheme II of configuration I

<table>
<thead>
<tr>
<th>Connecting links</th>
<th>Arrival rate</th>
<th>Channel holding time</th>
<th>Channel dimensions to minimize $P_{BkIII}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{A2}, L_{B1}$ given $L_{B2}, L_{A1}$ not blocked</td>
<td>$(2/3)(\alpha + \delta)\lambda_o$</td>
<td>$1/\mu_2$</td>
<td></td>
</tr>
<tr>
<td>$L_{A2}, L_{B1}$ given $L_{B2}, L_{A1}$ blocked</td>
<td>$(1/3)(\alpha + \delta)\lambda_o$</td>
<td>$1/\mu_2 + \omega$</td>
<td></td>
</tr>
</tbody>
</table>

$1800 \leq \lambda_o \leq 2300$

![Figure 3.16 Blocking probability $P_B$ of direct link $L_{B2}$ with optimal channel dimensions at $\lambda_o = 2000$/hr/cell of scheme II in configuration I for vehicle traffic](image)

Figure 3.16 Blocking probability $P_B$ of direct link $L_{B2}$ with optimal channel dimensions at $\lambda_o = 2000$/hr/cell of scheme II in configuration I for vehicle traffic
As in scheme I, more than 62 channels can be assigned to direct and cross links in scheme II so as to reduce blocking probabilities. Figure 3.18 shows optimal channel dimensions of cross links when there are more than 62 channels to be partitioned between direct and cross links. Figure 3.19 shows that when there are more than 62 channels available for direct and cross links, extra channels significantly reduce the new call blocking probability. Reduction of the handoff blocking probability is not very pronounced, as this probability is already very low.
Figure 3.18 Channel dimensions of scheme II in configuration I at $\lambda_o = 2000/\text{hr/cell}$ for vehicle traffic

Figure 3.19 New call and handoff blocking probability of scheme II in configuration I vs. total no. of channels in direct and cross links at $\lambda_o = 2000/\text{hr/cell}$ for vehicle traffic
As for scheme I, this thesis investigates optimal channel dimensions for scheme II to minimize handoff blocking probability $P_{BhIII}$ according to the mobility model of Chapter 2 with new call blocking probability, $P_{Bn} < 0.01$, and the results of this analysis are tabulated in Table 3.6. This table shows the same trend as Table 3.2 for scheme I: more channels are required in cross links for a larger cell size and faster mobility. Figure 3.20 shows the maximum new call arrival rate $\lambda_o$ that scheme II, configuration I, can accommodate under these situations. In comparison with the maximum attainable new call arrival rate of scheme I in Figure 3.7, the maximum attainable new call arrival rate for scheme II in Figure 3.20 is lower, as expected. The handoff blocking probability $P_{BhIII}$ in the mobility model ranges from 0.00020 to 0.00027. This range is significantly lower than the corresponding range of $P_{BhII}$ of scheme I.

Table 3.6 Effects of mobility parameter and cell size on channel dimensions of scheme II in configuration I with $P_{Bn} < 0.01$ according to the mobility model for vehicle traffic

<table>
<thead>
<tr>
<th>$L_{A1}, L_{A2}$</th>
<th>$R$</th>
<th>Probability of entering stopping interval $p$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>300</td>
<td>50, 12</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>50, 12</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>50, 12</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>51, 11</td>
</tr>
<tr>
<td></td>
<td>700</td>
<td>51, 11</td>
</tr>
<tr>
<td></td>
<td>800</td>
<td>51, 11</td>
</tr>
<tr>
<td></td>
<td>900</td>
<td>51, 11</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>51, 11</td>
</tr>
</tbody>
</table>
3.2.2.3 Results for Pedestrian Traffic

Similar to the analysis of channel assignment scheme I, this thesis uses the mobility model in Chapter 2 to investigate pedestrian traffic for channel assignment scheme II. Again, with the constraint that the total number of channels in direct links and cross links equals 62, Figure 3.21 shows that 51 channels should be assigned to direct link $L_{B2}$ and the remaining 11 channels to cross link $L_{A2}$ in order to minimize $P_{BhIII}$ at $\lambda_o = 1400/hr/cell$ for pedestrian traffic. Table 3.7 shows the pedestrian traffic parameters for scheme II, configuration I and the channel dimensions that would minimize $P_{BhIII}$ at $1200 \leq \lambda_o \leq 1700/hr/cell$. Similar to the comparison of the performance of vehicle traffic, the number of channels required in cross link $L_{B1}$ of scheme II is more than that required in scheme I for pedestrian traffic because scheme II assigns some channels in cross link $L_{B1}$ to the prolonged handoff calls. Again, the handoff blocking probability $P_{BhIII}$ in scheme II is much lower than the handoff blocking probability $P_{BhII}$ in scheme I when Figures 3.8 and 3.21 are compared. Figure 3.22 shows the blocking probability $P_B(L_{B2})$
of direct link LB2 for optimal channel dimension at $\lambda_o = 1400$/hr/cell. As expected, the blocking probability $P_B(L_{A2})$ of cross link L$_{A2}$ is too low to be of any interest. The new call and handoff blocking probabilities with optimal channel dimensions at $1200 \leq \lambda_o \leq 1700$/hr/cell are shown in Figure 3.23. Similar to the performance of vehicle traffic, the handoff blocking probability is much lower in scheme II than in scheme I for pedestrian traffic but the new call blocking probability in scheme II is higher than that in scheme I when Figures 3.23 and 3.10 are compared.

![Graph](image-url)

Figure 3.21 Inter-cluster handoff blocking probability for channel assignment scheme II of configuration I, $P_{\text{ShII}}$, vs. number of channels in L$_{A2}$ at $\lambda_o = 1400$/hr/cell for pedestrian traffic.
Table 3.7 Pedestrian traffic parameters of channel assignment scheme II of configuration I

<table>
<thead>
<tr>
<th>Connecting links</th>
<th>Arrival rate</th>
<th>Channel holding time</th>
<th>Channel dimensions to minimize $P_{B_{II}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{A1}, L_{B2}$</td>
<td>$(1+\alpha+\delta)\lambda_o$</td>
<td>$1/\mu_1$</td>
<td>$\lambda_o = 1700$</td>
</tr>
<tr>
<td>$L_{A2}, L_{B1}$ given $L_{B2}, L_{A1}$ not blocked</td>
<td>$(2/3)(\alpha+\delta)\lambda_o$</td>
<td>$1/\mu_2$</td>
<td></td>
</tr>
<tr>
<td>$L_{A2}, L_{B1}$ given $L_{B2}, L_{A1}$ blocked</td>
<td>$(1/3)(\alpha+\delta)\lambda_o$</td>
<td>$1/\mu_2$</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.22 Blocking probability $P_B$ of direct link $L_{B2}$ with optimal channel dimensions at $\lambda_o = 1400$/hr/cell of scheme II in configuration I for pedestrian traffic
As for scheme I, in scheme II more than 62 channels can be assigned to direct and cross links to reduce blocking probabilities for pedestrian traffic. Figure 3.24 shows optimal channel dimensions of cross links when more than 62 channels are partitioned between direct and cross links. Figure 3.25 shows that such extra channels significantly reduce new call blocking probability. The reduction in the handoff blocking probability $P_{BhIII}$ is not very pronounced as this probability is already very low.
Figure 3.24 Effects of mobility parameter and cell size on channel dimensions of scheme II in configuration II at $\lambda_0 = 1400$/hr/cell for pedestrian traffic.

Figure 3.25 New call and handoff blocking probability of scheme II in configuration II vs. total no. of channels in direct and cross links at $\lambda_0 = 1400$/hr/cell for pedestrian traffic.
Table 3.8 shows the results of an investigation of optimal channel dimensions to minimize the handoff blocking probability $P_{BHII}$ with new call blocking probability, $P_{Bn} < 0.01$, according to the mobility of pedestrians in Chapter 2. Like Table 3.4 in scheme I, Table 3.8 in scheme II shows that the number of channels in cross links increases with larger cell size and faster mobility. Figure 3.26 shows the maximum new call arrival rate $\lambda_0$ that scheme II, configuration I, can accommodate under these situations. Similar to the performance of vehicle traffic, the comparison between Figures 3.26 and 3.13 in pedestrian traffic shows that the maximum attainable new call arrival rate is lower for scheme II than for scheme I. The handoff blocking probability $P_{BHII}$ in the mobility model ranges from 0.00020 to 0.00027. These values are significantly lower than the corresponding values of $P_{BHII}$ in channel assignment scheme I for pedestrian traffic.

Table 3.8 Channel dimensions with $P_{Bn} < 0.01$ of scheme II in configuration I according to the mobility model for the pedestrian traffic

<table>
<thead>
<tr>
<th>$L_{A1}, L_{A2}$</th>
<th>Probability of entering stopping interval $p$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0</td>
</tr>
<tr>
<td>Cell radius (m)</td>
<td></td>
</tr>
<tr>
<td>$R$</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>49, 13</td>
</tr>
<tr>
<td>150</td>
<td>50, 12</td>
</tr>
<tr>
<td>200</td>
<td>51, 11</td>
</tr>
<tr>
<td>250</td>
<td>51, 11</td>
</tr>
<tr>
<td>300</td>
<td>52, 10</td>
</tr>
</tbody>
</table>
Figure 3.26 Max. new call arrival rate of scheme I in configuration I with $P_{Bn} < 0.01$ and optimal channel dimensions for pedestrian traffic
Chapter 4 NETWORK CONFIGURATION II

This chapter proposes a second network configuration. This network configuration is more complicated than network configuration I because it cross-links additional layers of microcells near the boundary of cell-clusters. That is, the overlap between cell-clusters is increased. Similar to the analysis of configuration I, this configuration dimensions the available 62 channels in each microcell to attain the overall minimum handoff blocking probability.

4.1 Description and Operation

Figure 4.1 Network configuration II
To eliminate handoff oscillations which may occur in configuration I, the inter-cluster handoff should be carried out after a MT has moved some distance into the new cell-cluster, as suggested by [15]. Configuration II, illustrated in Figure 4.1, accomplishes this objective. In addition to cross-linking the microcells at the cell-cluster boundary with the MSCs serving neighboring cell-clusters, as in the configuration I, configuration II similarly cross-links the next layer of microcells in the cluster adjacent to the boundary cells with the opposing MSCs. Figure 4.1 also shows that MTs moving from cell-cluster A to B, and those moving in the reverse direction use different inter-cluster handoff regions. For example, a MT in microcell 4 of cell-cluster A, upon moving into microcell 5 of cell-cluster B, delays the handoff from MSC A to B until it reaches the handoff region between microcells 5 and 6, after which it is considered to belong to cell-cluster B. Once the MT belongs to cell-cluster B, even if it moves from microcell 5 back to microcell 4 in cell-cluster A, MSC B still handles the handoff process in the normal manner, and the handoff between MSCs B and A is deferred until the MT crosses the handoff region between microcells 4 and 3. The use of two separate handoff regions completely eliminates the problem of oscillation. Furthermore, MTs originating calls in microcells 4 and 5 are considered to belong to cell-clusters A and B, respectively. A seamless soft handoff between different MSCs occurs exactly as in configuration I when a MT belonging to one cell-cluster enters the handoff region of the opposite cell-cluster.

By increasing the complexity of the interconnection network, configuration II overcomes the problem of oscillations occurring during handoffs between cell-clusters. This approach of increasing the complexity of connections can be further extended to include additional layers of cells to be cross-linked between cell-clusters. Effectively, this configuration expands the size of cell-clusters as it allows them to overlap. The time it takes an MT to travel through overlapping microcells delays the more complex handoff procedures between the MSCs. For example, suppose a MT is moving towards cell-cluster B from A. The handoff between the respective MSCs is not necessary until the MT crosses
the boundary of microcells 5 and 6 (instead of the boundary of microcells 4 and 5, as in configuration I). If this delay can be lengthened sufficiently relative to the durations of most calls, by the cross-linking of additional layers of microcells, the need for handoffs between different MSCs can be significantly reduced. The reduction of handoffs between cell-clusters due to the increase in the overlapping region of cell-cluster will be further discussed in Chapter 6.

4.2 Channel Dimensions

Similar to the analysis of configuration I, the following dimensions trunk groups in the cross links and direct links to provide overall minimum handoff blocking probability for configuration II.

4.2.1 Description

Figure 4.1 shows that an appropriate number of channels needs to be assigned to connection links $L_{Ak}$ for $k = 3, 4, 5$ and 6. By symmetry, links $L_{Bk}$ require the same capacity as links $L_{A(9-k)}$ for $k = 3, 4, 5$ and 6. The number of channels required for links $L_{A3}, L_{A5}$ and $L_{A6}$ is governed by the Erlang B equation (8). Link $L_{A4}$ is utilized by the traffic with rate $\lambda_o$ originating from microcell 4, and by the traffic with rate $(2/3)(\alpha+\delta)\lambda_o$ handing off from two surrounding microcells in two opposite directions, as well as by the traffic with rate $(1/3)(\beta+\gamma)\lambda_o$ handing off from the layers of microcell 5 and 6 in one direction. As two types of traffic are involved, the number of channels required for link $L_{A4}$ is governed by the blocking probability of a two dimensional Markov chain given by equation (26). Let $P_B(L_{Ak})$ and $P_B(L_{Bk})$ be the blocking probability of link $L_{Ak}$ and $L_{Bk}$ for $k = 3, 4, 5$ and 6 respectively. The following equation, which is obtained by the weighted sum of handoff blocking probabilities of each type of arrival rate of the whole
configuration, gives the overall handoff blocking probability $P_{BH2}$:

$$
P_{BH2} = 1 - \left\{ \alpha \lambda_0 [1 - P_B(L_{A3})] + \frac{4}{6} \alpha \lambda_0 [1 - P_B(L_{A4})] + \\
\frac{2}{6} \beta \lambda_0 [1 - P_B(L_{A4})][1 - P_B(L_{A5})] + \frac{2}{6} \alpha \lambda_0 [1 - P_B(L_{A5})] + \\
\frac{2}{6} \gamma \lambda_0 [1 - P_B(L_{A3})][1 - P_B(L_{A4})][1 - P_B(L_{A5})][1 - P_B(L_{A6})] + \\
\frac{2}{6} \beta \lambda_0 [1 - P_B(L_{A3})][1 - P_B(L_{A4})][1 - P_B(L_{A5})][1 - P_B(L_{A6})] + \\
\frac{4}{6} \delta \lambda_0 [1 - P_B(L_{A3})][1 - P_B(L_{A4})][1 - P_B(L_{A5})][1 - P_B(L_{A6})] + \\
\frac{2}{6} \delta \lambda_0 [1 - P_B(L_{A3})][1 - P_B(L_{A4})][1 - P_B(L_{A5})][1 - P_B(L_{A6})] + \\
\frac{2}{6} \delta \lambda_0 [1 - P_B(L_{A3})][1 - P_B(L_{A4})][1 - P_B(L_{A5})][1 - P_B(L_{A6})] + \\
\frac{2}{6} \delta \lambda_0 [1 - P_B(L_{A3})][1 - P_B(L_{A4})][1 - P_B(L_{A5})][1 - P_B(L_{A6})] + \\
\frac{2}{6} \delta \lambda_0 [1 - P_B(L_{A3})][1 - P_B(L_{A4})][1 - P_B(L_{A5})][1 - P_B(L_{A6})] + \\
\left\{ \left[ 2 \alpha + \frac{4}{6} \beta + \frac{2}{6} \gamma + 2 \delta \right] \lambda_0 \right\}
\right\}
$$

(29)

Channel assignment schemes I and II can both be applied to configuration II. However, the handoffs between cell-clusters in configuration II have an arrival rate of approximately $(1/3)(\beta + \gamma)\lambda_0$ which is very low as shown in the mobility model of Chapter 2. The application of channel assignment scheme II cannot significantly lower the overall handoff blocking probability. Therefore, only channel assignment scheme I is considered in conjunction with configuration II. In addition, as discussed in the mobility model of Chapter 2, the values of $\beta$ and $\gamma$, which contribute to the handoff calls between cell-clusters in configuration II, are too small to have any interest for pedestrian traffic. Therefore, configuration II is not important for pedestrian traffic and this situation will not be discussed in this thesis.

### 4.2.2 Results for Vehicle Traffic

Subject to the constraint that the total number of channels in $L_{Ak}$ and $L_{Bk}$ is 62, this thesis investigates all possible combinations of channel dimensions of $L_{Ak}$ to obtain the
minimum value of $P_{bh2}$ for $k = 3, 4, 5$ and $6$ at $\lambda_o = 2200/\text{hr/cell}$.

Both theoretical and simulation results shown in Figure 4.2 shows that in order to obtain the minimum value of $P_{bh2}$, 61 channels should be assigned to link $L_{A3}$, 53 channels to link $L_{A4}$, 9 channels to link $L_{A5}$ and 1 channel to link $L_{A6}$. The discrepancy between theoretical and simulation values accounts for the fact that the theoretical values are only weighted sums of the handoff blocking probabilities of all types of traffic in the configuration and these values may differ from the exact overall handoff blocking probability in the simulation. Table 4.1 shows the traffic parameters of configuration II and the channel dimensions minimizing $P_{bh2}$ at $1800 \leq \lambda_o \leq 2300/\text{hr/cell}$. Only one or two channels are required for the link $L_{A6}$ because the number of necessary handoffs between MSCs in configuration II is greatly reduced by expanding the overlapping layers of cell-clusters. Figure 4.3 shows the blocking probability, $P_B$, of the direct and cross links with optimal channel dimensions at $\lambda_o = 2200/\text{hr/cell}$. There is a discrepancy between the theoretical and simulation values of the blocking probability $P_B(L_{A6})$ because the arrival rate at link $L_{A6}$ is too small to provide accurate simulation. The blocking probability $P_B(L_{A6})$ which is definitely the main factor contributing for handoffs between MSCs, happens to be the highest among the blocking probabilities of various links; however, it has very little effect on the overall handoff blocking probability $P_{bh2}$. This result shows that handoffs between MSCs do not greatly contribute to handoff blocking in the configuration because most handoffs are carried out within the same MSC in configuration II as the overlapping layers of cell-clusters increase. The new call blocking probabilities in microcells 3 and 4 and the overall handoff blocking probability, $P_{bh2}$, with optimal channel dimensions at $1800 \leq \lambda_o \leq 2300/\text{hr/cell}$ are shown in Figure 4.4. The new call blocking probability in cell 3 is lower than that in cell 4 because there are more channels in the direct link of cell 3. The value of handoff blocking probability is between the values of new call blocking probabilities of cell 3 and cell 4. The new call blocking probability in cell 4 is the highest because link $L_{A4}$ need to accommodate many types of
traffic as shown in Table 4.1 and the number of channels assigned to it is not as many as that to link LA3.

![Graph](image)

Figure 4.2 Overall handoff blocking probability in configuration II, \( P_{BH2} \), vs. number of channels in cross links LA5 and LA6 at \( \lambda_o = 2200/\text{hr/cell} \)

![Graph](image)

Figure 4.3 Blocking probability \( P_B \) of direct and cross links in configuration II with optimal channel dimensions at \( \lambda_o = 2200/\text{hr/cell} \)
Table 4.1 Traffic parameters of configuration II

<table>
<thead>
<tr>
<th>Connecting links</th>
<th>Arrival rate</th>
<th>Channel holding time</th>
<th>Channel dimensions to minimize $P_{bh2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$1800 \leq \lambda_o \leq 1900$</td>
</tr>
<tr>
<td>$L_{A3}, L_{B6}$</td>
<td>$(1+\alpha+\delta)\lambda_o$</td>
<td>$1/\mu_1$</td>
<td>60</td>
</tr>
<tr>
<td>$L_{A4}, L_{B5}$</td>
<td>$(1+(2/3)(\alpha+\delta))\lambda_o$</td>
<td>$1/\mu_1$</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>$(1/3)(\beta+\gamma)\lambda_o$</td>
<td>$1/\mu_2$</td>
<td></td>
</tr>
<tr>
<td>$L_{A5}, L_{B4}$</td>
<td>$(1/3)(\alpha+\beta)\lambda_o$</td>
<td>$1/\mu_1$</td>
<td>10</td>
</tr>
<tr>
<td>$L_{A6}, L_{B3}$</td>
<td>$(1/3)(\beta+\gamma)\lambda_o$</td>
<td>$1/\mu_2$</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 4.4 New call and handoff blocking probability in configuration II with optimal channel dimensions

Similar to the analysis in configuration I, more than 62 channels may be assigned to direct and cross links in configuration II to reduce blocking probabilities. Figure 4.5 shows the channel dimensions of cross links when more than 62 channels are used in direct and cross links. When an extra channel is added to the configuration, it is usually added to direct link $L_{A4}$ and cross link $L_{A6}$ because direct link $L_{A4}$ ($L_{B5}$) greatly contributes to the overall handoff blocking probability, and direct link $L_{A3}$ ($L_{B6}$) has already attained maximum 62 channels and therefore the extra channels are assigned to
cross link $L_{A6}$. Figure 4.6 shows the new call blocking probabilities in microcells 3 and 4 and the overall handoff blocking probability $P_{BH2}$ when more than 62 channels exist in direct and cross links. Figure 4.6 also shows that adding extra channels to the total number of channels shared between direct and cross links reduces the new call blocking probability for cell 4 significantly, the handoff blocking probability to a lesser extent, and the new call blocking probability for cell 3 imperceptibly. The new call blocking probability for cell 4 is significantly reduced by adding extra channels to direct and cross links because the extra channels are usually added to link $L_{A4}$. When the total number of channels in direct and cross links is about 68, all three probabilities are approximately equalized.

![Graph showing channel blocking probabilities](image)

**Figure 4.5** Channel dimensions in configuration II for direct and cross links at $\lambda_o = 2200$/hr/cell
Just as the traffic parameters are varied in configuration I, so the traffic parameters in configuration II can be varied according to the mobility model developed in Chapter 2. The optimal channel dimensions to minimize overall handoff blocking probability $P_{bh2}$ with different cell sizes and degrees of mobility have been investigated. Table 4.2 shows the optimal channel dimensions to minimize overall handoff blocking probability $P_{bh2}$, as determined by the use of the mobility model when the new call blocking probability, $P_{bn} < 0.01$. As is true in configuration I, more channels in cross links are required in configuration II when the cell size decreases and the mobility increases (light traffic). Figure 4.7 shows the maximum new call arrival rate $\lambda_o$ which can be attained under these situations. In comparison with the maximum new call arrival rate in configuration I of Figures 3.7 and 3.20, configuration II can accommodate a few more new calls than scheme I, configuration I because handoff calls are handled better in configuration II than in scheme I, configuration I. Handoff calls carried out by the same MSC require two links while handoff calls carried out by different MSCs require four separate links. Because
some handoff calls between MSCs are replaced by handoff calls within the same MSC in configuration II; thus configuration II can handle somewhat more calls than scheme I, configuration I. The handoff blocking probability $P_{bh2}$ in the mobility model ranges between 0.0063 and 0.0090 which is lower than that in scheme I, configuration I, but higher than that in scheme II, configuration I.

Table 4.2 Effects of mobility parameter and cell size on channel dimensions in configuration II with $P_{bh} < 0.01$

<table>
<thead>
<tr>
<th>LA3, LA4, LA5, LA6</th>
<th>Probability of entering stopping interval $p$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0</td>
</tr>
<tr>
<td>Cell radius (m) $R$</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>60, 51, 11, 2</td>
</tr>
<tr>
<td>400</td>
<td>60, 51, 11, 2</td>
</tr>
<tr>
<td>500</td>
<td>60, 52, 10, 2</td>
</tr>
<tr>
<td>600</td>
<td>61, 53, 9, 1</td>
</tr>
<tr>
<td>700</td>
<td>61, 53, 9, 1</td>
</tr>
<tr>
<td>800</td>
<td>61, 53, 9, 1</td>
</tr>
<tr>
<td>900</td>
<td>61, 54, 8, 1</td>
</tr>
<tr>
<td>1000</td>
<td>61, 54, 8, 1</td>
</tr>
</tbody>
</table>
Figure 4.7 Max. new call arrival rate in configuration II with $P_{Bn} < 0.01$ and optimal channel dimensions according to the mobility model
This chapter proposes a third configuration, one which accommodates the highest number of calls among all three configurations. Configuration III improves on configurations I and II by directly connecting the MSCs of different cell-clusters. The calculation of its handoff blocking probability involves several transmission queues which interact in the sense that a traffic stream departing from one queue enters another queue. Unfortunately, it is impossible to carry out a precise and effective analysis of this network of queues except for \( M/M/I \) system (Jackson's Theorem) [26]. Therefore, computer simulation employing a model written in Simscript II.5 is used to investigate the handoff blocking probability.

### 5.1 Description and Operation

![Network Configuration III Diagram](image)

**Figure 5.1 Network configuration III**
In the first two configurations, four separate links are involved during soft handoffs. This involvement increases the traffic load and reduces the effective usage of channels in the network. To overcome these disadvantages by aggregating handoff traffic and improving trunking efficiency, this thesis proposes configuration III, shown in Figure 5.1. In addition to the direct links between MSCs and BSs, the MSCs of adjacent cell-clusters are directly connected by a trunk group shared by all calls engaging in soft handoffs between the two cell-clusters. Because forward and reverse signals travel between the MSCs via this trunk group, the MSCs need to be modified as shown in Figure 5.2. In comparison with the structure of a typical MSC as described in [8, 32],

![Diagram](image)

**Figure 5.2 Block diagram of modified MSC in configuration III**

the modified MSC of configuration III requires an additional switching circuit at the front end to transmit signals between adjacent modified MSCs before diversity combining of signals takes place.

In configuration III, since signals from any microcell in a cell-cluster may be routed from the MSC serving that cell-cluster to the MSC serving a neighboring cell-cluster, all
the different inter-cluster soft handoff methods presented above for configurations I and II can be realized. As Figure 5.1 shows, the same inter-cluster handoff method applies as in configuration I, since the boundary of cells 8 and 9 serves as the inter-cluster handoff region. Cells 1 and 2 in Figure 3.1 correspond respectively to cells 8 and 9 in Figure 5.1, and cross links $L_A_2$ and $L_B_1$ are represented respectively in Figure 5.1 by links $L_B_9$ and $L_A_8$ concatenated with the MSC-MSC link, $L_{AB}$. Furthermore, the connections in Figure 5.1, $L_B_9$ and $L_A_8$, replace the direct links $L_B_2$ and $L_A_1$ in Figure 3.1, respectively. Figure 5.1 also shows that Configuration III uses the inter-cluster handoff method of configuration II by positioning the handoff region from cluster A to B between cells 9 and 10 and that from cluster B to A between cells 8 and 7. The cross links shown in Figure 4.1 are likewise realized in configuration III by the sharing of the respective direct links in concatenation with the MSC-MSC link $L_{AB}$ in Figure 5.1. Substituting for the corresponding links, the inter-cluster soft handoff procedures described previously for configurations I and II become directly applicable to the respective case for configuration III. By directly connecting the modified MSCs of adjacent cell-clusters, the operation of the seamless soft handoff for configuration III, which is an improved configuration of I and II, is as follows.

When configuration III realizes configuration I, the handoff region between cell-clusters is at the boundary of the microcell 8 and 9. When a MT enters the handoff region from microcells 8 to 9, the MT receives a CDMA channel in microcell 9 in addition to the existing channel in microcell 8. Demodulated signal with an indication of signal quality from BS 9 is then transmitted to the front end switching circuit in modified MSC B which in turns transmits this signal to the receiver circuit of modified MSC A via link $L_{AB}$. The receiver circuit in modified MSC A then compares the signal from BS 8 and the front end switching circuit of modified MSC B and selects the best quality signal. It is also possible, although more complex, to transmit an undemodulated signal from BS 9 to the front end switching circuit of modified MSC B which in turn transmits
the signal to the receiver circuit of modified MSC A; here, diversity combining takes place with the undemodulated signal from BS 8. As soon as the signal quality from the front end switching circuit of modified MSC B is better than that from BS 8, a seamless handoff of network connections occurs [17], and all signals previously involved are then switched to modified MSC B through the network and the link L_AB. Eventually, the signal strength from the front end switching circuit of modified MSC A will drop below a certain threshold, at which time the CDMA channel in microcell 8 and the channel in link L_AB can be dropped. The seamless soft handoff operation for configuration III as a realization of configuration I is complete.

When configuration III realizes configuration II, two inter cell-cluster handoff regions exist. One appears at the boundary of microcell 9 and 10 for the traffic going from cell-cluster A to B; one at the boundary of microcell 7 and 8 services the traffic moving from cell-cluster B to A. For instance, when a MT travelling from cell-cluster A to B passes through the boundary of microcell 8 and 9, it will receive a CDMA channel in microcell 9 in addition to the existing channel it received in microcell 8. The signal from microcell 9 passes to modified MSC A from the front end switching circuit of modified MSC B through link L_AB to combine with the signal from BS 8. When the MT is inside microcell 9, the signal involved is still handled by modified MSC A via link L_AB, so the CDMA channel in microcell 8 can be dropped eventually. When the MT comes to the boundary between microcells 9 and 10, a CDMA channel is assigned from microcell 10 and an additional channel is set up through link L_AB. Both signals from microcell 9 and 10 are transmitted to modified MSC A to produce a combination of signals via link L_AB. When the signal from microcell 10 is stronger than that from microcell 9, a seamless handoff of network connections occurs [17] and all signals involved are switched to modified MSC B. Then the two channels in link L_AB can be dropped. The seamless soft handoff operation for configuration III as a realization of configuration II is complete.

In the use of configuration III to realize the operation of configuration II, the signal
from the inner region of a cell-cluster is allowed to be transmitted to the modified MSC of a different cell-cluster for diversity combining. As a result, the soft handoff between cell-clusters is delayed and is carried out in the inner regions of cell-cluster, and thus it reduces the necessary number of inter-cluster handoff and prevents oscillations when MTs roam back and forth across the boundary of adjacent cell-clusters.

Because configuration III allows the 62 channels in the BS-MSC links to be fully shared by new and handoff calls at the same time as it allows the MSC-MSC links to be shared by all inter-cluster handoff calls, this configuration can accommodate more calls than either configuration I and II, and this result will be discussed in Chapter 6.

5.2 Channel Dimensions

The lowest number of channels required to attain the theoretical minimum handoff blocking probability between MSCs of different cell-clusters under the constraint of 62 channels in direct links needs to be investigated. In addition, the relationship between the number of channels required in the MSC-MSC link $L_{AB}$ and the number of pair of microcells at the cell-cluster boundary should be examined because of the trunking efficiency in this configuration. These results have been obtained by computer simulations.

5.2.1 Description

The number of channels between the modified MSCs needs to be determined. If the number of channels in link $L_{AB}$ is high enough, the bottleneck contributing to the handoff blocking probability will be the 62 channels in the BS-MSC direct links. Theoretically, the minimum handoff blocking probability is equal to the new call blocking probability in BS-MSC direct links: this probability is given by equation (7) with the constraint of $m = 62$. Using the mobility model described in Chapter 2, a computer simulation model written in Simscript II.5 is employed to investigate the minimum number of channels
required in link $L_{AB}$ to closely approach this theoretical minimum handoff blocking probability.

### 5.2.2 Results for Vehicle Traffic

Figure 5.3 shows the handoff blocking probability for vehicle traffic against the number of channels in link $L_{AB}$ when there is a single pair of microcells at the cell-cluster boundary. This situation employs the same handoff procedure as in scheme I, configuration I. It shows that 9 channels in link $L_{AB}$ suffice to give a handoff blocking probability fairly close to the theoretical minimum possible value achieved by the BS-MSC direct links only, as discussed above. Figure 5.4 shows the minimum number of channels required with various numbers of pairs of microcells at the cell-cluster boundary when the theoretical minimum handoff blocking probability is attained. The trunking efficiency of configuration III is evident in Figure 5.4, since the number of channels required increases 3.3 times when the number of microcells at either side of the cell-cluster boundary increases from 1 to 6.
Figure 5.3 Blocking probability between a pair of microcells at the boundary of cell-clusters vs. no. of channels between modified MSCs in configuration III at $\lambda_o = 2300$/hr/cell for vehicle traffic.

Figure 5.4 Number of channels between modified MSCs vs. number of pairs of microcells at the boundary in configuration III at $\lambda_o = 2300$/hr/cell for vehicle traffic.
Figure 5.5 shows the handoff blocking probability with various numbers of channels in link $L_{AB}$ when four microcells at the boundary of cell-clusters are involved in inter-cluster handoffs, as in configuration II. This figure shows that in order to achieve the handoff blocking probability close to the theoretical minimum, there should be 16 channels in link $L_{AB}$. The number of channels in link $L_{AB}$ required to realize the handoff method used in configuration II is higher than that in configuration I because extra channels are needed for handoff calls in the inner region of the cell-clusters.

Comparison of the new call and handoff blocking probabilities of all three configurations shows that configuration III can accommodate a new call arrival rate of 2300/hr/cell with new call probability about 0.008, which is about 5–15% higher than the new call arrival rates in configurations I and II. Supported by concrete data, the next chapter will further compare among these three configurations.

![Figure 5.5 New call and handoff blocking probabilities between a pair of microcells at the boundary of cell-clusters as arranged in configuration II vs. no. of channels between modified MSCs in configuration III at $\lambda_o = 2300$/hr/cell for vehicle traffic]
5.2.3 Results for Pedestrian Traffic

Employing the same handoff procedure as in scheme I, configuration I, Figure 5.6 shows the handoff blocking probability for pedestrian traffic against the number of channels in link $L_{AB}$ when a single pair of microcells at the cell-cluster boundary is considered in configuration III. It shows that through the link $L_{AB}$, the same number of channels is needed for pedestrians as for vehicles in order to achieve a handoff blocking probability close to the theoretical minimum value possible. Figure 5.7 shows the minimum number of channels required with various numbers of pairs of microcells at the cell-cluster boundary when the theoretical minimum handoff blocking probability is attained. As shown in Figure 5.7, when the number of microcells at either side of the cell-cluster boundary increases from 1 to 6, configuration III shows the same trunking efficiency for pedestrian traffic as already shown in Figure 5.4 for vehicle traffic: the number of channels is increased only 3.0 times.

![Figure 5.6](image.png)

Figure 5.6 Blocking probability between a pair of microcells at the boundary of cell-clusters vs. no. of channels between modified MSCs in configuration III at $\lambda_o = 1600$/hr/cell for pedestrian traffic
Figure 5.7 Number of channels between modified MSCs vs. number of pairs of microcells at the boundary in configuration III at $\lambda_o = 2300$/hr/cell for pedestrian traffic.

Comparison of new call and handoff blocking probabilities of all three configurations in pedestrian traffic shows that configuration III can accommodate a new call arrival rate of 1600/hr/cell when the new call probability is about 0.009; it has about a 14% higher new call arrival rate than the corresponding values for configurations I and II. The next chapter will further compare the three configurations in regard to pedestrian traffic.
Chapter 6 COMPARISONS AMONG THE THREE CONFIGURATIONS

The three network configurations have been described in detail in the previous chapters. This chapter compares the performance of these three configurations in terms of the handoff procedures and blocking probabilities.

6.1 Comparison of Handoff Procedures

The handoff procedures in the proposed configurations have been discussed in detail in the previous chapters. The comparative advantages and disadvantages of each configuration are summarized as follows:

Scheme I, configuration I, is the simplest of the three configurations. However, some degree of oscillations is unavoidable in configuration I when MTs roam back and forth across the cell-cluster boundary because the same handoff region is shared by both MTs moving in one direction and those moving in the opposite direction. Oscillations are undesirable because they increase the signalling traffic in the network.

In scheme I, configuration I, the handoff blocking probability is higher than the new call blocking probability as shown previously. This property is undesirable because from the MT user’s point of view, forced termination of an ongoing call is clearly less desirable than the blocking of a new call attempt. As a result, scheme II, configuration I, has been proposed to lower the handoff blocking probability by lengthening the handoff transition time in cross links. However, there is a tradeoff: the new call blocking probability in scheme II is higher than that in scheme I because additional channels in the cross links need to be assigned for handoff calls.

To prevent oscillations completely, configuration II increases the layers of microcells being cross-linked. MTs travelling in different directions have separate handoff regions, and therefore no handoff between cell-clusters is required after a handoff is carried out.
even if MTs reverse direction. In addition, by increasing the overlapping region of cell-clusters, configuration II delays the complex handoff procedures between MSCs. If this delay is made long enough relative to the duration of calls, the need for the complex handoff procedures between MSCs can be significantly reduced. Figure 6.1 shows the result of the situation of vehicle traffic by computer simulation. It gives the fraction of MSC handoffs that configuration II can prevent, for two different degrees of overlapping between cell-clusters. Microcell a at the boundary of its cell-cluster is shown adjacent to various layers of microcells in the neighboring cell-clusters, which represent the overlapped regions of cell-clusters and are cross-linked to the MSC serving microcell.

Figure 6.1 Effects of degrees of cell-cluster overlapping to reduce handoffs between MSCs

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a's cell-cluster. When a MT crosses the boundary of cell-clusters from microcell a, the
handoff between MSCs is avoided until the MT moves outside these overlapped cell
layers. Movements of the MTs in the simulation follow the mobility model in Chapter
2 with \( p = 0.25 \). For \( R = 500 \text{ m} \), about 80% or 94% of the potential MSC handoffs of
vehicle traffic can be avoided if one or two cell layers are overlapped, respectively.

In configurations I and II, soft handoffs require the use of four separate links,
an arrangement which is an inefficient use of the network. To improve efficiency,
configuration III connects adjacent MSCs via a trunk group, providing a better usage
of channels in the network by exploiting all 62 channels in direct links for both new and
handoff calls. The next section provides comparison of blocking probabilities to verify
that configuration III has a higher traffic capacity than configurations I and II.

6.2 Comparisons of Blocking Probabilities

The new call and handoff blocking probabilities in all three proposed configurations
have been compared in between the previous chapters. Comparison of all these three
configurations in terms of new call and handoff blocking probabilities are summarized
as follows:

Figures 6.2 and 6.3 show new call and handoff blocking probabilities of configuration
I and II for vehicle and pedestrian traffic respectively. The handoff blocking probability
is higher than the new call blocking probability in scheme I, configuration I, because
the channels in both direct and cross links are required for a successful handoff call.
In contrast, the handoff blocking probability in scheme II, configuration I, is the lowest
in all the configurations because handoff calls are given priority in accessing the direct
links. Scheme II, configuration I, proves to be the best in accommodating handoff calls;
however, its new call blocking probability is the highest in all three configurations since
this is the necessary tradeoff to achieve the lowest handoff blocking probability. In
configuration II, the new call blocking probability in cell 3 is lower than it is in cell 4
because more channels are available in the direct link in cell 3. Furthermore, new call and handoff blocking probabilities in configuration II are somewhat lower than they are in scheme I, configuration I, because most handoff calls in configuration II are carried out within the same MSC.

Figure 6.2 New call and handoff blocking probabilities in configuration I and II with optimal channel dimensions for vehicle traffic
Figures 6.4 and 6.5 show the new call and handoff blocking probabilities when the same number of channels exists in both configuration I and III for vehicle and pedestrian traffic respectively. In this case, there are total 134 channels for each network configuration. That is, in configuration III, there are two groups of 62 channels in direct links and one group of 10 channels in link $L_{AB}$ between modified MSCs. In configuration I, there are two groups of 58 channels in direct links and two groups of 9 channels in cross links for scheme I and there are two groups of 55 channels in direct links and two groups of 12 channels in cross links for scheme II. Though there is same number of channels in both network configurations, the new call blocking probability is the lowest in configuration III. Also, the handoff blocking probability in configuration III is lower than that in scheme I, configuration I. This result shows that configuration III makes better use of channels in the network than configuration I. In fact, with a new call blocking probability of just less than 0.01, configuration III can accommodate new arrival rate higher than 2350/hr/cell for vehicle traffic, whereas scheme
I, configuration I can accommodate about 2200/hr/cell and scheme II, configuration I can accommodate about 2050/hr/cell, so that configuration III has about a 7% and 15% higher arrival rate than scheme I and scheme II of configuration I, respectively.

For pedestrian traffic, configuration III can accommodate about 1650/hr/cell whereas scheme I, configuration I can accommodate 1500/hr/cell and scheme II, configuration I can accommodate 1400/hr/cell, configuration III therefore having a 10% and 18% higher arrival rate than scheme I and scheme II of configuration I respectively and yet having a new call blocking probability of just less than 0.01.

![Figure 6.4 New call and handoff blocking probabilities in both configuration I and III with optimal channel dimensions and with same number of channels for vehicle traffic](image-url)
Figure 6.5 New call and handoff blocking probabilities in both configuration I and III with optimal channel dimensions and with same number of channels for pedestrian traffic.

Similarly, Figure 6.6 shows new call and handoff blocking probabilities for vehicle traffic when the same number of channels exists in both configurations II and III. In this case, there are total 264 channels for each of the network configurations. That is, in configuration III, there are four groups of 62 channels in direct links and one group of 16 channels in link L_{AB} between modified MSCs. In configuration II, there are two groups of 62 channels, two groups of 56 channels, two groups of 10 channels and two groups of 4 channels in the direct links and cross links. The new call blocking probabilities of configuration III and in cell 3 of configuration II are the same because there is same number of channels in the direct links of the cells of configuration III and in cell 3 of configuration II. However, new call and handoff blocking probabilities of configuration III are lower than both the new call blocking probability in cell 4 and the handoff blocking probability of configuration II. This result shows that configuration III makes a better use of the channels in the network than configuration II. In fact, with new call probability of just less than 0.01, configuration III can accommodate about 2350/hr/cell whereas
configuration II can accommodate about 2200/hr/cell, so that configuration III has a 7% higher traffic capacity than configuration II.

Appendix B gives a table summary for comparisons of advantages, disadvantages and data results of the three configurations.

Figure 6.6 New call and handoff blocking probabilities in both configuration II and III with optimal channel dimensions and with same number of channels for vehicle traffic

6.3 Effects of Handoff Transition Time and New Call Arrival Rate on Channel Dimensions

Tables 6.1 and 6.2 show the results of an investigation into the effect on the number of channels in cross links by varying the handoff transition time. For both vehicle and pedestrian traffic in configurations I and II, a change in handoff transition time does not significantly change the number of channels in cross links. In addition, as previous tables showing the channel dimensions in different configurations, the number of channels in cross links does not significantly change with respect to the new call arrival rate or the traffic parameters of the mobility model. That is, both vehicle and pedestrian traffic, in scheme I, configuration I, there should be 53 channels in the direct link and 9 channels in
the cross link; in scheme II, configuration I, there should be 51 channels in the direct link and 11 channels in the cross link; and in configuration II, there should be 61 channels in link \( L_{A3} \), 53 channels in link \( L_{A4} \), 9 channels in link \( L_{A5} \) and 1 channel in link \( L_{A6} \), with a 1 channel variation among various new call arrival rate, handoff transition times and traffic parameters in the mobility model. This merit shows that the optimal channel dimensions in all these three configuration are quite immune to the variation of new call arrival rate, handoff transition times and traffic parameters of the mobility model.

Table 6.1 Optimal channel dimensions with various handoff transition times at \( \lambda_0 = 2000/hr/cell \) for configuration I and at \( \lambda_0 = 2200/hr/cell \) for configuration II for vehicle traffic

<table>
<thead>
<tr>
<th>Handoff transition time ( 1/\mu_2 ) (s)</th>
<th>Configuration I, Scheme I ( L_{A1}, L_{A2} )</th>
<th>Configuration I, Scheme II ( L_{A1}, L_{A2} )</th>
<th>Configuration II ( L_{A3}, L_{A4}, L_{A5}, L_{A6} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>54, 8</td>
<td>52, 10</td>
<td>61, 53, 9, 1</td>
</tr>
<tr>
<td>16</td>
<td>54, 8</td>
<td>51, 11</td>
<td>61, 53, 9, 1</td>
</tr>
<tr>
<td>17</td>
<td>54, 8</td>
<td>51, 11</td>
<td>61, 53, 9, 1</td>
</tr>
<tr>
<td>18</td>
<td>53, 9</td>
<td>51, 11</td>
<td>61, 53, 9, 1</td>
</tr>
<tr>
<td>19</td>
<td>53, 9</td>
<td>51, 11</td>
<td>61, 53, 9, 1</td>
</tr>
<tr>
<td>20</td>
<td>53, 9</td>
<td>50, 12</td>
<td>61, 53, 9, 1</td>
</tr>
<tr>
<td>21</td>
<td>53, 9</td>
<td>50, 12</td>
<td>61, 53, 9, 1</td>
</tr>
</tbody>
</table>

Table 6.2 Optimal channel dimensions with various handoff transition times at \( \lambda_0 = 1400/hr/cell \) for configuration I for pedestrian traffic

<table>
<thead>
<tr>
<th>Handoff transition time ( 1/\mu_2 ) (s)</th>
<th>Configuration I, Scheme I ( L_{A1}, L_{A2} )</th>
<th>Configuration I, Scheme II ( L_{A1}, L_{A2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>54, 8</td>
<td>52, 10</td>
</tr>
<tr>
<td>44</td>
<td>54, 8</td>
<td>51, 11</td>
</tr>
<tr>
<td>46</td>
<td>54, 8</td>
<td>51, 11</td>
</tr>
<tr>
<td>48</td>
<td>54, 8</td>
<td>51, 11</td>
</tr>
<tr>
<td>50</td>
<td>53, 9</td>
<td>51, 11</td>
</tr>
<tr>
<td>52</td>
<td>53, 9</td>
<td>50, 12</td>
</tr>
<tr>
<td>54</td>
<td>53, 9</td>
<td>51, 12</td>
</tr>
</tbody>
</table>
Chapter 7 CONCLUSIONS

The interests in CDMA for cellular mobile communications are motivated by the unique feature of soft handoffs. By utilizing BS-MSC direct and cross links, this thesis attempts has proposed novel network configurations to enable soft handoffs between cell-clusters. The traffic capacities of these configurations have also been investigated.

7.1 Summary of Findings

This thesis develops three novel network configurations to provide seamless service for CDMA soft handoffs between cell-clusters. Configurations I and II employ cross links to allow diversity combining of signals for soft handoffs. For configuration I, a channel assignment scheme is developed which produces the lowest handoff blocking probability of all three configurations by lengthening the handoff transition time in cross links. With a slight increase in complexity, configuration II eliminates handoff oscillations between the two clusters even if a MT moves back and forth across the cluster boundary. This configuration also reduces the number of unnecessary handoffs between cell-clusters. The optimal number of channels to minimize handoff blocking probabilities at each connection link in each configuration has been determined by mathematical analysis and computer simulation. In proposed configuration III, the MSCs need to be modified so that they connect to each other via a trunk group for diversity signal combining during soft handoffs. Computer simulations have yielded the minimum number of channels necessary between the modified MSCs to attain the theoretical minimum handoff blocking probability. A mobility model with stop-and-go traffic has been developed to study how vehicle and pedestrian traffic affects the performance in each configuration. On the whole, configuration III accommodates more calls and is thus better than configuration I and II because during soft handoffs, it utilizes its channels more effectively than the other two configurations.
7.2 Topics for Further Investigation

The above proposed network configurations are novel, and the author welcomes further research. Future research may investigate the following topics:

1. Signaling and call flows for all three configurations

All network requires signaling and call flows. During soft handoffs in CDMA, special signaling and call flows, such as Joint Request message [9], are required because the MSCs and MTs need to be notified when they are communicating with old and new BSs simultaneously. In addition, signaling and call flows are needed to send from the old MSC to the new MSC through the IN to initiate the connection set up with BSs. In configuration III, signaling and call flows may transmit directly through the link between the modified MSCs between cell-clusters where the backbone IN may be less involved in handoffs between cell-clusters. From above discussion, signaling and call flows in CDMA soft handoffs require critical analysis.

2. Synchronization of traffic before and after handoffs

The synchronization of traffic before and after handoff is one of the major problems to provide the seamless service. Handoffs usually result in out of synchronization at destined BSs and switches. Mismatch of frame or cell transit time between old and new paths in the common switches and BSs can result in jitters and gaps. If the inaugural packet (frame) of the new paths arrives earlier than the expected time at the destination, a traffic jitter occurs. If the inaugural packet (frame) of the new path arrives later than the expected time at the destination, a traffic gap results. In order to filter the gaps, smooth the jitters and thus decreasing the mismatching of each data stream arriving at the destined base station, a buffer may be used to delay the incoming and outgoing data streams of the new paths at destined BSs. For voice message, another solution may be executing handoffs only at the silent period of time in the conversation. The human voice activity cycle is 35%. The rest of the time belongs to the listening period. This listening period of time may provide a precious period for the signal transmission so that
the calls may not be disrupted during handoffs. The synchronization is an old networking problem and requires much work for investigation.

3. Hysteresis in handoffs

Hysteresis accounts for the efficiency of handoffs. In the hysteresis, the signal strength should exceed a certain threshold $P_r$ for a certain amount of time $t$ before a handoff is carried out. The values of $P_r$ and $t$ need to be carefully designed for an efficiency of handoffs. Moreover, different types of handoff region, for example, on highway or at street corner, have different hysteresis. An appropriate handoff window will reduce the termination and redundancy of handoffs. An earlier handoff, a late handoff and a handoff back to the original BS are undesirable and thus hysteresis needs to be carefully planned. In addition, because diversity combining of signals occurs in CDMA soft handoffs, the hysteresis for CDMA soft handoffs may be different from other multiple access schemes. Hysteresis becomes more and more important when the size of cell decreases.

4. The development of modified MSC in configuration III

As discussed in Chapter 5, the MSC which directly links to each other needs some modification in configuration III. Figure 5.2 has already shown that a front end switching circuit needs to be added to the modified MSC. In addition, the modified MSC is expected to have certain intelligence. It should have the following abilities: determining the time when signals need to switch from old MSC to new MSC during soft handoffs, determining the criteria for transferring data and signals from the front end switching circuit to the new MSC, distinguishing what kind of signals and data needs to transfer to the new MSC or to its own receiver circuit or to the switches in the IN. Definitely, some further work requires to develop the modified MSC in configuration III so that it can match into the network.
REFERENCES


Appendix A  LIST OF ABBREVIATIONS AND VARIABLES

Here is a list of abbreviations in this thesis:

**ATM** Asynchronous Transfer Mode

**BISDN** Broadband Integrated Services Digital Network

**BS** Base Station

**CDMA** Code Division Multiple Access

**FEC** Forward Error Correction

**FDMA** Frequency Division Multiple Access

**FIFO** First-In-First-Out

**IS-95** Interim Standard 95

**IN** Intelligent Network

**MSC** Mobile Switching center

**MT** Mobile Terminal

**PCN** Personal Communication Network

**PN** Pseudo random Noise

**TDMA** Time Division Multiple Access

**TIA** Telecommunications Industry Association

**VCN** Virtual Circuit Number

Here is a list of variables in this thesis:

The variables of the mobility model are as follows:

- \( p \) Go-and-stop probability
- \( R \) Radius of microcell (m)
- \( r \) Distance of MT from BS (m)
- \( \theta \) Angle of MT from BS (°)
$V$ Speed of MT (km/hr)

$V_{max}$ Maximum value of $V$ (km/hr)

$\phi$ Angle of turning of MT ($^o$)

$T_m$ Duration of moving interval of MT (s)

$T_{m,max}$ Maximum value of $T_m$ (s)

$T_s$ Duration of stopping interval of MT (s)

$T_{s,max}$ Maximum value of $T_s$ (s)

$T$ Duration of unencumbered message (s)

$1/\mu$ Mean value of $T$ (s)

$P_r$ Received power at MT (dBm)

$P_t$ Transmitted power at BS (dBm)

$\kappa$ Pathloss slope (dB/dec)

$1/\mu_1$ Mean channel holding time (s)

$1/\mu_2$ Mean handoff transition time (s)

$\alpha$ Ratio of number of handoff calls from the circular ring of $R$ to $3R$ into the center hexagonal cell to the number of new calls originating from the center hexagonal cell

$\beta$ Ratio of number of handoff calls from the circular ring of $3R$ to $5R$ into the center hexagonal cell to the number of new calls originating from the center hexagonal cell

$\gamma$ Ratio of number of handoff calls from the circular ring of $5R$ to $7R$ into the center hexagonal cell to the number of new calls originating from the center hexagonal cell

$\delta$ Ratio of number of handoff calls from the center hexagonal cell, going out of it and returning back into the center hexagonal cell to the number of new calls originating from the center hexagonal cell

The variables in all three configurations are as follows:

$\lambda_o$ New call arrival rate (/hr/cell)
\( P_B(L_x) \) Blocking probability of link \( L_x \)

\( P_{BHII} \) Handoff blocking probability of channel assignment scheme I of configuration I

\( C \) Number of channels in direct link in configuration I

\( C_q \) Number of channels in cross link in configuration I

\( X \) The time period beginning at the instant that a handoff call joins the queue in cross link and ending at the instant that a channel in direct link is released in channel assignment scheme II in configuration I (s)

\( T_i \) The time remaining for the handoff call at \( i \)th queue position in cross link before MT moves out of the destined microcell in channel assignment scheme II in configuration I (s)

\( N(t) \) The state or occupancy of the queue in cross link at time \( t \) in channel assignment scheme II in configuration I

\( P_n \) The state probability of direct link of channel assignment scheme II in configuration I

\( P_{BO} \) Blocking probability of originating call blocked in direct link in channel assignment scheme II in configuration I

\( N_Q \) Average queue length for handoff calls in cross link in channel assignment scheme II in configuration I

\( w \) Average waiting time in the queue of handoff calls in cross link in channel assignment scheme II in configuration I (s)

\( P_{fh} \) Probability of a failed attempt occurring after MT has entered the queue in cross link in channel assignment scheme II in configuration I

\( P_{fh/k} \) Probability that the handoff attempt fails given that it enters the queue in position \( k+1 \) in cross link in channel assignment scheme II in configuration I

\( P(i | i+1) \) Probability that a handoff queued in position \( i+1 \) moves to position \( i \) before the corresponding MT moves away the destined microcell in channel assignment scheme II in configuration I
$P_{BhIII}$ Handoff blocking probability of channel assignment scheme II of configuration I

$P_{Bh2}$ Overall handoff blocking probability of configuration II

$P_{Bn}$ New call blocking probability
## Appendix B TABLE SUMMARY

Table B.1 A table summary for all three configurations

<table>
<thead>
<tr>
<th></th>
<th>Configuration I (cI), Scheme I</th>
<th>Configuration I, Scheme II</th>
<th>Configuration II (cII)</th>
<th>Configuration III (cIII)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td>Simplest</td>
<td>Providing the lowest handoff blocking probability</td>
<td>Eliminating handoff oscillation</td>
<td>Accomodating the highest number of calls</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Reducing the number of handoffs between MSCs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Trunking Efficiency</td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td>Handoff oscillation</td>
<td>Providing the highest new call blocking probability</td>
<td>Complicated configuration</td>
<td>MSCs needed to be modified to match into the network</td>
</tr>
<tr>
<td></td>
<td>$P_n &gt; P_s$</td>
<td>Handoff oscillation</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Most probably channel dimensions</strong></td>
<td>$(L_{A1}, L_{A2}) = (53, 9)$</td>
<td>$(L_{A1}, L_{A2}) = (51, 11)$</td>
<td>$(L_{A3}, L_{A4}, L_{A5}, L_{A6}) = (61, 53, 9, 1)$</td>
<td>$L_{AB} = 9$; realized as cI</td>
</tr>
<tr>
<td></td>
<td>$L_{AB} = 16$; realized as cII</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vehicle traffic for</strong> $R = 500\ m, p = 0.25$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New call blocking probability $P_n$ at $\lambda_o = 2200$/hr/cell</td>
<td>0.011</td>
<td>0.022</td>
<td>0.0036 (cell 3)</td>
<td>0.0036</td>
</tr>
<tr>
<td>Handoff blocking probability $P_h$ at $\lambda_o = 2200$/hr/cell</td>
<td>0.014</td>
<td>0.00051</td>
<td>0.0065</td>
<td>0.0036</td>
</tr>
<tr>
<td>Maximum arrival rate for $P_n &lt; 0.01$ (/hr/cell)</td>
<td>2200</td>
<td>2050</td>
<td>$&gt;2200$</td>
<td>2350</td>
</tr>
<tr>
<td><strong>Pedestrian traffic for</strong> $R = 150\ m, p = 0.25$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New call blocking probability $P_n$ at $\lambda_o = 1500$/hr/cell</td>
<td>0.010</td>
<td>0.021</td>
<td>0.0031</td>
<td></td>
</tr>
<tr>
<td>Handoff blocking probability $P_h$ at $\lambda_o = 1500$/hr/cell</td>
<td>0.012</td>
<td>0.00045</td>
<td>0.0031</td>
<td></td>
</tr>
<tr>
<td>Maximum arrival rate for $P_n &lt; 0.01$ (/hr/cell)</td>
<td>1500</td>
<td>1400</td>
<td>1650</td>
<td></td>
</tr>
</tbody>
</table>

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Table B.2 A table summary of traffic parameters and data obtained from simulations of the mobility model

<table>
<thead>
<tr>
<th>Traffic parameters</th>
<th>Vehicle traffic</th>
<th>Pedestrian traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unencumbered message duration $1/\mu$ (s)</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Max. speed $V_{\text{max}}$ (km/hr)</td>
<td>70</td>
<td>8</td>
</tr>
<tr>
<td>Max. moving interval $T_{m_{\text{max}}}$ (s)</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Max. stopping interval $T_{s_{\text{max}}}$ (s)</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Max. angle of turning $\phi$</td>
<td>$\pm100^\circ$</td>
<td>$\pm180^\circ$</td>
</tr>
<tr>
<td>Pathloss slope $\kappa$ (dB/dec)</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>Handoff window size (dB)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>(Handoff region) / (cell area)</td>
<td>44%</td>
<td>68%</td>
</tr>
<tr>
<td>Stop-and-go probability $p$</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Microcell radius $R$ (m)</td>
<td>500</td>
<td>150</td>
</tr>
<tr>
<td>Channel holding time $1/\mu_1$ (s)</td>
<td>53</td>
<td>89</td>
</tr>
<tr>
<td>Handoff transition time $1/\mu_2$ (s)</td>
<td>18</td>
<td>48</td>
</tr>
<tr>
<td>Ratios of handoff calls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.330</td>
<td>0.157</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.0148</td>
<td></td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>$\delta$</td>
<td>0.074</td>
<td>0.061</td>
</tr>
</tbody>
</table>
Appendix C  MARKOV CHAIN FOR TWO-CLASS QUEUE

A mathematical model for two dimensional Markov chains is to be developed [26]. Consider a system with \( m \) servers of equal capacity. There are two types of traffic arriving with Poisson rates \( \lambda_1 \) and \( \lambda_2 \) respectively. If an arrival finds all \( m \) servers busy, it does not enter the system and is lost. The service times of these two types of traffic are exponentially distributed with means \( 1/\mu_1 \) and \( 1/\mu_2 \) respectively. The appropriate Markov chain model involves the two dimensional state \((n_1, n_2)\), where \( n_i \) is the number of servers occupied by the traffic of type \( i \), for \( i = 1, 2 \). The transition diagram for this chain is shown in Figure C.1. Let \( P(n_1, n_2) \) be the steady state probability in the state \((n_1, n_2)\) where \( n_1 \geq 0, n_2 \geq 0 \) and \( n_1 + n_2 \leq m \). The global balance equations are

![Figure C.1 Markov chain for the two-class queue](image-url)

state \((n_1, n_2)\) where \( n_1 \geq 0, n_2 \geq 0 \) and \( n_1 + n_2 \leq m \). The global balance equations are
derived as follows:

\[ \lambda_1 P(n_1 - 1, n_2) = n_1 \mu_1 P(n_1, n_2) \]
\[ \lambda_2 P(n_1, n_2 - 1) = n_2 \mu_2 P(n_1, n_2) \]

Let \( \rho_i = \lambda_i / \mu_i \), where \( i = 1, 2 \). The following equations are obtained by solving equation (30).

\[ P(n_1, n_2) = \frac{\rho_1^{n_1}}{n_1!} P(0, n_2) \]
\[ P(n_1, n_2) = \frac{\rho_2^{n_2}}{n_2!} P(n_1, 0) \]
\[ P(n_1, n_2) = \frac{\rho_1^{n_1} \rho_2^{n_2}}{n_1! n_2!} P(0, 0) \]

The probabilities \( P(n_1, n_2) \) are all positive and add up to unity. That is,

\[ \sum_{n_1, n_2 \in S} P(n_1, n_2) = 1 \]

where \( S \) is the set of states of the system. Rewrite the above equation,

\[ \sum_{n_1=0}^{m} \sum_{n_2=0}^{m-n_1} P(n_1, n_2) = 1 \]

Solving equations (31) and (33),

\[ P(n_1, n_2) = \frac{\rho_1^{n_1} \rho_2^{n_2}}{n_1! n_2!} \sum_{i=0}^{m} \sum_{j=0}^{m-i} \frac{\rho_1^i \rho_2^j}{i! j!} \]

As a result, the steady state blocking probability \( P_{2Q} \) for this system is

\[ P_{2Q} = \sum_{n_1 + n_2 = m} P(n_1, n_2) = \frac{\sum_{n_1=0}^{m} \rho_1^{n_1} \rho_2^{m-n_1}}{n_1!(m-n_1)!} \]
\[ \sum_{i=0}^{m} \sum_{j=0}^{m-i} \frac{\rho_1^i \rho_2^j}{i! j!} \]
Appendix D DESCRIPTION OF MAIN SIMULATION MODELS

The mobility model in Chapter 2 is written by C programming language. The center hexagonal cell and the surrounding circular rings are specified in x and y coordinates. The originating position of the MT is recorded and then its movement is kept track. The MT exists in the simulation for an encumbered message time of exponential distribution with a fixed value of mean. If the MT is originating from the center hexagonal cell, channel holding time is recorded when it goes outside the center hexagonal cell or when the unencumbered message time is complete. Even when the MT moves outside the center hexagonal cell, it movement is still kept track to see if it will return to the center hexagonal cell for further data collection. If the MT is originating from the surrounding circular rings, the time when the MT enter the center hexagonal cell is recorded. Afterwards, the time for the MT exiting the center hexagonal cell or completing the unencumbered message time is recorded and the difference in time will account the channel holding time. Since the originating position of the MT and the moment that MT enters the center of hexagonal cell are recorded, the ratios of handoff calls can be obtained in simulation. The handoff transition time of the MT is obtained with similar simulation algorithm.

After the data of the mobility model, such as mean channel holding time, handoff transition time and ratios of handoff calls, are collected, the new call and handoff blocking probabilities of all three configurations are investigated by computer simulation written in Simscript II.5. A group of servers represents the total number of channels in the direct link and another group of server represent the total number of channels in the cross link with certain arrival rate and service time. The arrival rate and the service time are assumed to be exponential distributed. Handoff calls are represented by the calls arriving the cross link and then arriving the direct link with another certain service time. Blocking probabilities before the handoff calls are also taken into the account for
simulation. The handoff calls are counted to be successful if the calls can go through the above two links one by one. New calls are counted to be successful if the calls can go through the direct link. The new call and handoff blocking probabilities are obtained by the ratios the number of successful new and handoff calls to the number of trials of new and handoff calls, respectively. For scheme II of configuration II, a queue is put in the cross link, so that the position of handoff calls in the cross link can be recorded. For configuration II and III, handoff calls may go through several types of servers (links) to simulate the situation that the handoff calls go through several microcells in configuration II or several connection links in configuration III.