DYNAMIC CALL ADMISSION CONTROL SCHEME BASED ON PREDICTIVE MOBILITY BEHAVIOR OF USER FOR CELLULAR NETWORKS

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หัวข้อวิทยานิพนธ์	การควบคุมการเรียกเข้าแบบพลวัตด้วยวิธีการทำนายพฤติกรรมการเคลื่อนที่ของผู้ใช้สำหรับเครือข่ายเซลลูลาร์
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บทคัดย่อ

วิทยานิพนธ์นี้ได้นำเสนอวิธีการปรับปรุงประสิทธิภาพในการจองทรัพยากรและการควบคุมการเรียกเข้าสำหรับเครือข่ายเซลลูลาร์ที่เรียกว่า Predictive User Mobility Behavior (PUMB) โดยวิธีการที่นำเสนอนี้จะใช้พารามิเตอร์ที่เกี่ยวกับการเคลื่อนที่(Mobility Parameter) มาช่วยในการพิจารณาจัดสรรแบนด์วิดท์ใน Neighboring Cell ให้มีประสิทธิภาพมากขึ้น เพื่อเป็นการรับประกันคุณภาพการให้บริการในการส่งข้อมูล โดยการใช้วิธีการคำนวณหาค่าความน่าจะเป็นที่โมบายจะเคลื่อนที่ไปยังเซลล์ต่าง ๆ มาช่วยใช้ในการสร้าง Shadow Cluster ของโมบาย นอกจากนี้ ในกรณีที่โมบายมีการเปลี่ยนทิศทางในการเคลื่อนที่และเข้าไปใช้งานในเซลล์ที่ไม่ได้อยู่ใน Shadow Cluster ที่ได้ทำการจองแบนด์วิดท์ไว้ ก็ได้มีอัลกอริทึมในการรองรับกรณีดังกล่าวไว้ในส่วนของ Predicted Nonconforming Call และเพื่อให้มั่นใจว่า Call ที่เข้ามาใช้งานในเครือข่ายจะได้รับการให้บริการอย่างต่อเนื่องรวมทั้งมีการใช้ประโยชน์จากทรัพยากรอย่างมีประสิทธิภาพ แบนด์วิดท์อาจถูกยืมจาก Predicted Nonconforming Call และ Adaptive Call ที่มีอยู่ขณะนั้นเพื่อรองรับ Handoff Call โดยใช้หลักการที่ส่งผลกระทบต่อการรับประกันคุณภาพการให้บริการของเครือข่ายน้อยที่สุด ในการวัดประสิทธิภาพจะทำการวัดจากค่า New Call Blocking Probability, Handoff Call Dropping Probability, Bandwidth Utilization และ Call Successful Probability ที่เกิดขึ้นในกรณีที่อัตราการเข้าใช้งานที่แตกต่างกัน กรณีที่มีการปรับเปลี่ยนค่าความเร็วที่ใช้ในการเคลื่อนที่ของผู้ใช้เคลื่อนที่ (Mobile User) และกรณีที่ค่า Shadow Cluster Probability Threshold มีค่าแตกต่างกัน จากผลการจำลองแสดงให้เห็นว่าวิธีการที่นำเสนอสามารถลดค่า Handoff Call Dropping Probability ลงได้ ซึ่งแสดงให้เห็นว่าวิธีการที่นำเสนอสามารถจัดการกับ Handoff Call ได้อย่างมีประสิทธิภาพที่ดีกว่า

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ABSTRACT

In this thesis, we propose a scheme for improving the performance of resource reservation and call admission control for cellular networks, called "Predictive User Mobility Behavior (PUMB)". This scheme is proposed to allocate bandwidth more efficiently to neighboring cells by using key mobility parameters in order to assure Quality of Service (QoS) for data transmission. The probability theory is used to calculate the cell visiting probability that a mobile unit (MU) visits the neighboring cell which used to form the shadow cluster. When the MU more likely to change the direction and migrate to the cell that does not belong to its shadow cluster, we support this case by using predicted nonconforming call. Concurrently, to ensure the continuity of ongoing calls with better utilization of resources, the bandwidth is borrowed from predicted nonconforming calls and existing adaptive calls without effecting to the minimum QoS guarantees. We have evaluated the performance of our proposed scheme by the simulation. We consider several performance metrics such as new call blocking probability, handoff call dropping probability, call successful probability and bandwidth utilization while the arrival rate, the moving speed of mobile unit and the shadow cluster probability threshold are varied. The simulation results show that the proposed scheme can reduce handoff call dropping probability, so that it is more efficient to support handoff call.

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Silada Intarasothonchun

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LIST OF ABBREVIATIONS

BS	Base Station
BSC	Base Station Controller
CAC	Call Admission Control
CDMA	Code Division Multiple Access
CP	Complete Partitioning
CRT	Cell Residence Time
CS	Complete Sharing
CSP	Call Successful Probability
CVP	Cell Visiting Probability
DACS	Distributed Admission Control Scheme
DGCS	Dynamic Guard Channel Scheme
DT-CAC	Dual Threshold-Call Admission Control
DS	Direct Sequence
ETD	Expected Travel Distance
FBB	Fair Borrowable Bandwidth
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FGCS	Fractional Guarded Channel Scheme
FH	Frequency Hopping
FTP	File Transfer Protocol
GCS	Guard Channel Scheme
GPRS	General Packet Radio Service
GPS	Global Positioning System
HCDP	Handoff Call Dropping Probability
LWS	Linear Weighting Scheme
MBB	Maximum Borrowable Bandwidth
MSC	Mobile Switching Center
MSODB	Mobility Support On-Demand Borrowing
MU	Mobile Unit
NCBP	New Call Blocking Probability

ODB	On-Demand Borrowing
PMS	Predictive Mobility Support
PSTN	Public Switched Telephone Network
PUMB	Predictive User Mobility Behavior
Qos	Quality of Service
RF	Radio Frequency
RLI	Resource Leasing Interval
RRI	Resource Reservation Interval
RTW	Reservation Time Window
SC	Shadow Cluster
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
WSS	Weighted Sum Scheme

CHAPTER 1

INTRODUCTION

1.1. STATEMENT AND SIGNIFICANCE OF THE PROBLEM

Currently, the wireless networks such as cellular networks are extending to support several types of traffics under diverse bandwidth requirements. These networks will serve multiple traffic classes with each class having different requirements of *Quality of Service* (QoS). In the research area of wireless networks, the scarcity of wireless bandwidth, the movements of users, and channel imperfections cause QoS provisioning is an extreme challenging task. Furthermore, in cellular networks while an ongoing call is handing off to an adjacent cell. The ongoing call can be dropped if that cell has insufficient free resources to support the call.

From the user's perspective, a new call is unable to be initialized because of the bandwidth constrain is undesirable. However, failing to continue an ongoing call, while moving across cells, is even more undesirable. In order to provide the QoS to users, the Call Admission Control (CAC) scheme is needed. The CAC is such a strategy to limit the number of call connection into the networks, and will be used to reduce the network congestion and call dropping. In order to support handoff call, any cellular network must implement a resource reservation strategy within its CAC scheme. The resource reservation decreases the handoff call dropping probability at the expense of denying more new call services, as the results, the new call blocking probability increases. On the other hand, excessively resource reservation can lead to reduced bandwidth utilization. Therefore, accurate estimation of the level of resources to be reserved is considered as one of the most challenging tasks in designing an efficient CAC scheme.

1.2 GOAL AND OBJECTIVES

The main objectives of this thesis are as follows:

1) To propose the new scheme, called Predictive User Mobility Behavior (PUMB) that can guarantee an uninterrupted service for admitted calls while they move from one cell to one of other cells, and the bandwidth utilization is maximized.

The PUMB is the modified scheme which is extended from the Mobility Support On Demand Borrowing (MSODB) and Predictive Mobility Support (PMS) schemes. In this research scheme, two functions have been added into the PUMB. There are (1) adjusting the window size of Shadow Cluster (SC) by considering the typical behavior of mobile unit (MU) such as direction and speed, and (2) weighting reposes from all cells in the SC by considering the Cell Visiting Probability (CVP). We found that the decision accuracy for call accepting or call rejecting is increased with the implementation of PUMB. From the result, the PUMB can guarantee an uninterrupted service for admitted call as they move from one cell to one of other cells.

2) To study the effect on the arrival rate, the moving speed and the shadow cluster probability threshold in the performance of the PUMB by the simulation results.

1.3 SCOPE OF THE RESEARCH

In this thesis, we focus on a wireless cellular network which the bandwidth is perhaps the most precious and scarce resource of the entire communication system. It is of great importance to use this resource in the most efficient manner. Call admission control (CAC) is such a strategy to limit the number of call connection into the networks in order to reduce the network congestion and call dropping. We propose *Predictive User Mobility Behavior* (PUMB) to improve performance of resource reservation and CAC for cellular networks. The performance of the PUMB is demonstrated by simulation with MATLAB. The simulation shows that the effect of new call arrival rate, the moving speed of MU, and the threshold of shadow cluster probability and compare between the PUMB and MSODB. Our considerations are focused on performance metrics such as New Call Blocking Probability (NCBP), Handoff Call Dropping Probability (HCDP), Call Successful Probability (CSP), and Bandwidth Utilization (BU).

1.4. CONTENTS OF THE RESEARCH

The contents of this thesis are divided into 6 chapters. Chapter 1 consists of introduction and objective of the thesis. The other chapters are organized as follows.

The cellular system infrastructures, the cellular concept and handoff algorithms are described in Chapter 2.

The CAC algorithms are given in Chapter 3. Also the resource reservation schemes for CAC based on shadow cluster are explained.

In Chapter 4, Predictive User Mobility Behavior (PUMB) scheme is described together with mobility model and CAC algorithm. In addition, quality of service parameters such as NCBP, HCDP, CSP and bandwidth utilization, are explained.

Later the method for performance evaluation and the simulation results are given in Chapter 5. The simulation parameters such as traffic characteristics, mobility parameters and traffic parameters are explained. The simulation results of comparing between our proposed PUMB and MSODB are demonstrated in three parts: new call arrival rate, moving speed of MU, and the shadow cluster probability threshold.

Chapter 6 is devoted to conclusion and suggestion of the thesis.

Finally, the parts of research that were published on international journal and conferences are given in the Appendix.

CHAPTER 2

CELLULAR NETWORK SYSTEM

2.1. CELLULAR SYSTEM INFRASTRUCTURES

In a cellular structure, a Mobile Unit (MU) needs to communication with the Base Station (BS) of the cell where the MU is currently located, and the BS acts as a gateway to the rest of the world. Therefore, to provide a link, the MU needs to be in the area of one of the cells (and hence a BS) so that mobility of the MU can be supported. Several BSs are connected through hardwires and are controlled by a Base Station Controller (BSC), which in turn is connected to a Mobile Switching Center (MSC). Several MSCs are interconnected to a Public Switched Telephone Network (PSTN). To provide a better perspective of wireless communication technology, the cellular system is shown in Figure 2.1.

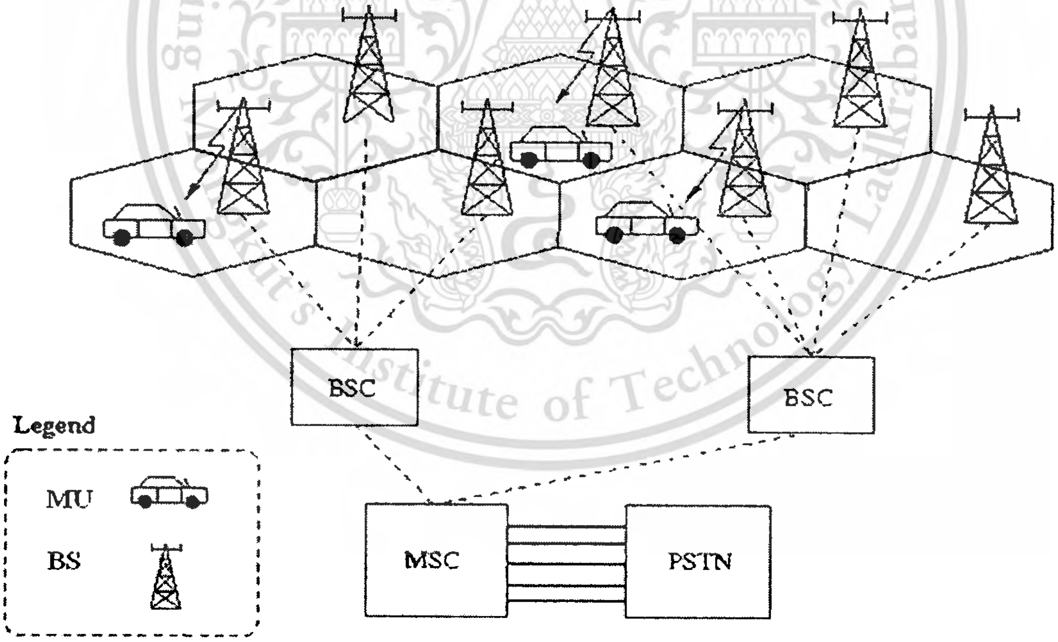

Figure 2.1 Cellular system infrastructures

In any cellular scheme, four simplex channels are needed to exchange synchronization and data between BS and MU, and such a simplified arrangement is shown in Figure 2.2. The control links are used to exchange control messages (such as authentication, subscriber information, and call parameter negotiations) between the BS and MU, while traffic (or information) channels are used to transfer actual data between the two. The channels from BS to MU are known as *forward channels*, and the term *reverse channels* are used for communication from MU to BS. Control information needs to be exchanged before actual data information transfer can take place. Simplified handshake steps for call setup are illustrated in Figure 2.3 and 2.4 [1,4].

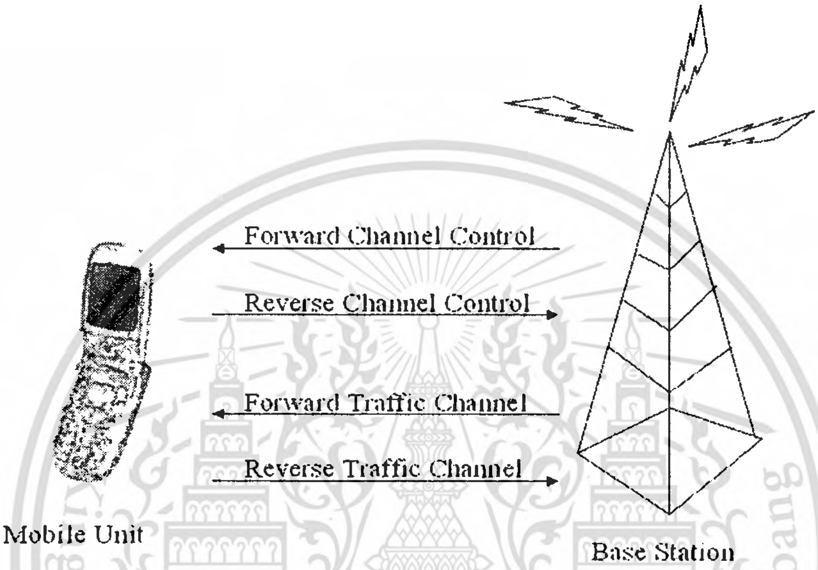

Figure 2.2 Four simplex channels between BS and MU in a cell

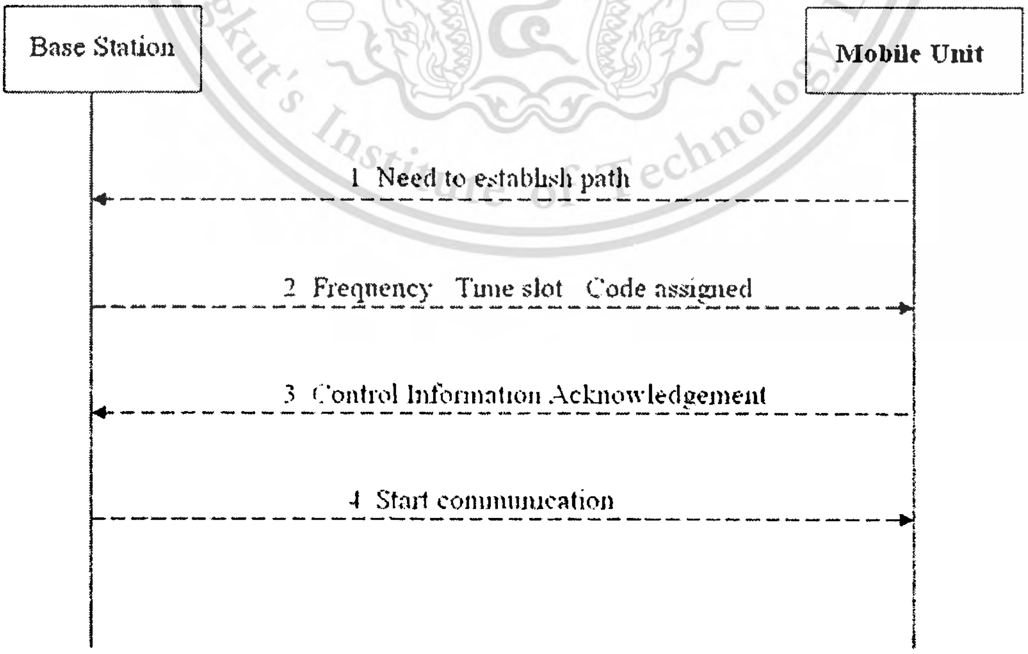

Figure 2.3 Steps for a call setup from MU to BS

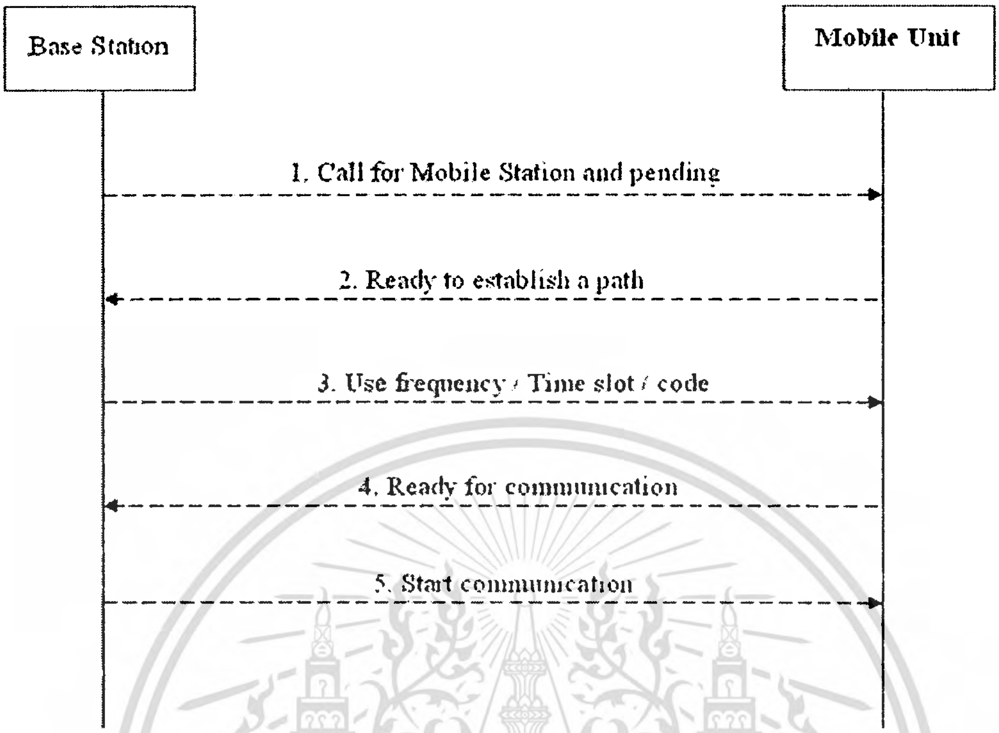

Figure 2.4 Steps for a call setup from BS to MU

2.1.1. CELL AREA

Under ideal radio environments, the shape of the cell can be circular around the microwave transmitting tower. The radius of the circle is equal to the reachable range of the transmitted signal. It means that if the BS is located at the center of the cell, the cell area and periphery are determined by the signal strength within the region, which in turn depends on many factors, such as the contour of the terrain, height of the transmitting antenna, presence of hills, valleys and tall buildings, and atmospheric conditions. Therefore, the actual shape of the cell, indicating a true coverage area, may be of a zigzag shape. However, for all practical purpose, the cell is approximated by a hexagon as shown in Figure 2.5.

A cell is the radio area covered by a transmitting station or a BS. In that area, all MUs are connected and serviced by the BS. Therefore, ideally, the area covered by a cell could be represented by a circular cell, with a radius R from the center of the BS. The actual shape of the cell is determined by the received signal strength in the surrounding area. An appropriate model of a cell is needed before a cellular system can be analyzed and evaluated.

The hexagon is a good approximation of a circular region. Moreover, it allows a larger region to be divided into non-overlapping hexagonal sub-regions of equal size, with each one representing a cell area. The square is another alternative shape that can be used to represent the cell area. The triangle is another less frequently used coverage area. Octagons and decagons do represent shapes closer to a circular area as compared to a hexagon. However, they are not used to model a cell as it is not possible to divide a larger area into non-overlapping sub-areas of the same shape.

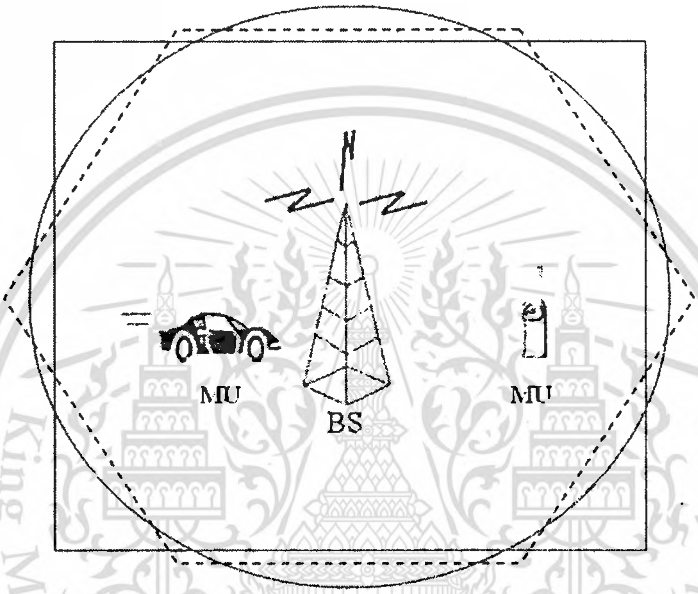

Figure 2.5 Illustration of a cell with a BS and MUs

There are many possible models that can be used, to represent a cell boundary and the most popular alternatives of hexagon, square, and equilateral triangle are shown in Figure 2.6. The size and capacity of the cell per unit of area and the impact of the shape of a cell on service characteristics are shown in Table 2.1 [1,2].

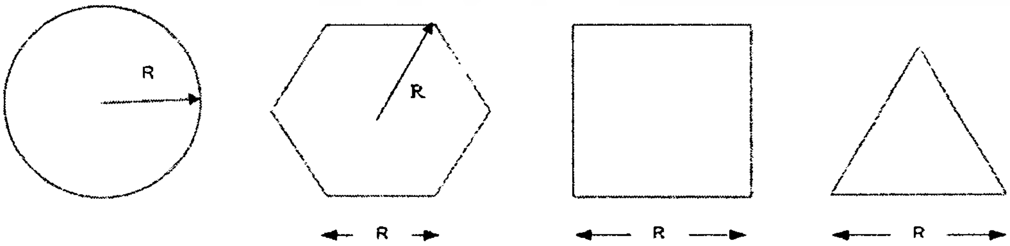

Figure 2.6 Shape of the cell coverage area

Table 2.1 Impact of cell shape and radius on service characteristics

Shape of the cell	Circular cell (radius = R)	Triangular cell (side = R)	Square cell (side = R)	Hexagonal cell (side = R)
Area	πR^2	$\frac{\sqrt{3}}{4}R^2$	R^2	$\frac{3\sqrt{3}}{2}R^2$
Boundary	$2\pi R$	$3R$	$4R$	$6R$
Boundary Length / Unit Area	$\frac{2}{R}$	$\frac{4\sqrt{3}}{R}$	$\frac{4}{R}$	$\frac{4}{\sqrt{3}R}$
Channels/ Unit Area with N channels/cells	$\frac{N}{\pi R^2}$	$\frac{4\sqrt{3}N}{3R^2}$	$\frac{N}{R^2}$	$\frac{N}{1.5\sqrt{3}R^2}$
Channels/ Unit Area when number of channels increases by a factor K	$\frac{KN}{\pi R^2}$	$\frac{4\sqrt{3}KN}{3R^2}$	$\frac{KN}{R^2}$	$\frac{KN}{1.5\sqrt{3}R^2}$
Channels/ Unit Area when size of cell is reduced by factor M	$\frac{K^2N}{\pi R^2}$	$\frac{4\sqrt{3}K^2M^2N}{3R^2}$	$\frac{K^2N}{R^2}$	$\frac{K^2N}{1.5\sqrt{3}R^2}$

2.1.2. FREQUENCY REUSE

Because only a small number of radio channel frequencies were available for mobile systems, engineers had to find a way to reuse radio channels to carry more than one conversation at a time. The solution the industry adopted was called frequency planning or frequency reuse. Frequency reuse was implemented by restructuring the mobile telephone system architecture into the cellular concept.

The concept of frequency reuse is based on assigning to each cell a group of radio channels used within a small geographic area. Cells are assigned a group of channels that is completely different from neighboring cells. The same frequency band or channel used in a cell can be "reused" in another cell as long as the cells are far apart and the signal strength do not interfere with each other. This enhances the available bandwidth of each cell. A typical cluster of seven such with no overlapping area is shown in Figure 2.7.

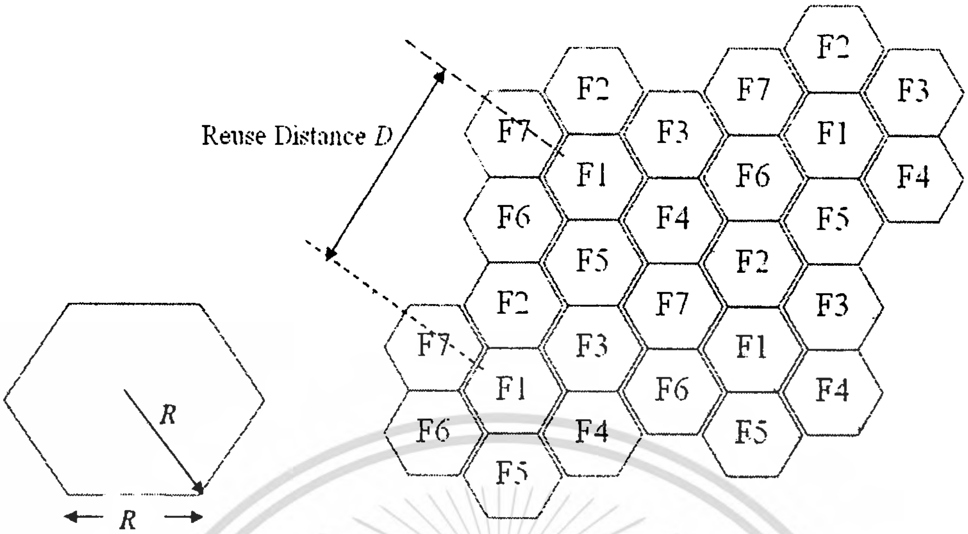

Figure 2.7 Illustration of frequency reuse

In Figure 2.7, the distance between the two cells using the same channel is known as the “reuse distance” and is represented by D. In fact, there is a close relationship between the D, R (the radius of each cell), and N (the number of cells in a cluster), which is given by

$$D = \sqrt{3N}R \tag{2.1}$$

Another popular cluster size is with $N = 4$. In fact, the arguments made in selecting a rectangular versus hexagonal shape of the cell are also applicable to the size of the hex cell clusters such that multiple copies of such cluster should fit well with each other, just like a puzzle. Additional areas can be covered by additional clusters without having any overlapped area. In general, the number of cells N per cluster is given by

$$N = i^2 + ij + j^2 \tag{2.2}$$

Where i represents the number of cells to be traversed along direction i, starting from the center of a cell, and j represents the number of cells in a direction 60° to the direction of i.

Finding the center of all clusters around a reference cell is illustrated in Figure 2.8. Repeat this for all six sides of the reference cell until the center for all adjacent clusters substituting different values of i and j leads to $N = 1,3,4,7,9,12,13,16,...$; the most popular values are 4 and 7. Many possible cluster sizes with different values of N are shown in Figure 2.9 [4,5].

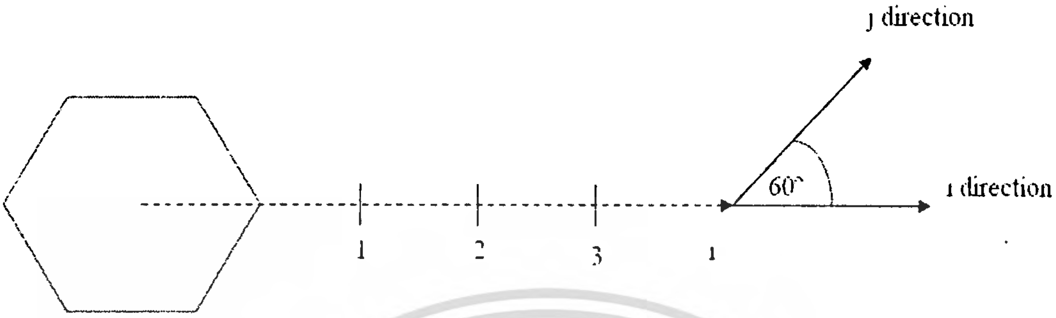

Figure 2.8 Finding the center of an adjacent cluster using integer i and j

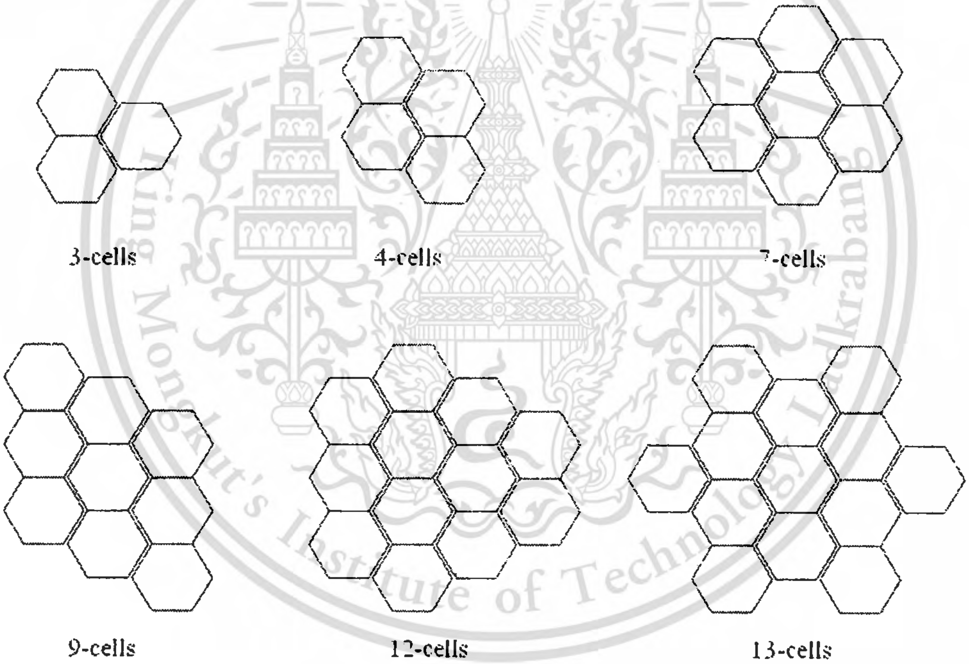

Figure 2.9 Common reused pattern of hexagonal cell clusters

2.2. MULTIPLE DIVISION TECHNIQUE

In a mobile cellular system, each MU not only can distinguish a signal from the serving BS but also can discriminate the signals from an adjacent BS. Therefore, a multiple access technique is important in mobile cellular systems. Multiple access techniques are based on the orthogonal of signal. A radio signal can be presented as a function of frequency, time, and code as

$$s(f,t,c) = s(f,t)c(t) \tag{2.3}$$

where $s(f,t)$ is a function of frequency and time, and $c(t)$ is a function of code [3].

There are three basic ways to have many channels within an allocated bandwidth:

1. If a system employs different carrier frequencies to transmit the signal for each user, it is called a Frequency Division Multiple Access (FDMA) system.

2. If a system uses distinct time to transmit the signal for different users, it is a Time Division Multiple Access (TDMA) system.

3. If a system uses different code to transmit the signal for each user, it is a Code Division Multiple Access (CDMA) system.

2.2.1. FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)

The orthogonal condition of the two signals in FDMA is given by

$$\int_F s_i(f,t)s_j(f,t)df = \begin{cases} 1, & i = j \\ 0, & i \neq j \end{cases} ;\ i,j = 1,2,\ldots,k. \tag{2.4}$$

Equation (2.4) indicates that there is no overlapping frequency in frequency domain F for the signals $s_i(f,t)$ and $s_j(f,t)$, and the two signals do not interfere with each other.

FDMA is a multiple access system that has been widely adopted in existing analog systems for portable and automobile telephones. The BS dynamically assigns a different carrier frequency to each active user (MU). A frequency synthesizer is used to adjust and maintain the transmission and reception frequencies. The concept of FDMA is shown in Figure 2.10.

Figure 2.11 shows the basic structure of an FDMA system, consisting of a BS and many MUs. There is a pair of channels for the communication between the BS and the MU. The pair channels are called forward channel and reverse channel. Different frequency bandwidths are assigned to different users. This implies that there is no frequency overlapping between the forward and reverse channels. For example, the forward and reverse channels for MU#1 are f_1 and f_1', respectively.

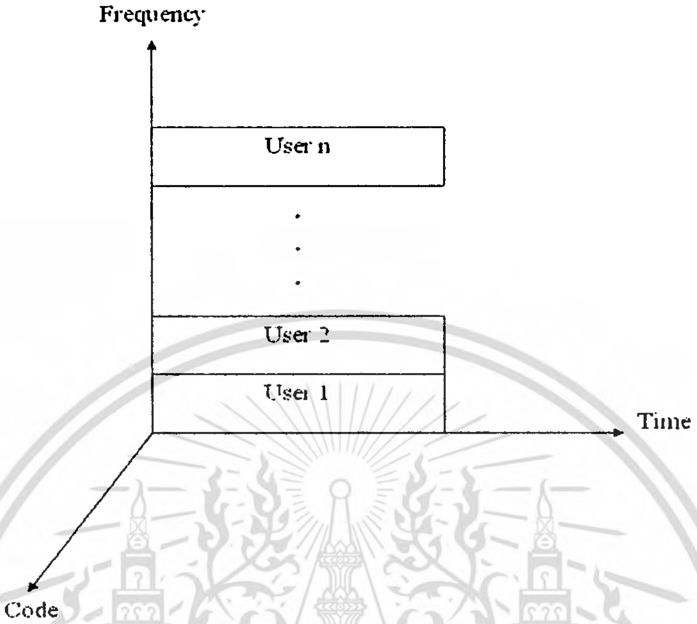

Figure 2.10 The concept of FDMA

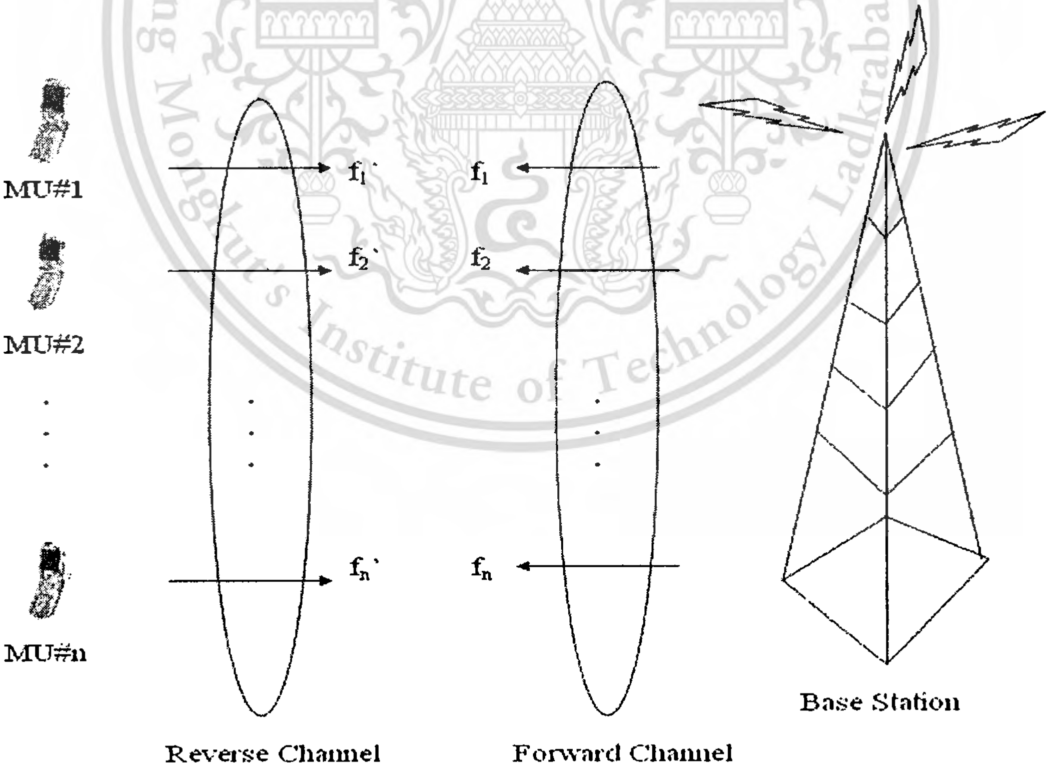

Figure 2.11 The basic structure of a FDMA system

The structure of forward and reverse channels in FDMA is shown in Figure 2.12. A protecting bandwidth is used between the forward and reverse channels and a guard band W_g between two adjacent channels in Figure 2.13 is used to minimize interference between them. The frequency bandwidth for each user is called sub-band W_c. If there are N channels in FDMA system, the total bandwidth is equal to $N \cdot W_c - W_g$.

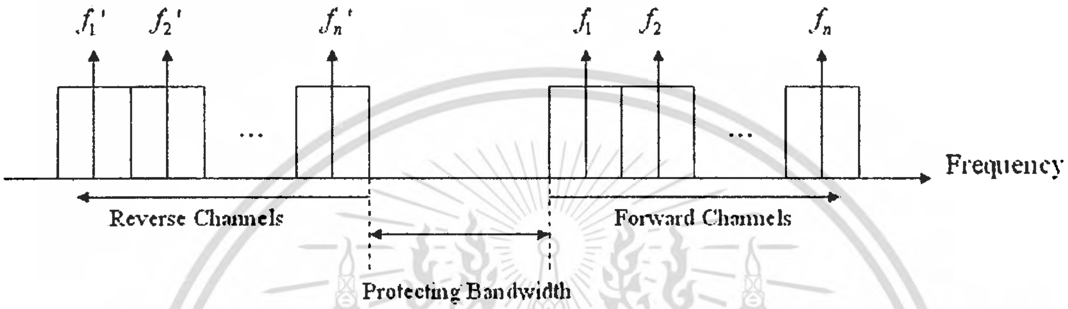

Figure 2.12 Structure of forward and reverse channels in FDMA

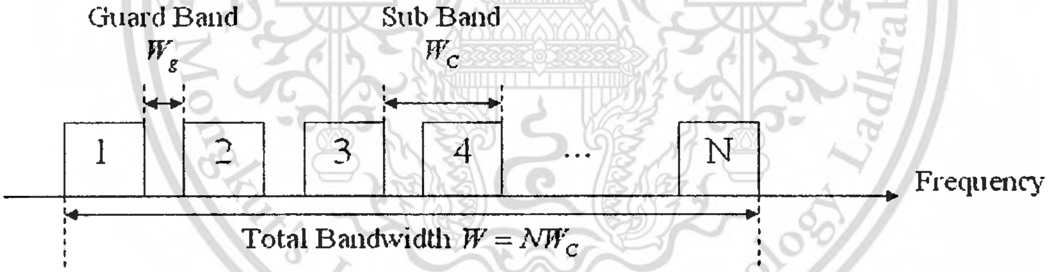

Figure 2.13 Guard band in FDMA

2.2.2. TIME DIVISION MULTIPLE ACCESS (TDMA)

The orthogonal condition of the two signals in TDMA is given by

$$\int_T s_i(f,t)s_j(f,t)df = \begin{cases} 1, & i = j \\ 0, & i \neq j \end{cases} \; ; \; i, j = 1, 2, \ldots, k. \tag{2.5}$$

Equation (2.5) indicates that there is no overlapping time in time axis T for the signals $s_i(f,t)$ and $s_j(f,t)$, and the two signals do not interfere with each other. TDMA splits a single carrier wave into time slots and distributes the slots among multiple users, as shown in Figure 2.14. The communication channels essentially consist of many units, called time slots, over a time cycle, which makes it possible for one frequency channel to be efficiently utilized by multiple users as each utilizes a different time slot as shown in Figure 2.15.

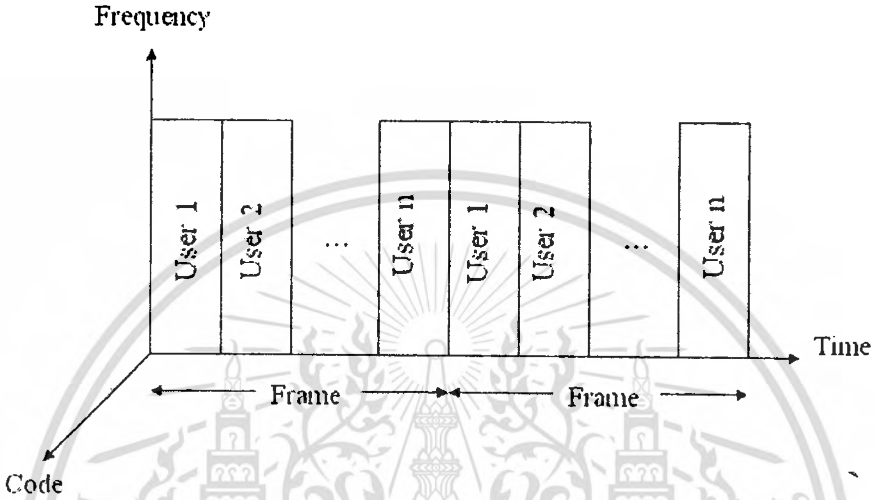

Figure 2.14 The concept of TDMA

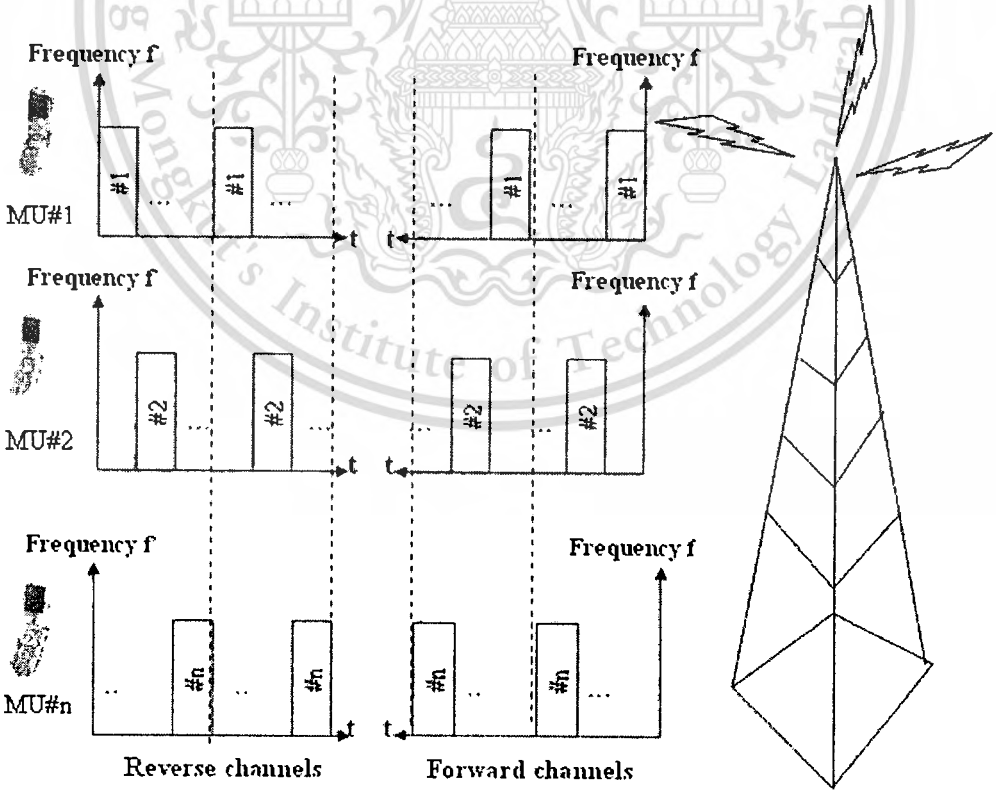

Figure 2.15 The basic structure of a TDMA system

A TDMA system may be in either of two modes: Frequency Division Duplex (FDD: in which the forward/reverse communication frequencies differ) and Time Division Duplex (TDD: in which the forward/reverse communication frequencies are the same). Figure 2.16 and 2.17 show the structure of forward and reverse channels in TDMA/FDD system and TDMA/TDD, respectively.

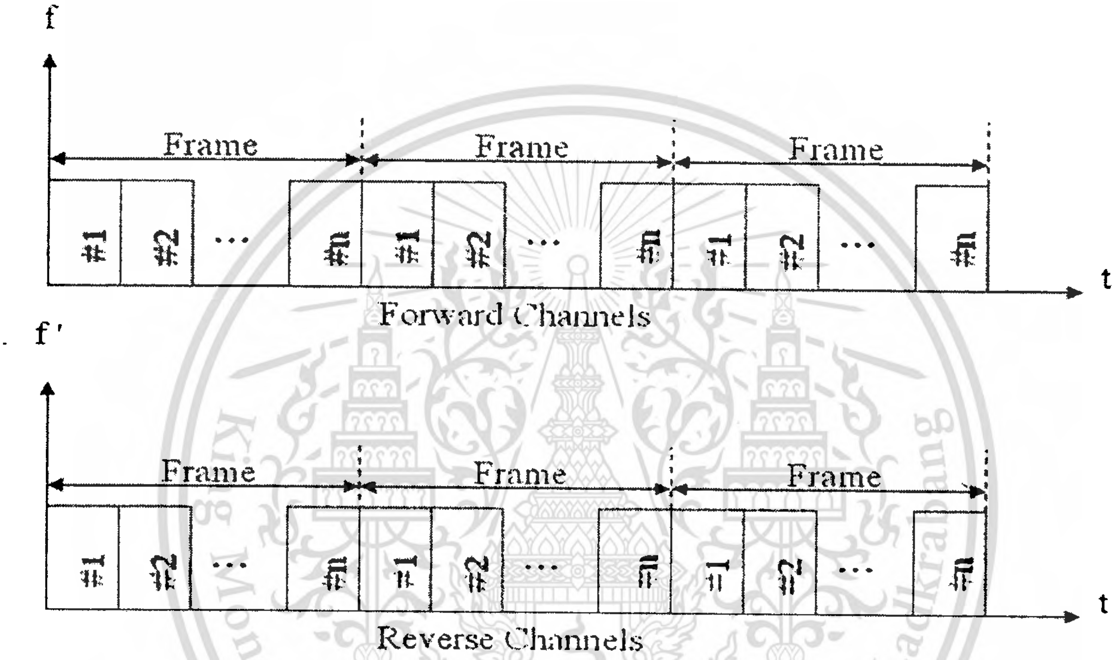

Figure 2.16 Structure of forward and reverse channels in TDMA/FDD system

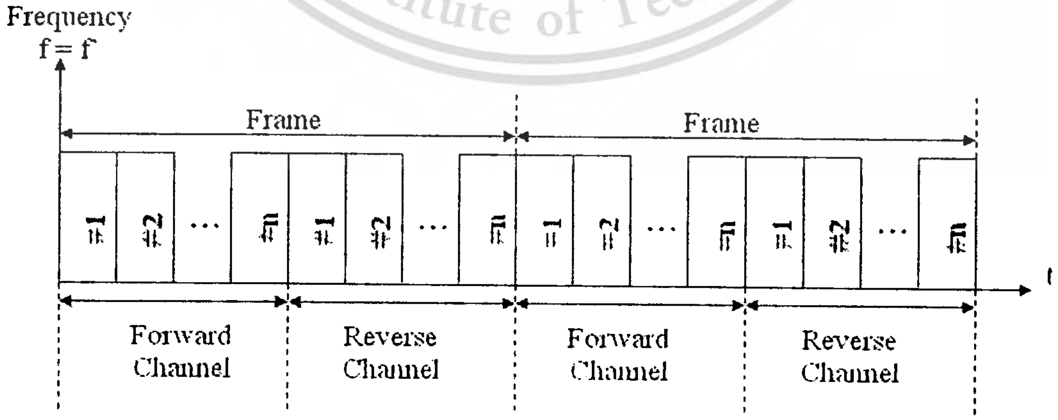

Figure 2.17 Structure of forward and reverse channels in TDMA/TDD system

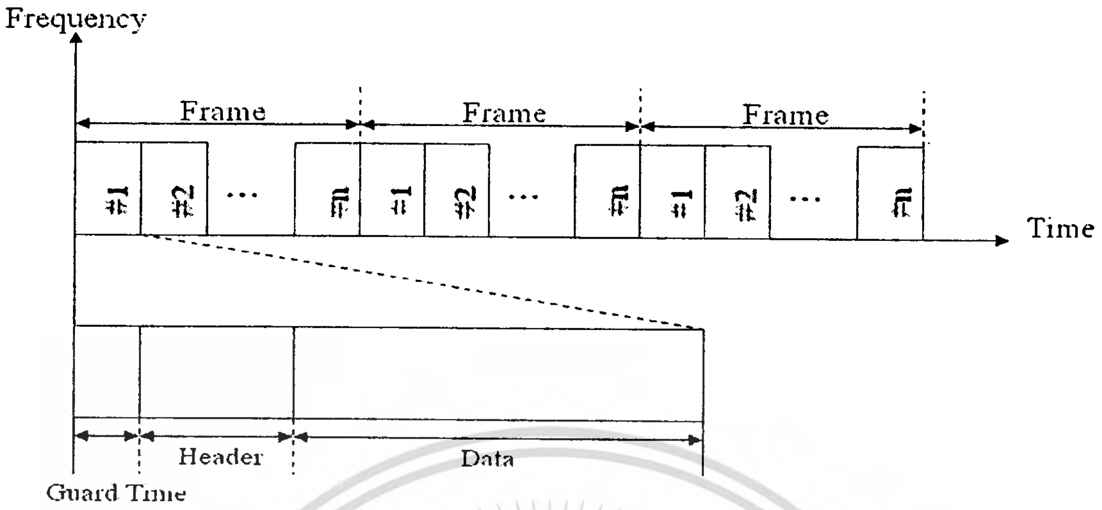

Figure 2.18 Frame structure of TDMA

Figure 2.18 shows a frame structure of TDMA. For a TDMA system, there is guard time between the slots so that interference due to propagation delays along a different path can be minimized.

2.2.3. CODE DIVISION MULTIPLE ACCESS (CDMA)

The orthogonal condition of the two signals in CDMA is given by

$$\int_C s_i(t)s_j(t)df = \begin{cases} 1, & i = j \\ 0, & i \neq j \end{cases} \;;\; i,j = 1,2,\ldots,k \tag{2.6}$$

Equation (2.6) indicates that there is no overlapping of signals in code axis C for signals $s_i(t)$ and $s_j(t)$ and implies that the signals do not have any common codes in the code space.

In a CDMA system, different spread spectrum codes are selected and assigned to each user, and multiple users share the same frequency, as shown in Figure 2.19 and 2.20. CDMA is a system based on spread spectrum technology, which makes it less susceptible to the noise and interference by substantially spreading over the bandwidth range of modulated signal.

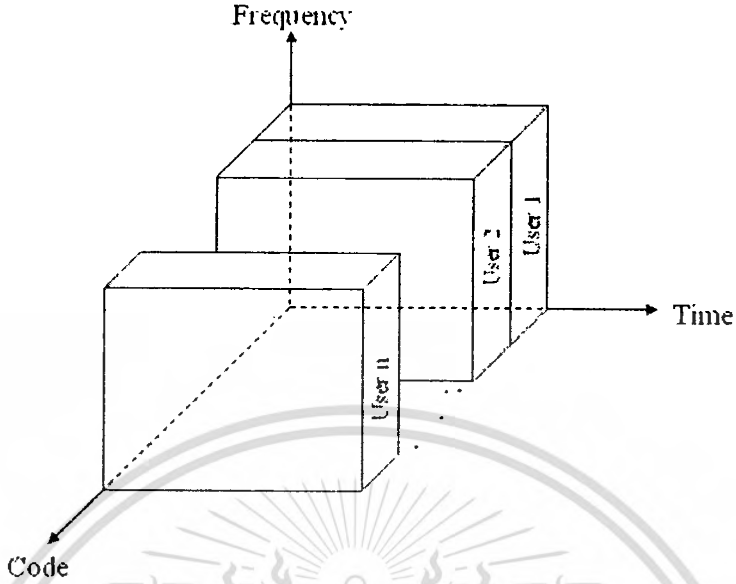

Figure 2.19 The concept of CDMA

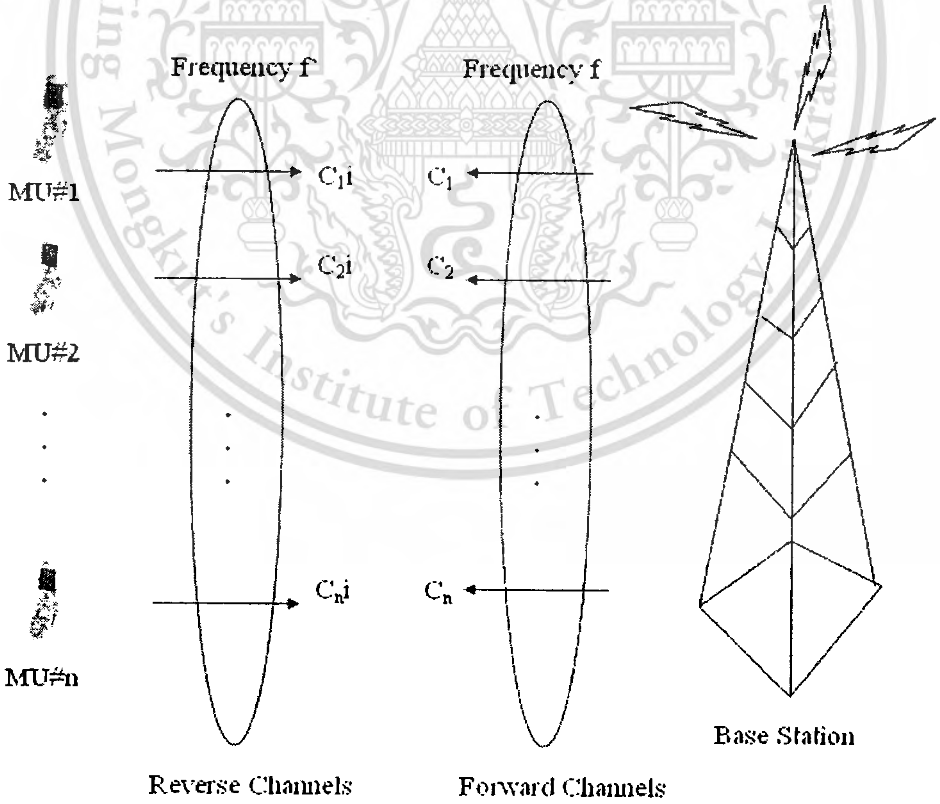

Figure 2.20 Structure of a CDMA system

In addition, because of its broadband characteristics, fading resistance can be achieved by the multipath synthesis. Reserving a wider bandwidth for a single communication channel was once regarded as disadvantageous in terms of effective frequency utilization. However, high efficiency of frequency usage has been demonstrated in CDMA since the introduction of power control to adjust the antenna emitting power so that the near-far problem could be solved. In a general CDMA system, received signals at the BS from a far-away MU could be masked by signals from a close-by MU in the reverse channel.

There are two basic types of CDMA implementation methodologies: Direct Sequence (DS) systems and Frequency Hopping (FH). As it is difficult to use the FH system on a practical basis unless a super-fast synthesizer is employed, the DS system is considered the most feasible generic method when the code is selected and assigned dynamically to each MU.

Spread spectrum is a transmission technique wherein data occupy a larger bandwidth than necessary. Bandwidth spreading is accomplished before the transmission through the use of a code that is independent of the transmitted data. The same code is used to demodulate the data at the receiving end. Figure 2.21 illustrates the spreading done on the data signal $s(t)$ by the spreading signal $c(t)$ resulting in the message signal to be transmitted, $m(t)$. That is,

$$m(t) = s(t) \otimes c(t) \tag{2.6}$$

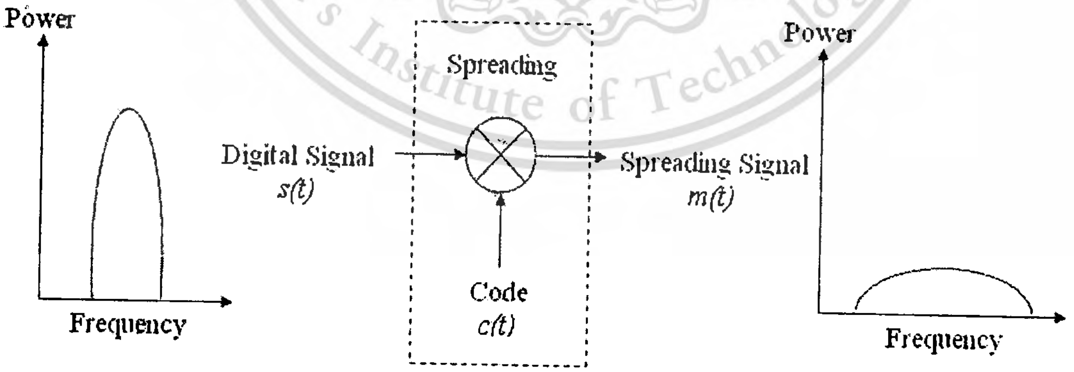

Figure 2.21 Spread spectrum

Originally designed for military use to avoid jamming (interference created on purpose to make a communication channel unusable), spread spectrum modulation is now used in person communication systems also due to its superior performance in an interference-dominated environment.

2.2.3.1. DIRECT SEQUENCE SPREAD SPECTRUM (DSSS)

In the DS method, the radio signal is multiplied by a pseudorandom sequence whose bandwidth is much greater than that of the signal itself, thereby spreading its bandwidth as shown in Figure 2.22. This is a modulation technique wherein a pseudorandom sequence directly phase modulates a data-modulated carrier, thereby increasing the bandwidth of the transmission and lowering the spectral power density. The resulting Radio Frequency (RF) signal has a noise-like spectrum, and in fact can be intentionally made to look like noise to all but the intended radio receiver. The received signal is de-spread by correlating it with a local pseudorandom sequence identical to and in synchronization with the sequence used to spread the carrier at the radio transmitting end.

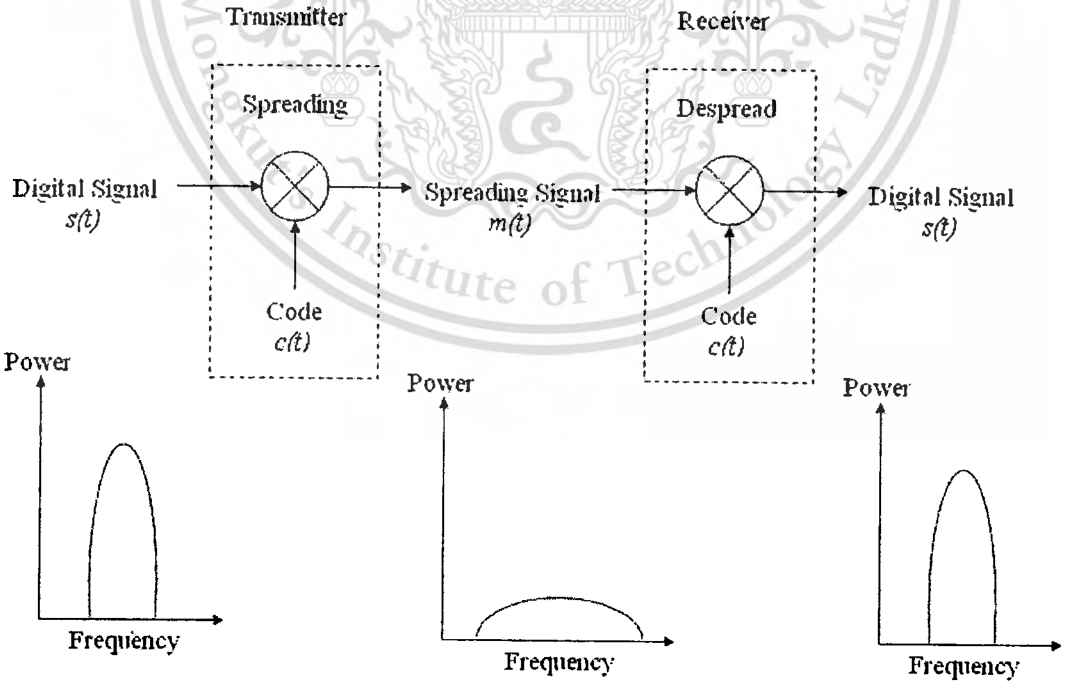

Figure 2.22 Concept of direct sequence spread spectrum system

2.2.3.2. FREQUENCY HOPPING SPREAD SPECTRUM (FHSS)

In a FH method, a pseudorandom sequence is used to change the radio signal frequency, across a broad frequency band in a random fashion as shown in Figure 2.23. A spread spectrum modulation technique implies that the radio transmitter frequency hops from channel to channel in a predetermined but pseudorandom manner. The RF signal is de-hopped at the receiver end using a frequency synthesizer controller by a pseudorandom sequence generator synchronized to the transmitter's pseudorandom sequence generator. A frequency hopper may be fast hopped, where there are multiple hops per data bit, or slow hopped, where there are multiple data bits per hop.

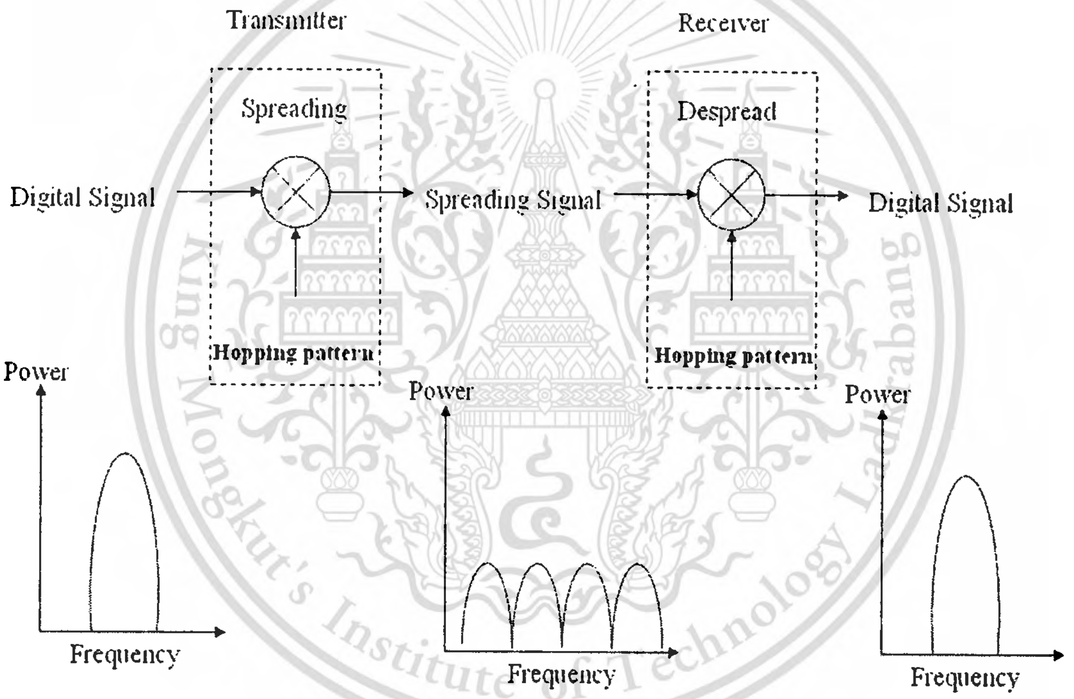

Figure 2.23 Concept of frequency hopping spread spectrum system

Figure 2.24 shows an example of frequency hopping pattern. Multiple simultaneous transmission from several users is possible using FH, as long as each uses different frequency hopping sequences and none of them "collide" (no more than one unit using the some band) at any given instant of time.

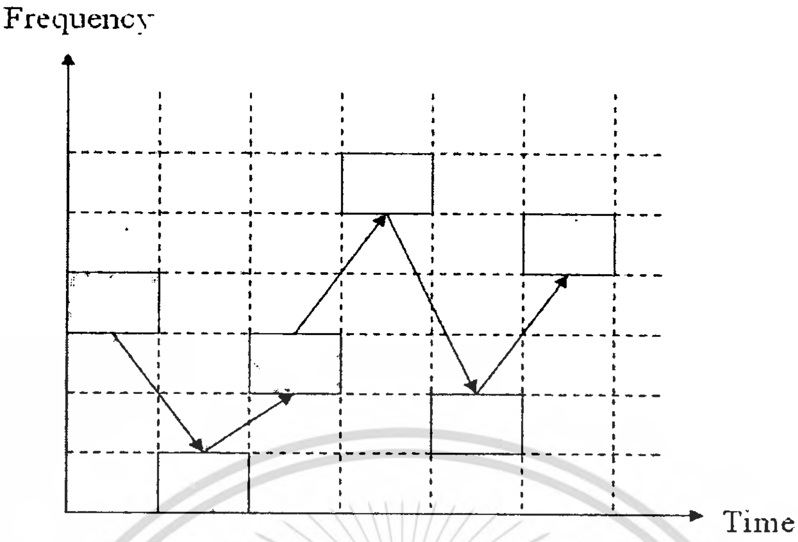

Figure 2.24 An example of a frequency hopping pattern

2.3. HANDOFF

Cellular systems depend on the radio signals received by a MU throughout the cell and on the contours of signal strength emanating from the BS of two adjacent cells *i* and *j*, as illustrated in Figure 2.25.

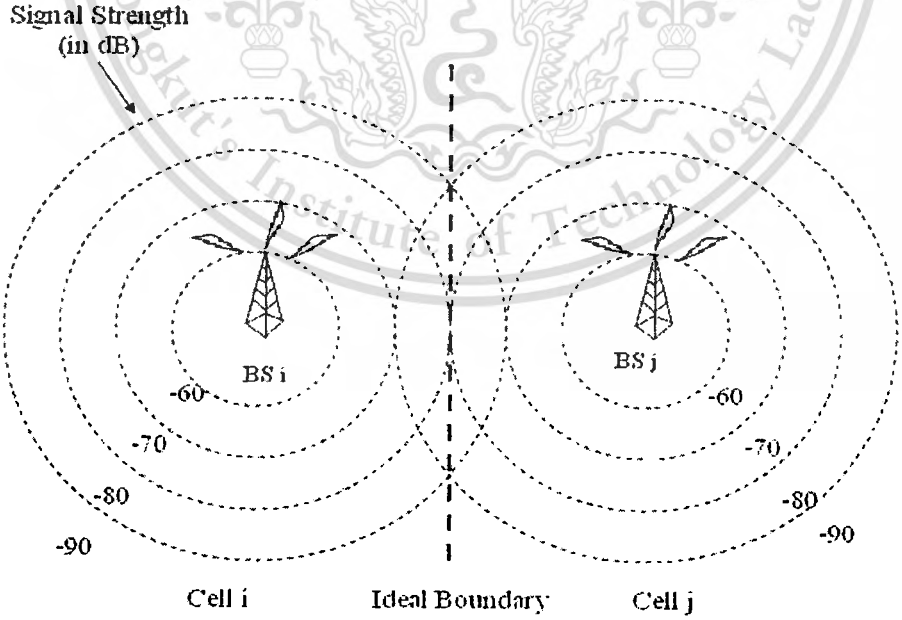

Figure 2.25 Signal strength contours around two adjacent cell *i* and *j*

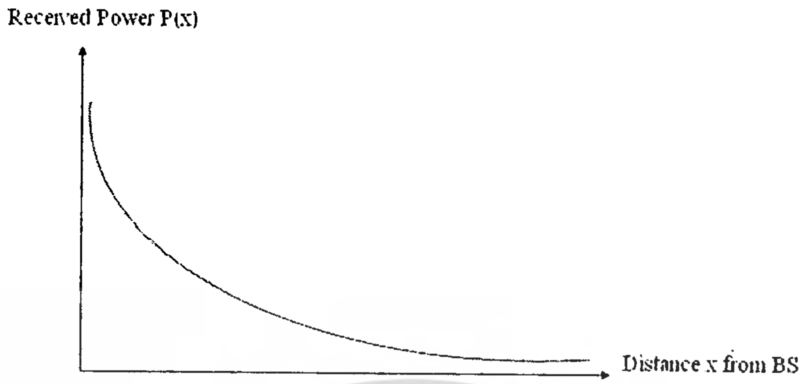

Figure 2.26 Variation of received power from a base station

It is clear that signal strength goes down as a MU moves away from the BS. The deviation of received power as a function of distance is given in Figure 2.26. As the MU moves away from the BS of the cell, the signal strength weakness, and at some point a phenomenon know as "handoff" occurs. This implies a radio connection to another adjacent cell.

Figure 2.27 shows the handoff region, as the MU moves away from cell i and get closer to cell j. Assuming that $P_i(x)$ and $P_j(x)$ represent the power received at MU from BS_i and BS_j, the received signal strength at the MU can be approximated by curves shown in Figure 2.27. At distance X_1, the received signal from BS_j is close to zero and the signal strength at the MU could be primarily attributed to BS_i. Similarly, at distance X_2, the signal from BS_i is negligible.

To receive and interpret the signals correctly at the MU, the radio received signals must be at a given minimum power level $P_{\min}$, and distance X_3 and X_4 represent two such points for BS_j and BS_i, respectively. This means that, between points X_3 and X_4, the MU can be served by either BS_i or BS_j, and the choice is left to the service provider and the underlying technology.

If the MU has a radio link with BS_i and is continuously moving away toward BS_j, then at some point it has to be connected to the BS_j radio link, and the change of such linkage from BS_i to BS_j is known as handoff. Therefore, region X_3 to X_4 indicates the handoff area. Where to perform handoff depends on many factors. One option is to do handoff at X_5, where two BSs have equal signal strength. A critical consideration is that the handoff should not take place too quickly to make the MU change BS_i and BS_j too frequently if the MU moves back and forth between the two cell areas due to underlying terrain or intentional movements.

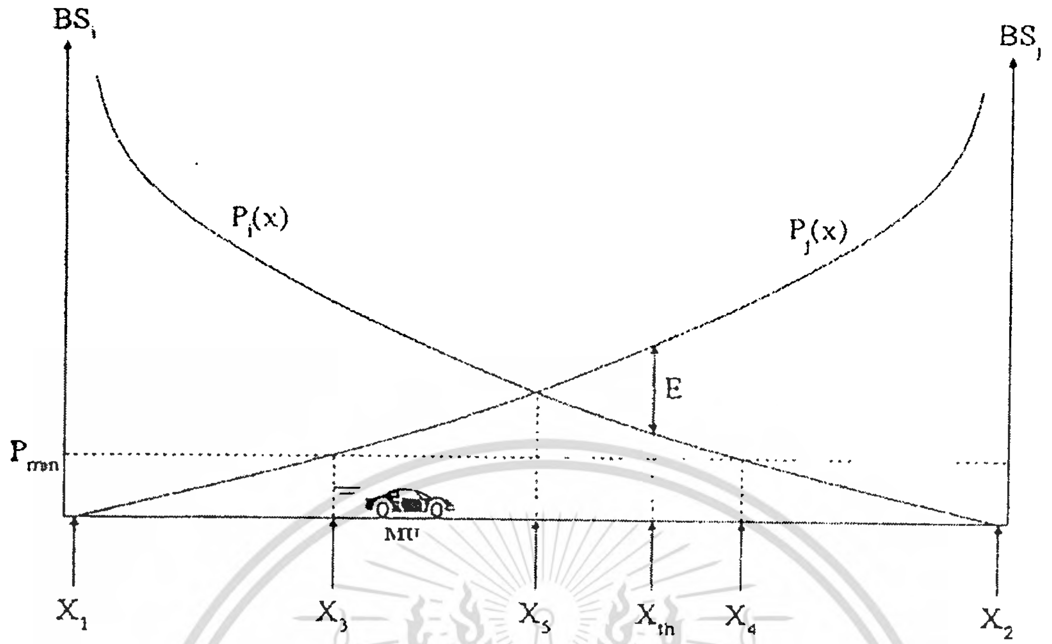

Figure 2.27 Handoff region

To avoid such a “ping pong” effect, the MU is allowed to continue maintaining a radio link with the current BS_i until the signal strength from BS_j exceeds that of BS_i by some pre-specified threshold value E as is shown by point X_{th} in Figure 2.27. Thus, besides transmitting power, the handoff also depends on the mobility of the mobile station.

The handoff schemes can be classified according to the way the new channel is setup and the method with which the call is handed off from the old BS to the new one. At call-level, there are two classes of handoff schemes, namely hard handoff and soft handoff.[1,10]

1. **Hard handoff:** In hard handoff, the link from old BS (BS_1) is broken before the link from new BS (BS_2) is established and a mobile terminal communicates at most with one BS at a time as shown in Figure 2.28. The mobile terminal changes the communication channel to the new BS with the possibility of a short interruption of the call in progress. If the old link is disconnected before the network completes the transfer, the call is forced to terminate. Thus, even if idle channels are available in the new cell, a handoff call may fail if the network response time for link transfer is too long.

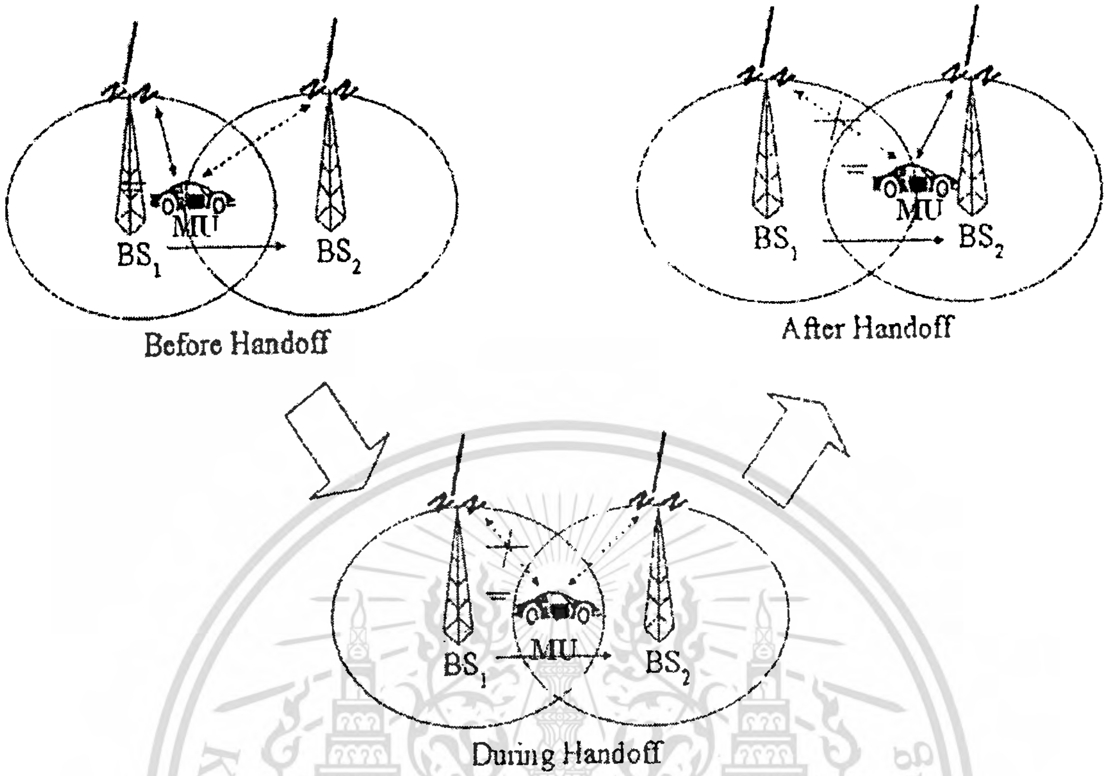

Figure 2.28 Hard handoff scheme

2. Soft handoff: In soft handoff, a mobile terminal may communicate with the network using multiple radio links through different BSs at the same time as shown in Figure 2.29. The handoff process is initiated in the overlapping area between cells some short time before the actual handoff takes place. When the new channel is successfully assigned to the mobile terminal, the old channel is released. Thus, the handoff procedure is not sensitive to link transfer time.

Soft handoff decreases call dropping at the expense of additional overhead (two busy channels for a single call) and complexity (transmitting through two channels simultaneously). Two key issues in designing soft handoff schemes are the handoff initiation time and the size of the active set of BSs the mobile is communicating with simultaneously.

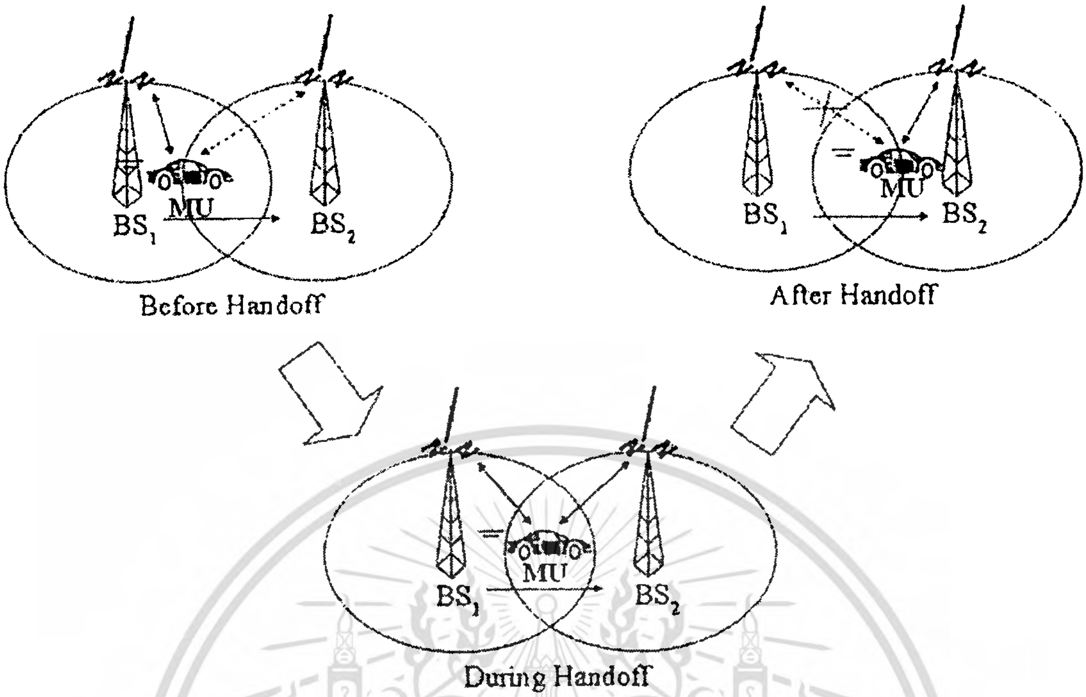

Figure 2.29 Soft handoff scheme

CHAPTER 3

CALL ADMISSION CONTROL SCHEMES

3.1. CALL ADMISSION CONTROL

There has been a rapid development and deployment in wireless cellular communications. The next generation of networks is expected to eventually carry multimedia traffic - combinations of voice, video, images, and data. One of the key issues is to ensure that the Quality of Service (QoS) requirements of different applications are guaranteed. The scarcity of wireless bandwidth, the movements of users, and the channel imperfections make QoS provisioning an extreme challenging task for wireless networks, in contrast to wired networks. The challenge is heightened further in cellular networks where an ongoing call can be dropped while being handoff to an adjacent cell if there are insufficient free channels to be supported the call.

In cellular networks, the traffic can be classified into two types of traffic:

1) **New call traffic:** This kind of traffic occurs when the user wants to communicate with another user. He has to request to a cell in order to obtain a channel if the free channel is available.

2) **Handoff call traffic:** This kind of traffic means the user that can obtain the channel in current cell and the call move into the adjacent cell. The call is transferred to the adjacent cell in order to avoid call termination when the call gets outside the range of the current cell.

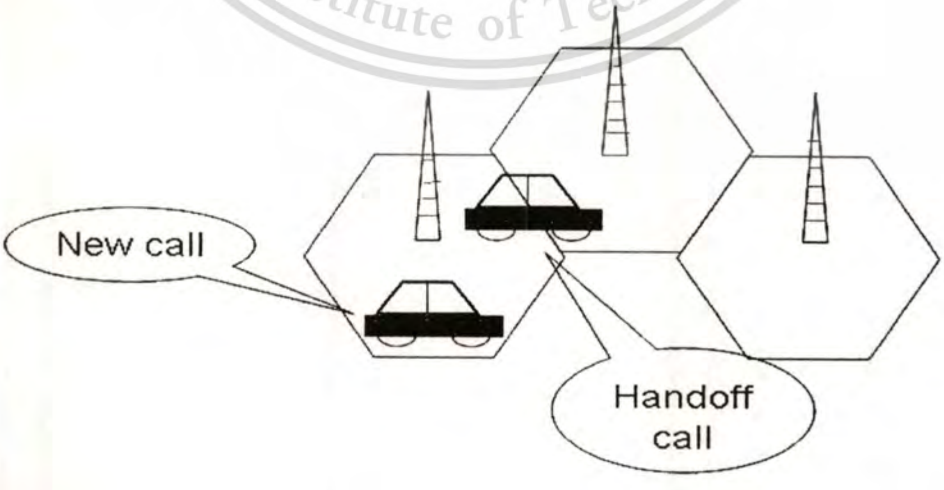

Figure 3.1 The traffic types

With cell sizes being systematically decreased to enable better frequency reuse, the capacity of the overall system increases, but the number of handoffs during a mobile unit's (MU's) lifetime also increases considerably. Therefore, it becomes increasingly critical in wireless networks to have necessary control mechanisms that meet the following two challenges.

First, dropping a call in progress is more undesirable to the users than blocking a new call. Therefore, one of the key design goals is to maintain the handoff dropping probability at pre-specified target QoS levels, independent of the traffic conditions in the system [14].

Second, in view of the increasing popularity of data services from simple short messages to General Packet Radio Service (GPRS), there also arises a need for data service to be guaranteed, and the network must satisfy the different QoS requirements of all types of traffic.

One of the new challenges in a multi-service network is that the wireless resource is shared among multiple traffic types. This can usually be done by Complete Partitioning (CP), Complete Sharing (CS), or their Hybrids [6,9].

1. Complete Partitioning (CP): The available bandwidths in cell are divided into separate sub-pools dedicated to each type of traffic. Partitioning is equivalent to logically dividing the network into smaller networks overlapping in the same geographical region, each serving a different type of traffic with different QoS bounds. If independent QoS control for different types of traffic is desired, cell capacity partitioning is required. Partitioning will result in a less complex management system which provides independent QoS controls for different traffic types at the expense of possible lower overall utilization.

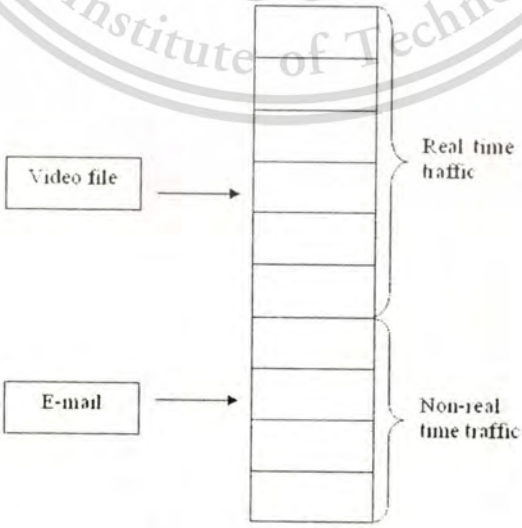

Figure 3.2 Complete Partitioning concept

2. Complete Sharing (CS): The available bandwidths in cell are not divided into separate sub-pools dedicated to each type of traffic. The base stations allow different types of calls to share the same pool of channels at all times. Complete sharing networks can obtain high bandwidth utilization at the expense of providing only single fixed QoS profile, which does not offer any guarantee for handoff traffic.

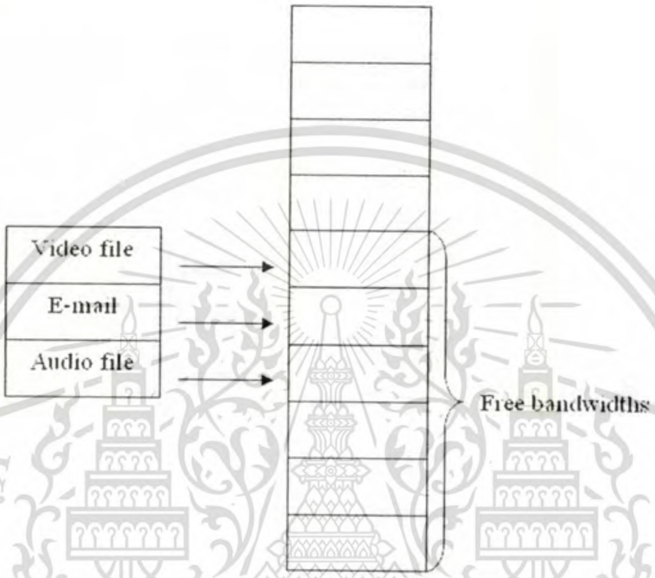

Figure 3.3 Complete Sharing concept

3. Hybrid Schemes: the base stations choose resource allocation algorithm based on network environment. Hence to maximize channel utilization, we adopt the CS approach, which allows all types of traffic to access all available channels at all times, yielding a higher efficiency in resource utilization. On the other hand, CP can provide guarantee to the respective QoS specified by each traffic type, at the expense of system utilization. The results showed that better performance can be obtained by hybrid schemes.

3.2. RESOURCE RESERVATION SCHEMES FOR CALL ADMISSION CONTROL

From the user's perspective, being unable to initiate a new call because of bandwidth constraints is undesirable. However, failing to continue an ongoing call, while moving across cells, is even more undesirable, if not unacceptable. In order to support hand-off calls, any cellular network must implement a resource reservation strategy within its call admission control (CAC) scheme. Accurate estimation of the level of resources to be reserved is therefore considered as one of the most challenging tasks in designing an efficient CAC scheme. Reserving more resources provides the potential to support more ongoing calls, which is decreasing the handoff call dropping probability (HCDP) while increasing the new call blocking probability (NCBP). On the other hand, excessively reserving resources can lead to reduced bandwidth utilization. Accurate estimation of the level of resources to be reserved is therefore considered as one of the most challenging tasks in designing an efficient CAC scheme.

Many existing resource reservation schemes are as follows:

3.2.1 GUARDED CHANNEL SCHEME (GCS)

The basic idea is to reserve a number of channels exclusively for handoff calls in each cell by introducing a threshold T in each cell, where T is an integer between 0 and the cell capacity C. So that, the control policy reserves $C-T$ channels for handoff calls as shown in Figure 3.4.

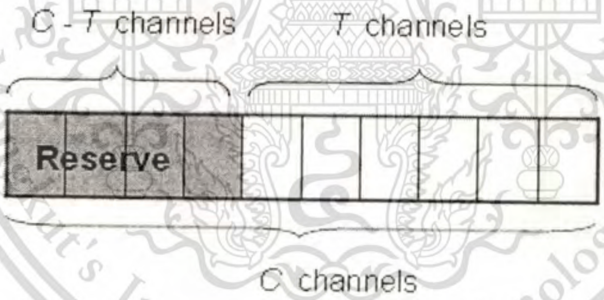

Figure 3.4 Guard Channel Concept

T channels are allocated to new call and handoff call, while $C-T$ channels are reserved only for handoff call. When a new call arrives at a cell, the system accepts the new call only if the number of ongoing calls in the cell is less than T, otherwise the call will be blocked [7,11,13]. Handoff calls will be dropped by the system only when no channels are available in the cell. In order to meet the target call dropping probability P_{QoS}, we can choose T such that the call dropping probability $P_{Drop} \leq P_{QoS}$. Although the number of reserved channels is increased for handoff will lower the P_{Drop}, but causing the new call blocking probability to rise. The use of fixed number of guard channels can lead to waste or lack the guard channels.

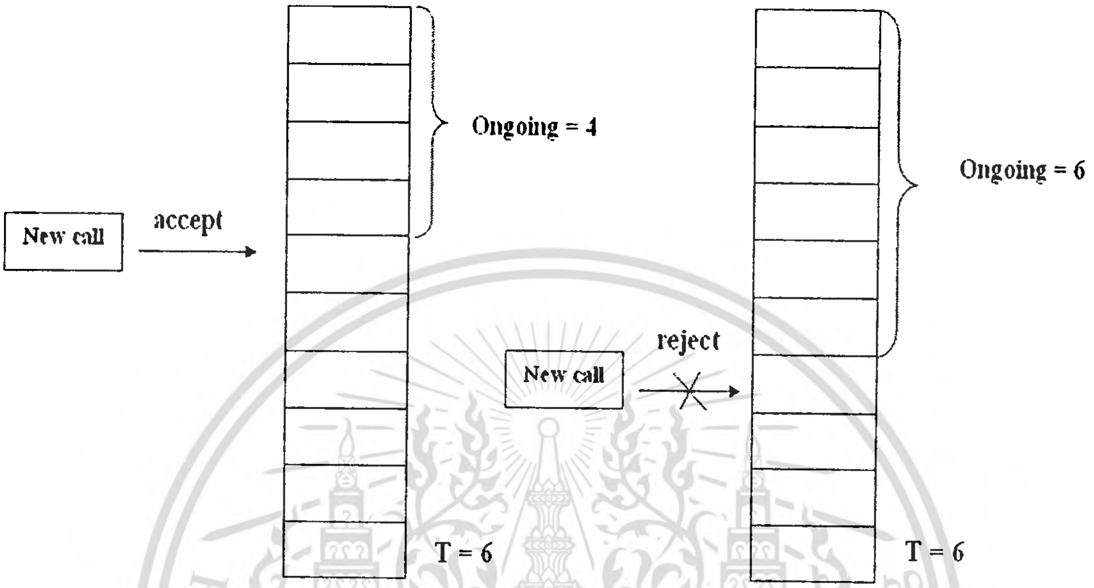

Figure 3.5 Guard Channel Algorithm

3.2.2. FRACTIONAL GUARDED CHANNEL SCHEME (FGCS)

R. Ramjee, D. Towsley, and R. Nagarajan [7,13] proposed Fractional Guarded Channel (FGC) policy. The FGC policy can reserve a non-integral number of guarded channels for handoff calls. The basic idea is to allow the value of the threshold to be a real number, which has an integer part T , and a fractional part α. When a new call arrives at a cell, the system accepts the new call only if the number of ongoing calls in the cell is less than T, but the call will be blocked if the number of ongoing calls in the cell is more than T. In addition to, the number of ongoing calls in the cell is equal to T, new arrival calls will be accepted with probability α. The value of the threshold $T+\alpha$ can be obtained by bisection method with the constraint $P_{Drop} = P_{QoS}$.

In FGC scheme, if the fractional part of the threshold is greater, probability of new call which can use guard channel is higher. This causes effect to increase HCDP. Therefore, the fixed threshold can lead to increase the HCDP or NCBP.

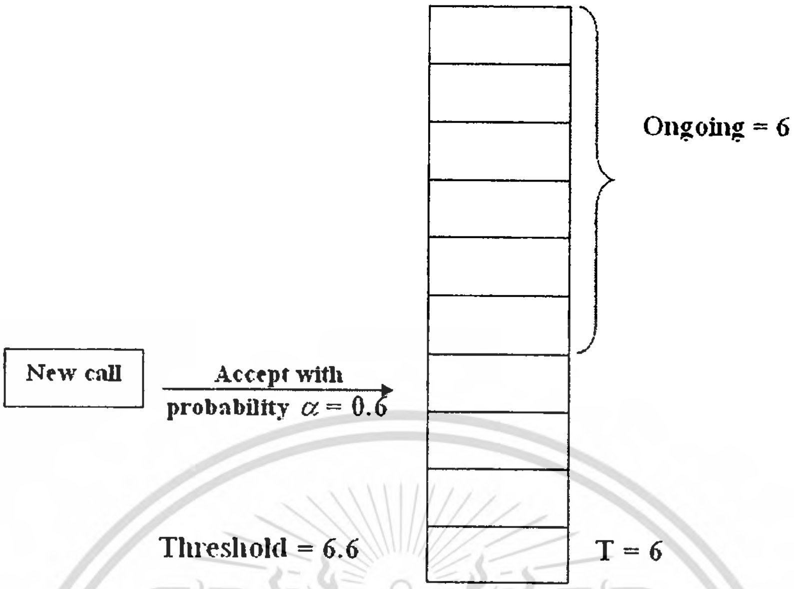

Figure 3.6 Fractional Guard Channel Algorithm

3.2.3. DYNAMIC GUARD CHANNEL SCHEME (DGCS)

The use of guard channels for handoff calls needs a proper compromise between system performance and channel reuse efficiency. In fact, any channel reserved for handoff calls contributes in decreasing the effectiveness of channel reuse plan. Even we can carefully choose a proper number of guard channels, the use of fixed number of guard channels can lead to waste or lack the guard channels. The reason is that the handoff traffic which depends on the mobility of users is not always stationary. For example, the mobility of users may be higher in the countryside than that in the downtown because the traffic is slighter there. In addition to location, time is another factor that effects to the mobility of users. The mobility of a user may be lower when in a traffic jam. In order to achieve better utilization of guard channels, we suggest assigning the number of guard channels in a cell dynamically according to the number of the calls which may enter this cell. When a call (new or handoff) arrives or leaves a cell, the corresponding base station informs its neighbor base stations. A base station decides the number of guard channels according to the number of ongoing calls in its neighbor cells which can handoff to this cell [7,11,13]. However, in the congestion connection, the message from the neighbor base station can lead to waste the channel.

3.2.4. LINEAR WEIGHTING SCHEME (LWS)

The linear weighting scheme [12] uses the mean number of calls underway in all cells within a maximum number of hops D from the originating cell in determining the admission (i.e., the region of awareness contains all cells within D hops from C_0).

Let $N_h (N_h \geq 0)$ be the number of channels reserved specifically for call handoffs, let S be the set containing all cells in the region of awareness, and let $N - N_h$ be the threshold. New calls are only admitted to the originating cell 0 if

$$\frac{1}{|S|} \sum_{i,i \in S} N_i < N - N_h \qquad (3.1)$$

Note that the linear weighting scheme reduces to the reservation scheme when $D = 0$.

3.2.5. DISTRIBUTED ADMISSION CONTROL SCHEME (DACS)

The distributed admission control scheme [12] takes into consideration the number of ongoing calls in the originating cell and its adjacent cells in making the admission decision. Let P_{QoS} be the user-declared QoS, and the overload probability be the probability that a call is terminated during a handoff at any given time. In both one-dimensional and two-dimensional systems, a new call is admitted at time t_0 only when the following conditions are met:

Condition 1: At time $t_0 + T$, the overload probability of cell C_0 must be smaller than P_{QoS}.

Condition 2: At time $t_0 + T$, the overload probability of each cell adjacent to the originating cell must be smaller than P_{QoS}.

For some arbitrary value of T must be determined experimentally. The first condition is intended to maintain the desired P_{QoS} of calls that are underway in the system, and the second admission condition is intended to provide the desired P_{QoS} of the new call.

3.2.6. WEIGHTED SUM SCHEME (WSS)

The weighted sum scheme [12] uses the weighted sum of the number of ongoing calls in the originating cell and in other cells in determining the admission. Let n_i be the mean number of calls underway in cells that are distance i from the originating cell, and p_i be the weighting

($\sum_{i=0}^{\infty} p_i = 1$, $p_i \geq 0$ for $\forall i$). Let the admission threshold be $N - N_h$. New calls are admitted only when there is at least one channel available in a cell and

$$\sum_{i=0}^{\infty} p_i n_i < N - N_h \tag{3.2}$$

The optimal weights p_i can be determined experimentally. Note that the weighted sum scheme reduces to the linear weighting scheme when

$$p_i = \begin{cases} (1/|S|) & , i \leq D \\ 0 & , i > D \end{cases} \tag{3.3}$$

3.2.7. DUAL THRESHOLD CALL ADMISSION CONTROL SCHEME (DT-CAC)

Tat-Chung Chau et al [8] proposed *Dual-Threshold Call Admission Control* (DT-CAC) policy. Both voice and data traffic are considered, where the data traffic refers to all information encoded as data streams which consume more bandwidth than the voice traffic. The proposed DT-CAC policy builds upon the FGC scheme used in a voice-only cellular network. As proposed by Ramjee et al, the FGC scheme provides accurate guarantees for target QoS, such as the handoff dropping probability. The idea is to allow the value of the threshold to be a real number which has an integer part T and a fractional part α. When there are less than T calls in the cell, the system will accept all calls. When there are more than T calls, only handoff calls will be allowed. When there are T calls, new arrival calls will be accepted with probability α.

The set of thresholds T_v and T_d is determined based on minimizing the maximal new call blocking probability, $\min_{T_v, T_d} \max(P_{bv}, P_{bd})$, while satisfying the hard constraints on the handoff dropping probabilities for both voice and data traffic. They consider control policies which can take four possible actions on new calls, depending on the state location in this triangular region: (a) accepting both voice and data new calls; (b) accepting only voice new calls; (c) accepting only data new calls; (d) rejecting both voice and data new calls.

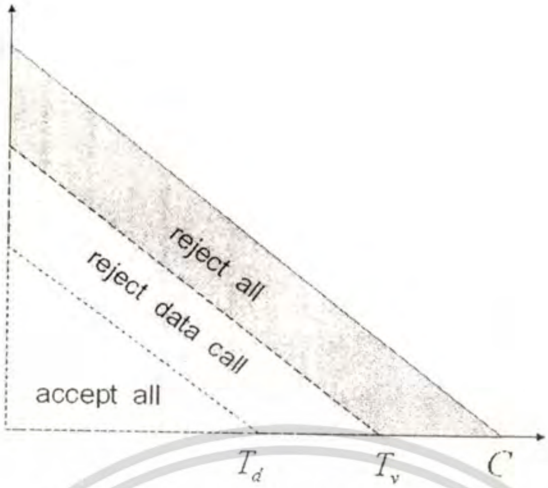

Figure 3.7 Dual Threshold Call Admission Control Scheme

3.2.8. SHADOW CLUSTER SCHEME

The fundamental idea of the shadow cluster scheme [15] is that every mobile with an active wireless connection establishes an influence upon the cells (and their base stations) in the vicinity of its current location and its direction of travel. As an active mobile travels and handoffs to other cells, the region of influence also moves, following the active mobile to its new location. The base stations (and their cells) currently being influence are said to conform a shadow cluster, because the region of influence follows the movements of the active mobile like a shadow, as shown in Figure 3.8.

The shadow cluster (and therefore the level of influence) is strongest near the active mobile, and fades away as a function of factors such as the distance to the mobile, current call holding time and priority, bandwidth resources being used, and the mobile's current trajectory and velocity. Because of these factors, the shape of a shadow cluster is usually not circular and can change over time. The center of a shadow cluster is not the geometric center of the area described by the shadow, but the cell where the mobile is currently located. This cell is referred as the mobile's current cell. A bordered neighboring cell is a cell that shares a common border with the shadow cluster's center cell. In contrast, a non-bordered neighboring cell, although being a part of shadow cluster, does not share a border with the shadow cluster's center cell.

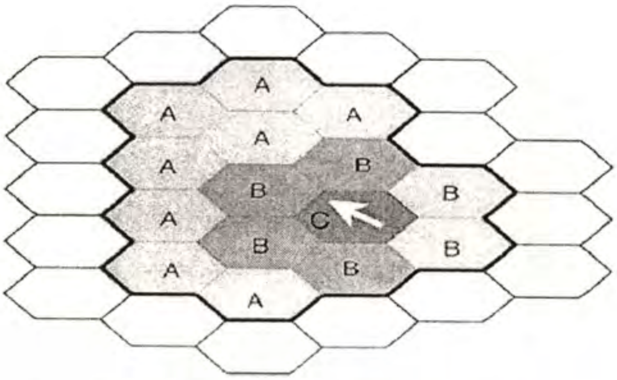

Figure 3.8 Shadow cluster of active mobile unit

A: non-bordered neighboring, B: bordered neighboring, and C: current cell

From above definition, the amount and "darkness" of the shadows that cover a cell (as shown in Figure 3.8) reflect the amount of resources that the cell's base station needs to support the active mobiles currently in its own and in neighbor cell. With this information, the base stations can determine, on an individual basis, if new call requests can be supported by the wireless network. In practice, a shadow cluster is a virtual message system where a base station informs its neighbors about the probability that its active mobile will move to their neighbor cells in the future. With this information, neighbor base stations project future demands and reserve resources by denying network access to new call requests, and by waiting for active mobiles to end their calls.

When an active mobile hands off to another cell, the shadow cluster moves. After a handoff, all of the base stations within the old shadow cluster must be notified about this movement, and the mobile's new current base station has to assume the responsibility of supplying the appropriate information to the base station within the new shadow cluster. The base stations that were in an old shadow cluster but that are not in a new one must delete any entries corresponding to the active mobile establishing the shadow cluster, and free reserved resources if appropriate. The base stations that enter into a shadow cluster that has recently moved must be given appropriate information on the shadow cluster's active mobile, such as the respective QoS requirements, e.g., bandwidth demands, and any other useful information, e.g., the wireless connection's elapsed time, for the new shadow cluster.

From this concept, the bandwidth is reserved only in a cell which has higher probability of MU's migrating to that cell. It can prevent the unnecessary resource reservation while reduce

HCDP. This idea was extended further in the schemes such as Predictive Mobility Support (PMS), On-Demand Borrowing (ODB), and Mobility Support On-Demand Borrowing (MSODB).

3.3. RESOURCE RESERVATION SCHEMES FOR CALL ADMISSION CONTROL BASED ON SHADOW CLUSTER

3.3.1. PREDICTIVE MOBILITY SUPPORT (PMS)

Aljadhai and Znati [14] present "Predictive Mobility Support (PMS)", which efficiently integrates mobility prediction and CAC, to provide support for predictive timed-QoS guarantees, where each call is guaranteed its QoS requirements for the time interval that the MU is expected to spend within each cell it is likely to visit during the lifetime of the call.

In this scheme, efficient support of predictive timed-QoS guarantees is achieved based on an accurate estimate of MU's trajectory as well as the arrival and departure times for each cell along the path is required. Using these estimates, the network can determine if enough resources are available in each cell along the MU's path to support the QoS requirements of the call.

At any point in time t, the directional probability of any cell being visited next by a MU can be derived based on the current cell, where the mobile resides, and the estimated direction $\tilde{D}_t$ of the mobile unit at time t. More specifically, consider a MU currently residing at cell i coming from cell m and let j , $j = 1, 2, \dots$ represent a set of adjacent cells to cell i. Each cell j is situated at an angle ω_{ij} from the horizontal axis passing by the center of cell i, as depicted in Figure 3.9. Furthermore, define the *directional path* from i to j as the direct path from the center of cell i to the center of cell j. Based on the directional path, the *directionality* D_{ij} for a given cell can be expressed as

$$D_{ij} = \begin{cases} \dfrac{\theta_{ij}}{\phi_{ij}} & , \phi_{ij} > 0 \\ \theta_{ij} & , \phi_{ij} = 0 \end{cases} \tag{3.4}$$

Where ϕ_{ij} is an integer representing the deviation angle between the straight path to destination and the directional path from i to j, while θ_{ij} represents the angle between the directional path from m to i and the directional path from i to j.

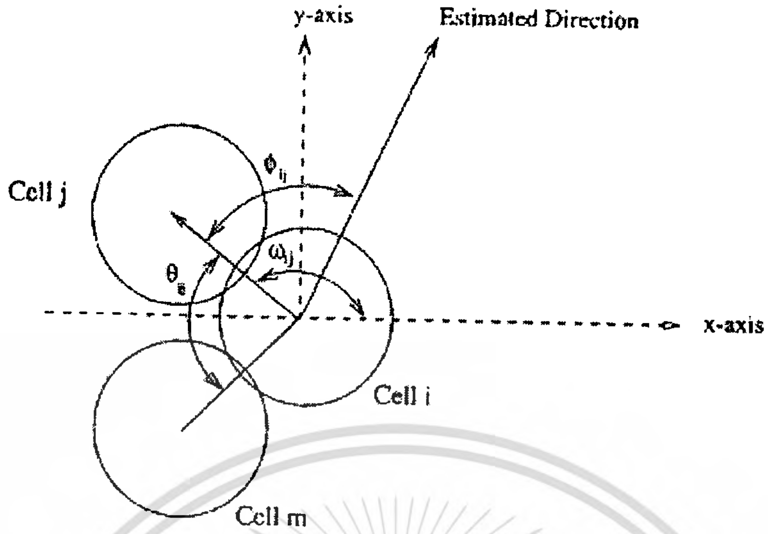

Figure 3.9 Parameters used to calculate the directional probability

Based on its directionality D_{ij}, the directional probability $P_{i\to j}$ of cell j being visited next by a MU currently at cell i can be expressed as follows:

$$P_{i\to j}=\frac{D_{ij}}{\sum_k D_{ik}} \tag{3.5}$$

Where k is a cell at the same *ring* as j with respect to i.

Define the forward span as the set of cells situated within an angle δ_i with respect to the estimated direction $\tilde{D}_i$ of the MU. After determining the forward span, the next step in the process of forming the shadow cluster is to decide on the size of the shadow cluster window size. The shadow cluster window is defined as the number of adjacent rings of cells to be included in the shadow cluster. If the MU moves along the predicted direction, the shadow cluster window size is increased for supporting the required QoS by including more rings.

For each shadow cluster cell, the time of arrival and residence time of the MU can be estimated. The cell residence time within cell j for a MU currently in cell i is characterized by three parameters: expected earliest arrival time $(T_{EA}(i,j))$, expected latest arrival time $(T_{LA}(i,j))$, and expected latest departure time $(T_{LD}(i,j))$. Consequently, $[T_{EA}(i,j),T_{LD}(i,j)]$ is the expected residence time of the MU within cell j. This interval is referred to as the resource reservation interval (RRI), while the interval $[T_{EA}(i,j), T_{LA}(i,j)]$ is referred to as the resource leasing interval (RLI). Resources are reserved for the entire duration of RRI. However, if the MU does not arrive to cell before RLI expires, all resources are released and the reservation is canceled. This is necessary to prevent MUs from holding resources unnecessarily.

Based on the requested service guarantees, a call is accepted if the required bandwidth is allocated in the current cell and $\gamma\%$ bandwidth is reserved in the $\tau\%$ of the shadow cluster cells. Let B_u be the bandwidth capacity required by MU u. The MU can receive a service from a cell if the cell can provide $\gamma \cdot B_u$ units of bandwidth for the time duration RRI, where the MU is expected to reside in that cell. Each cell in the shadow cluster uses the reservation request to decide whether the request can be accepted or rejected send to the original cell i.

When originating cell accepts the call i, it sends a message to all cells that are able to reserve bandwidth, indicating that the reservation must now be performed. Every cell reserves the required bandwidth for the RRI duration and updates its available bandwidth accordingly. However, that cell j cancels the reservation if the MU does not arrive prior to the expiration of the RLI.

Due to the changing behavior of the MUs in a cellular network, calls may handoff to cells that are not part of their shadow cluster and calls may not arrive within RLIs. Therefore, PMS defines the status of a call to be either *prediction conforming* or *prediction nonconforming*. When a call is accepted to the network, it is said to be prediction conforming as long as it visits cells that belong to its shadow cluster and resides within each cell for the RRI period. A call arrives to a cell earlier than its earliest arrival time or to a cell that is not part of its shadow cluster, is considered prediction nonconforming. The CAC gives higher priority to prediction conforming calls over prediction nonconforming calls. A prediction nonconforming call is dropped when a prediction conforming call arrives and cannot be accommodated by the available bandwidth. When more than one prediction nonconforming call exists within a cell, different policies can be used to decide which call is to be dropped. For instance, the lifetime of a call, bandwidth requirements, or call priorities can be used to implement different dropping policies.

The basic step of the CAC algorithm used to verify the feasibility of accepting new calls and handoff calls are presented in Figure 3.10 and 3.11.

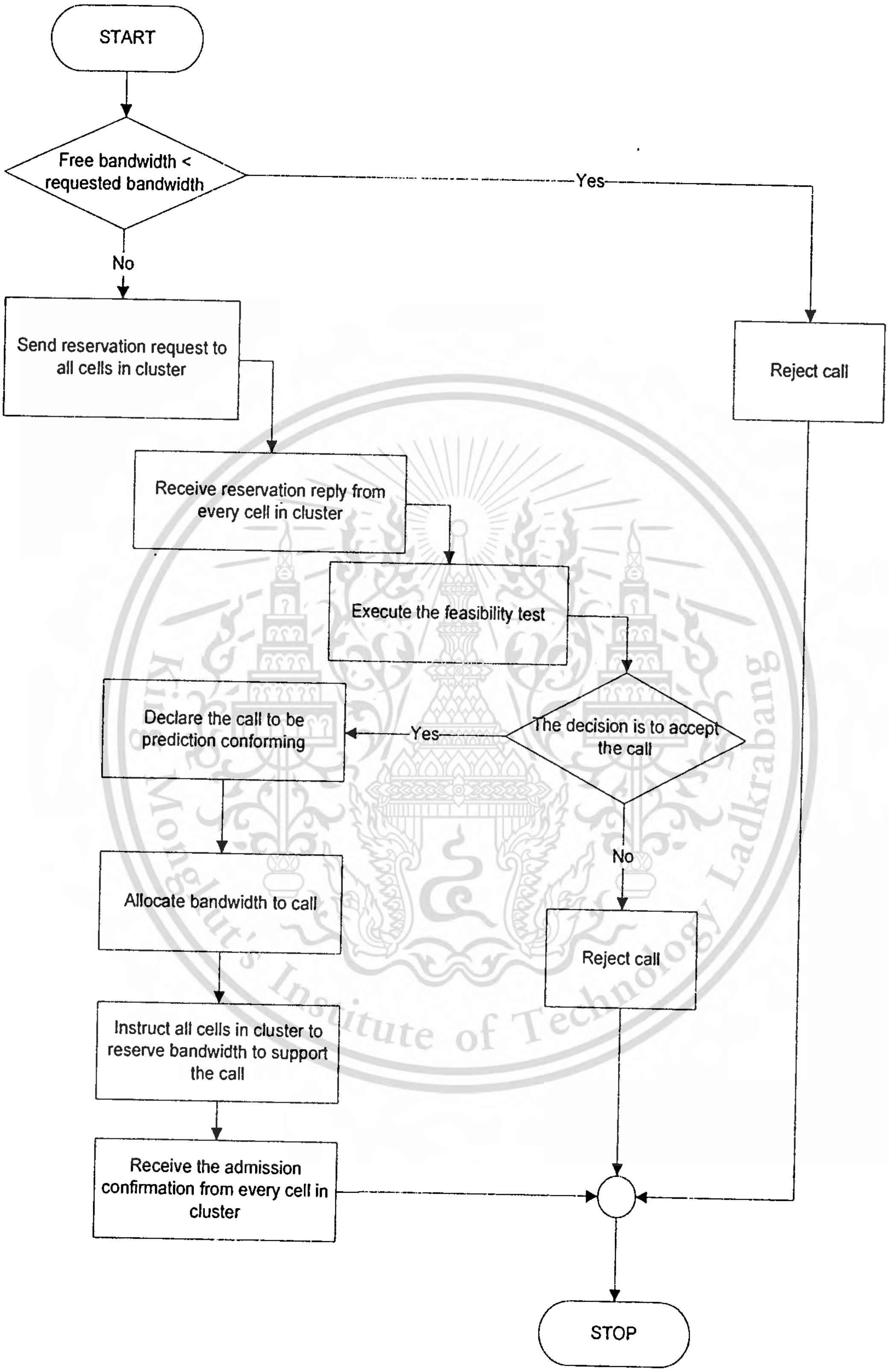

Figure 3.10 CAC algorithm of PMS scheme for new calls

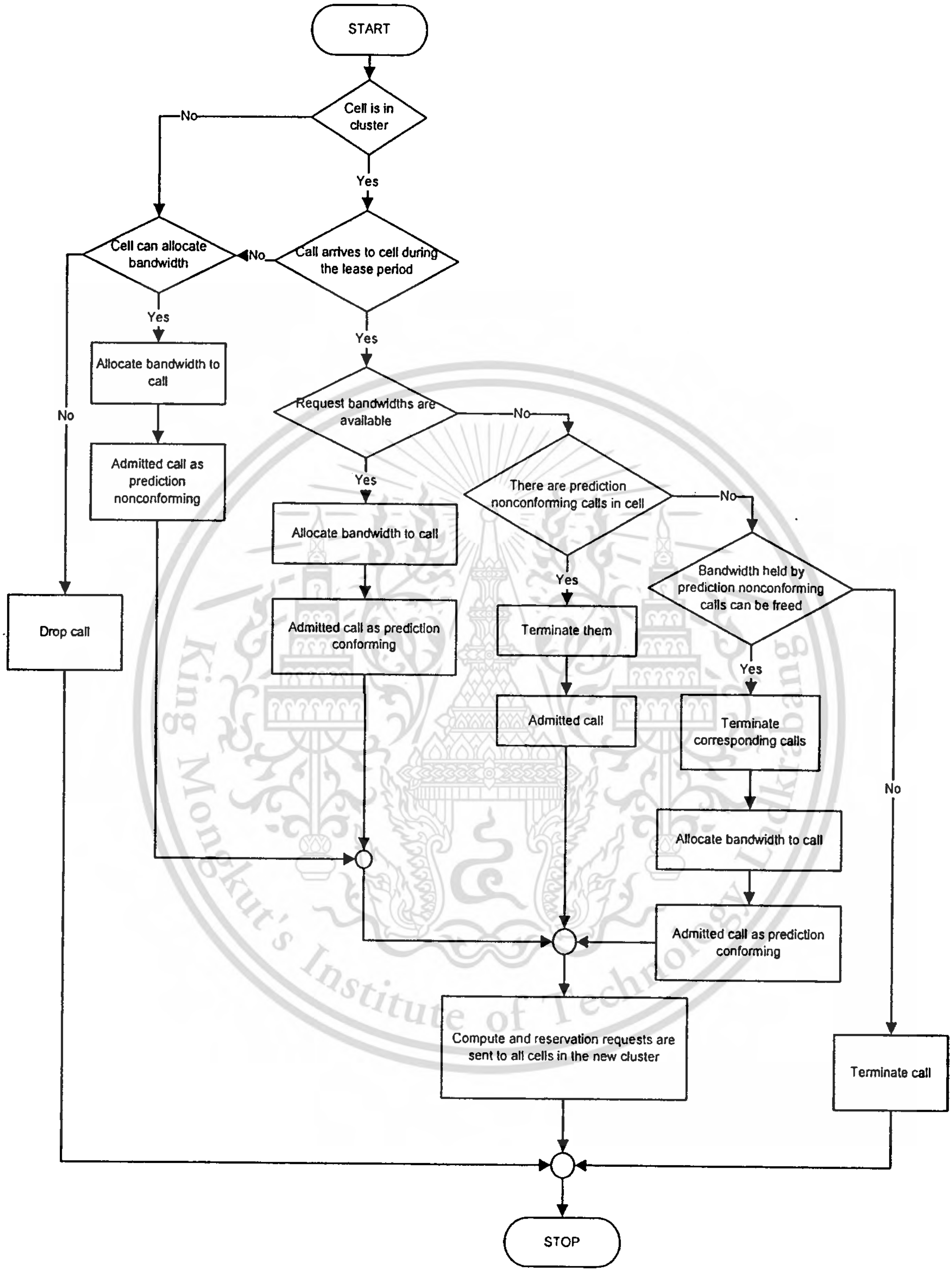

Figure 3.11 CAC algorithm of PMS scheme for handoff calls

However, the PMS scheme is also restrictive for the following reasons. Firstly, PMS considers only the direction from the centers of the cells, and does not take other parameters such as position and speed into account. In the PMS scheme the direction probability of all the neighboring cells whose centers lie on along the same line as that of the current cell are equal for different positions of the cells which have the same shadow cluster. Secondly, directional probability is not calculated if the MU has not encountered handoff, since PMS scheme calculates directional probability from previous cell direction and estimated direction at the handoff.

3.3.2. ON-DEMAND BORROWING (ODB)

M. Mahfuzul Islam and Manzur Murshed [17] propose a mobility based bandwidth reservation scheme, called On-Demand Borrowing (ODB). The main concept is that bandwidth is reserved in a cell only if the MU has a higher probability of arriving in that cell, based on some quantifiable mobility parameters. If however a MU arrives in a cell where there is no bandwidth currently reserved, then bandwidth is borrowed from the existing rate-adaptive calls.

Adaptive rate describes whether a call is either flexible in its bandwidth requirements or not. If a call is adaptive, then its service quality may be degraded while network traffic is heavy. Conversely, rate non-adaptive call will be either continued with full quality or disconnected. So that, in this research, calls are divided into two priority classes based on adaptive rate — class I and class II. If a class I call comes into a cell with insufficient bandwidth, some class II calls should be terminated, if necessary, for making space. Class II calls do not receive any special consideration. The Resource Reservation estimator function is based on the following two keys observations:

1. The base station in the direction of a MU's mobility will have a higher probability with respect to receiving a handoff from this MU. This probability decreases as the angle of the base station from the direction of the MU increases. When the angle is 90° or higher, the probability is almost zero (Figure 3.12).

2. The smaller the estimated time for a MU to move into a particular cell, the higher the probability for that MU to be handed-off at that cell. The estimated time is calculated as the ratio of the distance of a MU from the base station and the velocity of the MU in that particular direction. This means for a stationary MU the bandwidth will only be allocated in the current cell, with no reservation made in neighbor cells. For a moving MU, the probability decreases as the distance between the MU and the base station increases, as shown in Figure 3.12.

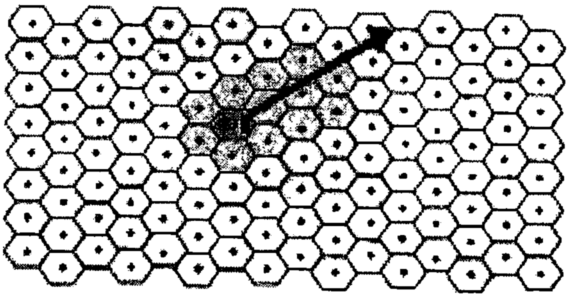

Figure 3.12 Shadow cluster from ODB scheme

The estimator function for reserving bandwidth incorporates three mobility parameters (distance, direction, and velocity). Based on these parameters, a probability P_m of an MU visiting a particular cell, is defined as Equation (3.6).

$$P_m = \left(\frac{1}{T}\right) v \cos\delta = \frac{v^2 \cos\delta}{d} \tag{3.6}$$

Where d is the distance from the MU to base station, v is the speed of the MU, and δ is the angle of the base station from the direction of the MU. Figure 3.13 explains the relevance of angle δ, where BA is the direction of mobility and C is the base station under consideration for bandwidth reservation for the MU currently residing in cell B.

Fig. 3.13 Definition of δ

The reservation probability function P_r can be calculated from P_m as defined in Equation (3.7)

$$P_r = \begin{cases} 1 & , \mathit{if}\ P_m \geq \chi\ ; \\ P_m & , \mathit{if}\ \eta \leq P_m < \chi\ ; \\ 0 & , \mathit{Otherwise}. \end{cases} \tag{3.7}$$

If probability P_m is greater than or equal to a threshold χ (say 0.8), the reservation probability becomes 1, that is the bandwidth is reserved in the cell. If P_m is higher than or equal to η (say 0.2), but smaller than χ, then bandwidth is reserved in the cell with probability P_m and if the value of P_m is less than η, then no bandwidth is reserved in the cell.

For reservation of bandwidth at a particular cell, the ODB scheme calculates the reservation probability, P_r and free bandwidth in that cell. If sufficient bandwidth is available to be reserved for the requested call, the reservation is permitted with probability P_r. However, if there is insufficient bandwidth, then the remaining available free bandwidth is reserved, provided $P_r > 0$.

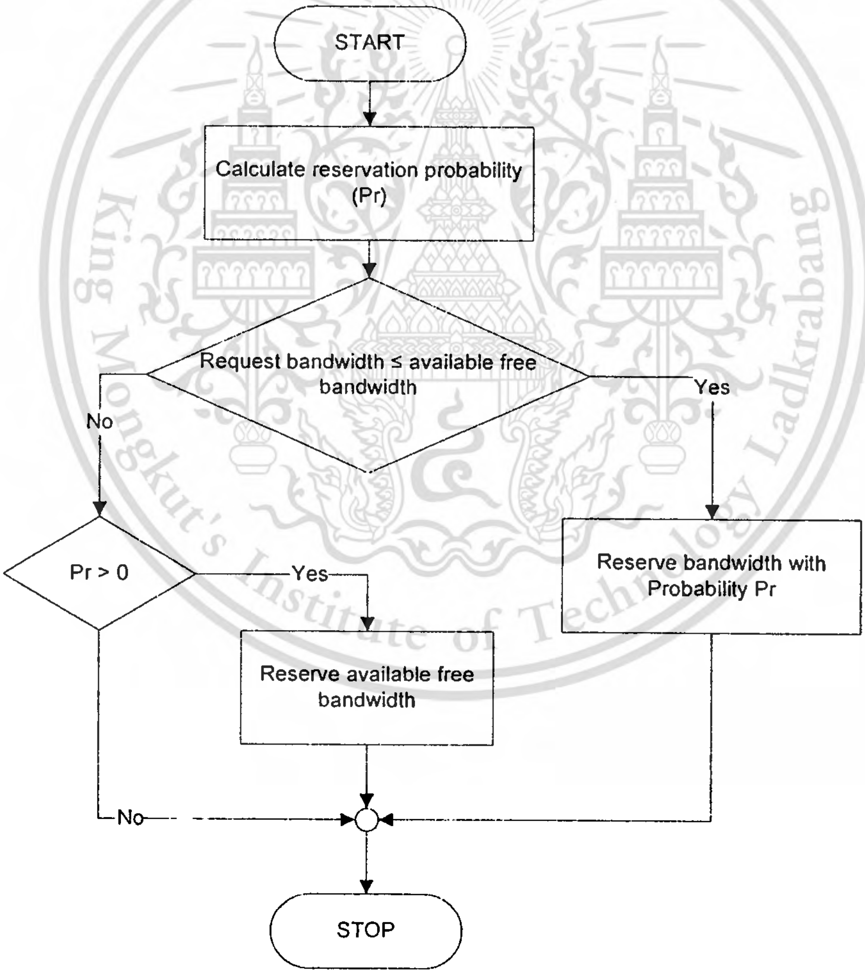

Figure 3.14 Resource Reservation Algorithm of ODB scheme

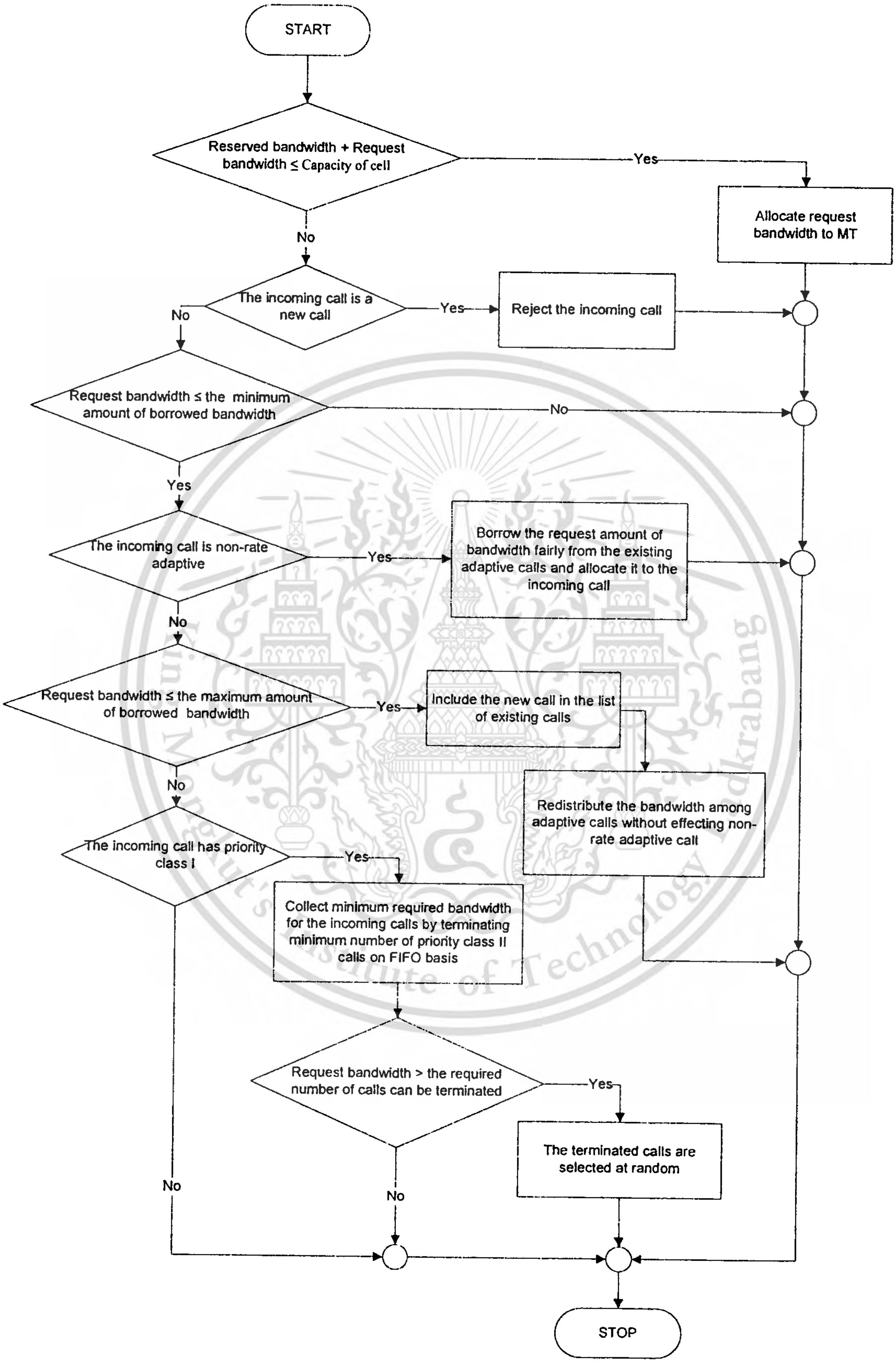

Figure 3.15 Resource Allocation Algorithm of ODB scheme

The various steps in the proposed algorithm for reserving bandwidth in different neighbor cells are presented in Figure 3.14.

The bandwidth allocation algorithm to new calls or handoff calls coming from neighbor cells, for both types of calls, if sufficient bandwidth is available to accommodate the call, then the call is accepted. However, new calls are rejected immediately if there is insufficient bandwidth available. For handoff calls, an attempt is made to borrow bandwidth from existing rate-adaptive calls to accommodate them. If however, the maximum allowable borrowed bandwidth is insufficient to accommodate the call, then priority class II calls are dropped, while priority class I handoff calls are sustained, by terminating long aged priority class II calls, as detailed in Figure 3.15.

However, the ODB scheme is also restrictive for the following reasons. When a call is accepted to the network, each cell in its shadow cluster will reserve bandwidth in all MU's life time because reservation time window is not created in ODB scheme. As the results, when a call may arrive to a cell that is not a part of its shadow cluster, it may be dropped because bandwidths are not reserved for it while the available bandwidths in this cell are reserved for other calls.

3.3.3. MOBILITY SUPPORT ON-DEMAND BORROWING (MSODB)

M. Mahfuzul Islam and Manzur Murshed [18] extend the ODB scheme further to propose the mobility support on-demand borrowing (MSODB) scheme. The MSODB scheme calculates cell visiting probability (CVP) normalized over a ring of cells similar to PMS. However, unlike the ODB scheme, the MSODB scheme, in its resource allocation decisions, also calculates CVP and reservation time window (RTW) by incorporating the expected travel distance (ETD) in order to take into account the reserved resources and available bandwidth information for all of the cells in the shadow cluster.

Let v_x be the average speed of x, $\tilde{D}_{i,j}$ be expected travel distance, and $\delta_{x,j}$ be the directional angle between the direction of x and a line joining the centre of cell j with the position of x, as shown in Figure 3.16.

The basic properties of the CVP are as follows:

1. The CVP is a maximum for those cells that lie in the direction of mobility. It decreases as $\delta_{x,j}$ increases, and equals zero when the directional angle more than or equal $\pi/2$.

2. The CVP is higher if the MU is moving faster, while it is zero for a stationary MU.

3. The CVP is inversely proportional to the average time to reach the centre of cell j.

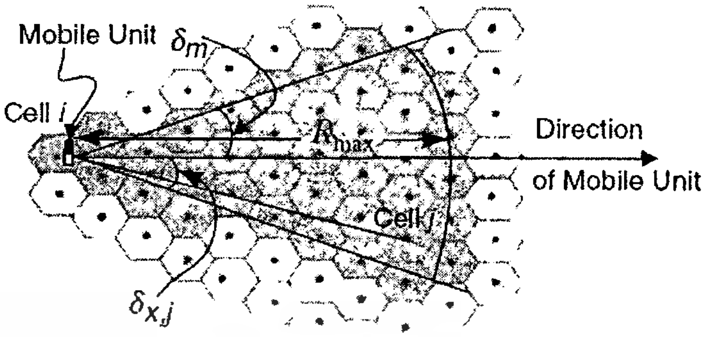

Figure 3.16 Definition of $\delta_{x,j}$ and formation of shadow cluster

From the basic properties, the CVP ($P_{x,j}$) can be calculated from Equation (3.8).

$$P_{x,j} = \begin{cases} \dfrac{\dfrac{v_x^2 \cos \delta_{x,j}}{\tilde{D}_{i,j}}}{\displaystyle\sum_{k \in R_{i,n} | j \in R_{i,n}} \dfrac{v_x^2 \cos \delta_{x,j}}{\tilde{D}_{i,j}}} & if \;\; \delta_{x,j} \le \pi/2 \\ 0 & Otherwise. \end{cases} \tag{3.8}$$

Here the summation is over the cells k that are in the same ring as j.

Based on the calculated CVPs, we define the shadow cluster for an active x (currently in cell i) to include all neighbor cells j such that $P_{x,j} \ge \psi$, where ψ is a shadow probability threshold, which can be set in a cellular network to achieve handoff call dropping probability under a predefined value.

The MSODB scheme considers ETD and its standard deviation to estimate the RTW of a MU in each cell of the shadow cluster, in terms of the expected earliest arrival time $\tilde{T}_{i,j}^{EA}(x)$, the expected latest arrival time $\tilde{T}_{i,j}^{LA}(x)$ and the latest departure time $\tilde{T}_{i,j}^{LD}(x)$. So that the time (after the present) when x arrives in cell j from cell i can be calculated by dividing the minimum ETD ($\tilde{D}_{i,j}^{\min}$) by v_x and the maximum ETD ($\tilde{D}_{i,j}^{\max}$) by v_x, respectively, as shown in Equation (3.9):

$$\tilde{T}_{i,j}^{EA}(x) = \frac{\tilde{D}_{i,j}^{\min}}{v_x} \qquad \text{and} \qquad \tilde{T}_{i,j}^{LA}(x) = \frac{\tilde{D}_{i,j}^{\max}}{v_x} \tag{3.9}$$

$\tilde{T}_{i,j}^{EA}(x)$ defines the lower end of RTW. While $\tilde{T}_{i,j}^{I,D}(x)$ is the higher end of RTW and it can be found by adding the maximum of the expected cell residence time (CRT) to $\tilde{T}_{i,j}^{I,A}(x)$. The CRT can be calculated by dividing the maximum trajectory of the cell ($2R_j$) by v_x where R_j is the radius of cell j. The details of calculating $\tilde{T}_{i,j}^{I,D}(x)$ are given in Equation (3.10).

$$T_{i,j}^{I,D}(x) = T_{i,j}^{I,A} + \frac{2R_j}{v_x}\ , \tag{3.10}$$

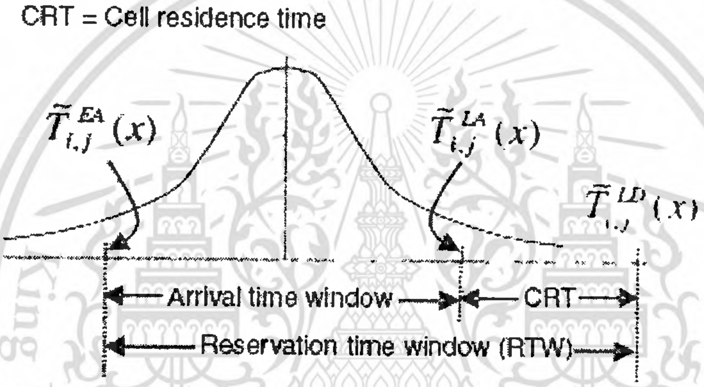

Figure 3.17 Definition of RTW

Therefore, for a given time t, where $\tilde{T}_{i,j}^{EA} \le t \le \tilde{T}_{i,j}^{I,D}$, the amount of resources reserved for a service y ($R_{y,j}$) is as follows:

$$R_{y,j} = P_{x,j} B_{\max}^{y} \tag{3.11}$$

Where $B_{\max}^{y}$ is the maximum bandwidth required for service y. The network is assumed capable of handling both classes: Class I (CI) – real-time and Class II (CII) – non-real time traffic. Because CII is fully elastic and has non-real time behavior, a CII service is accepted if any bandwidth greater than zero can be allocated to it. The expected bandwidth $B_{\exp}^{y}$ is calculated from the maximum bandwidth required ($B_{\max}^{y}$) and the minimum bandwidth required ($B_{\min}^{y}$), based on a maximum difference between $B_{\max}^{y}$ and $B_{\min}^{y}$, when setting their elasticity limits as shown in Equation (3.12).

$$B^{y}_{\exp} = B^{y}_{\max} - \frac{(B^{y}_{\max} - B^{y}_{\min})^2}{B^{y}_{\max}} = 2B^{y}_{\min} - \frac{(B^{y}_{\min})^2}{B^{y}_{\max}} \tag{3.12}$$

The name fair borrowable bandwidth (FBB) is given to $\max\{B^{y}_{a}(t) - B^{y}_{\exp}, 0\}$, while the name maximum borrowable bandwidth (MBB) is defined as the maximum amount of bandwidth that can be borrowed from a service, i.e., $B^{y}_{a}(t) - B^{y}_{\min}$, where $B^{y}_{a}(t)$ is the amount of currently allocated bandwidth to service y at a given time t .A CI handoff service is accepted if it is possible to allocate an amount $B^{y}_{\min}$ of bandwidth, even after borrowing the amount of MBB from the existing services to meet the users' demands of reducing handoff call dropping probability.

Upon receiving the reservation request, each cell in the shadow cluster decides whether it has sufficient bandwidth to reserve for the service. The base station sends a positive response (i.e., 1) if it can support the service through reserving resources, and a negative response otherwise, as shown in Equation (3.13).

$$A^{x}_{i,j} = \begin{cases} 1 & if\ C^{f}_{j} \geq P_{x,j} B^{y}_{\max}; \\ 0 & Otherwise. \end{cases} \tag{3.13}$$

Where $A^{x}_{i,j}$ is the response from base station and $C^{f}_{j}(t)$ is the free bandwidth in cell j at a given time t .The values of $A^{x}_{i,j}$ are collected (to the base station) for all cells j, in the shadow cluster of the originating cell i for the MU x. The decision to accept is taken if the following holds:

$$\frac{1}{N} \sum_{j \in SC^{x}} A^{x}_{i,j} \geq \tau, \tag{3.14}$$

Where N is the number of cells in the shadow cluster and τ is the minimum percentage of amount of cell that can support the bandwidth reservation in the shadow cluster.

For call admission control algorithm for new call at a particular cell, the proposed CAC algorithms consider CI and CII services differently while admitting a new service in a cell. The details of the CAC algorithms for CI and CII new services are shown in Figure 3.18 and 3.19. Figure 3.20 presents the detailed CAC algorithm for handoff CI and CII services.

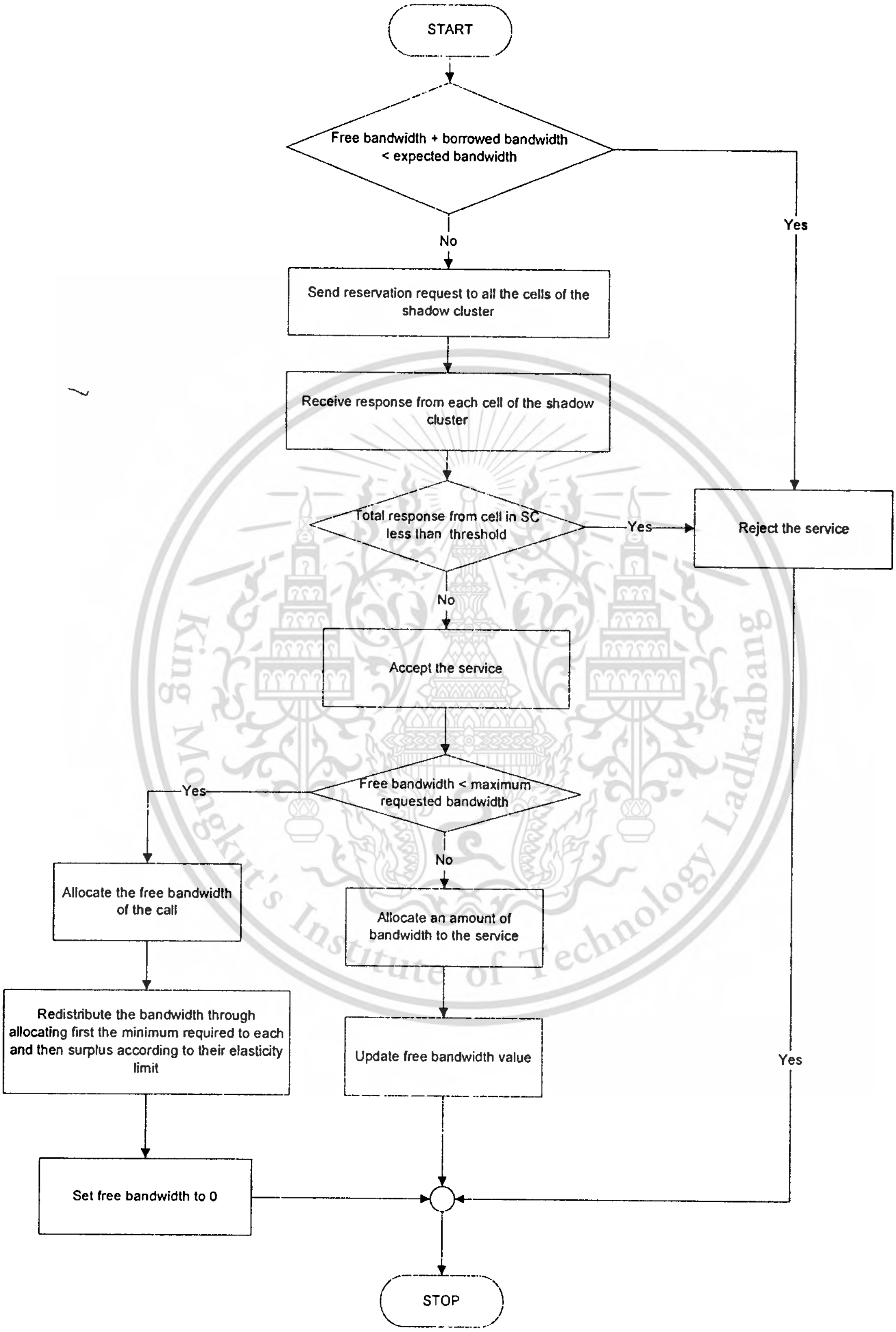

Figure 3.18 CAC algorithm of MSODB scheme for CI new calls

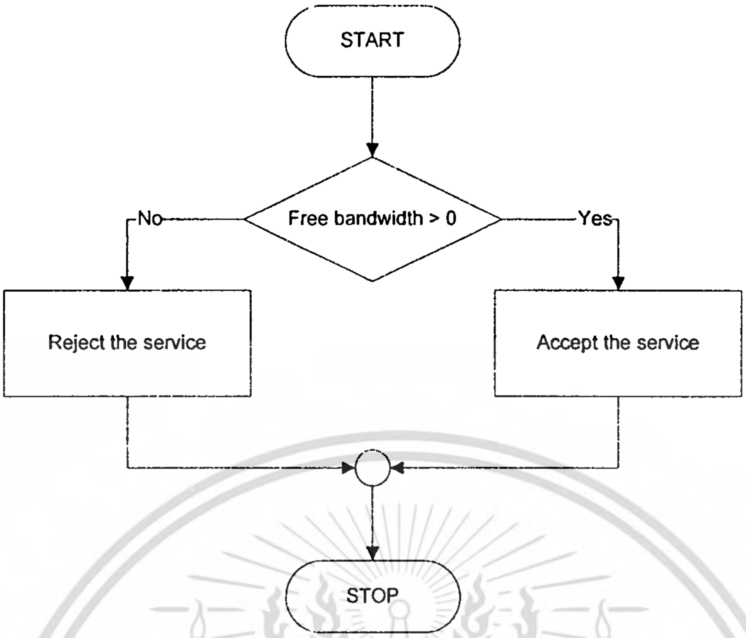

Figure 3.19 CAC algorithm of MSODB scheme for CII new calls

However, the MSODB scheme is also restrictive for the following reasons. Firstly, in MSODB scheme, a call is not considered for prediction conforming call and prediction nonconforming call. When a call is accepted to the network, each cell in its shadow cluster will reserve bandwidth in all RTW. Although when a call may arrive to a cell that is not a part of its shadow cluster, it may be dropped because bandwidths are not reserved for it while the reserved bandwidths in its shadow cluster are not released. As the result, the remaining available bandwidths for supporting the other calls decrease. When they arrive to the cell, they cannot use these bandwidths. This may cause the unnecessary blocking for new call and handoff call. Secondly, reposes from all cells in the shadow cluster have equal priority, irrespective of their distance to the current cell and their CVPs. As a result, sometimes handoff call may be dropped, due to the fact that the cell with less CVP which is far away from current cell can be supported while the cell which is near the current cell cannot be supported.

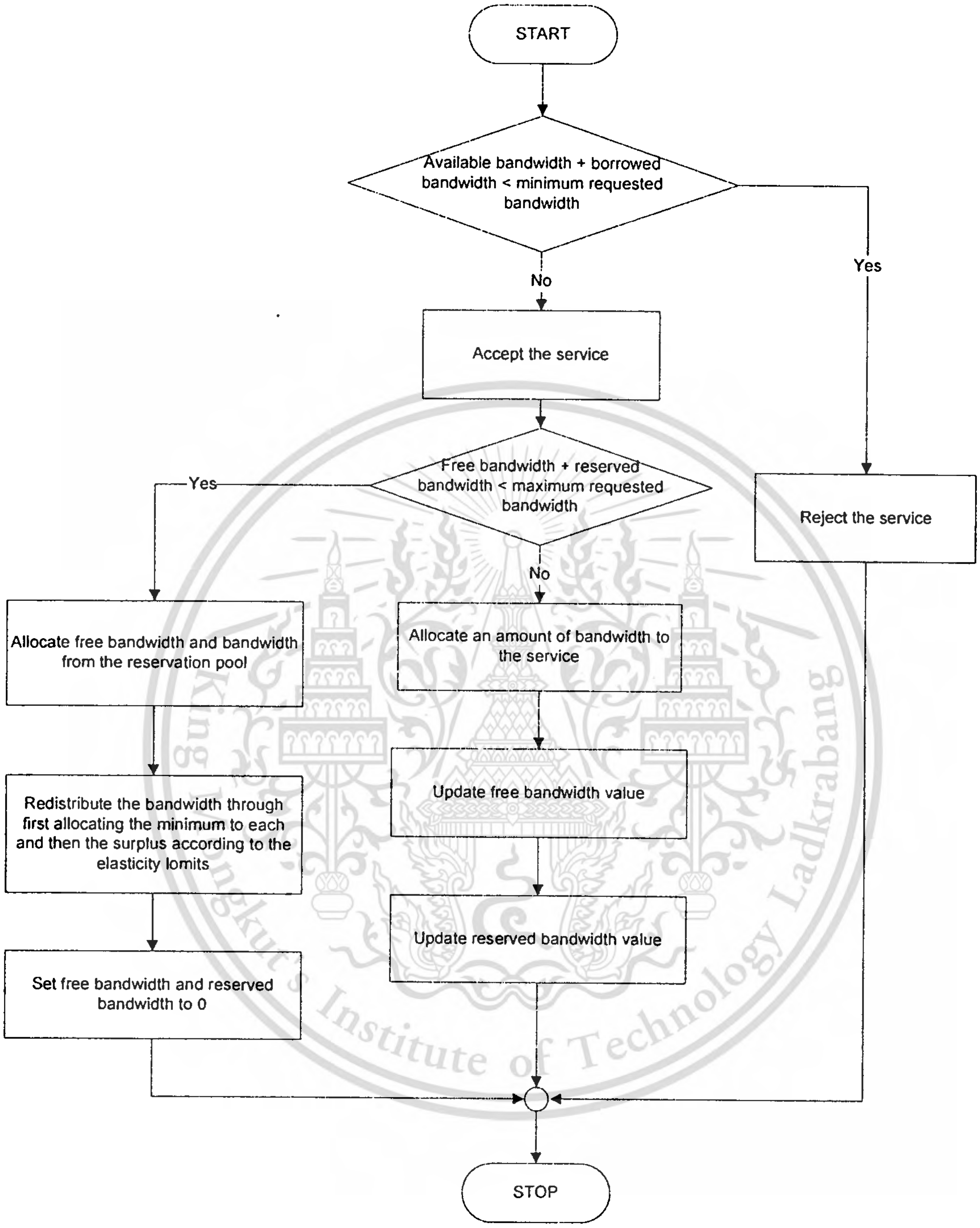

Figure 3.20 CAC algorithm of MSODB scheme for handoff calls

CHAPTER 4

THE PROPOSED CALL ADMISSION CONTROL SCHEME

4.1. PREDICTIVE USER MOBILITY BEHAVIOR SCHEME

In this research, a new bandwidth reservation scheme is proposed using *Predictive User Mobility Behavior* (PUMB) as the extended or modified scheme of Mobility Support On-Demand Borrowing (MSODB) and Predictive Mobility Support (PMS). The main objectives of the call admission control (CAC) in PUMB upon accepting a connection request are as follows:

1) Verifying the feasibility of accepting a new call into the system.

2) Guaranteeing an uninterrupted service for admitted calls as they move from one cell to another.

3) Maximizing the utilization of the network resources.

In order to achieve our objectives, the advantages of PMS and MSODB are integrated together into PUMB scheme including the following our proposed extended functions:

1) Adjusting the window size of shadow cluster (SC) considering the typical behavior of mobile unit (MU) such as direction and speed.

2) Weighting reposes from all cells in the SC by considering the cell visiting probability (CVP).

The characteristics comparison of PMS, MSODB, and PUMB can be summarized as shown in Table 4.1.

The main concept is that the bandwidth is reserved only in a cell which has higher probability of mobile unit's (MU's) migrating to that cell for reservation time window (RTW) based on key mobility parameters. The most difficult points are to predict the cell that MU will migrate in order to estimate the handoff time to that cell. From these points, we use the key mobility parameters these are position, direction, speed and expected travel distance (ETD), to estimate the CVP and RTW of neighboring cells for predicting the MU's mobility behavior, which was not incorporated in the MSODB scheme. These estimated parameters are used for making decision in our proposed scheme called PUMB algorithm [19].

The call in our consideration is classified into two types as presented in PMS; the prediction conforming call and the prediction nonconforming call. The prediction conforming call has the higher priority than the one of prediction nonconforming call. If a prediction conforming call comes into a cell with insufficient bandwidth, some prediction nonconforming call should be terminated, if necessary, for making space. From the resource reservation interval point of view, the PUMB scheme and the PMS scheme, if a call arrives to any cell without the resource leasing interval, the reserved bandwidths are released in order to avoid the unnecessary bandwidth reservation. Also, in the PUMB scheme, the SC window can be adjusted based on the typical behavior of MU but the PMS scheme considers only direction. Furthermore, the PUMB algorithm weights reposes from all cells in the SC by considering the CVP. The response from a cell with more CVP has higher priority than a cell with less CVP which is far the current cell. This may increase the decision accuracy for call accepting or call rejecting. As the result, it can guarantee an uninterrupted service for admitted call as they move from one cell to one of other cells.

Table 4.1 Characteristics comparison of PMS, MSODB, and PUMB

Characteristics \ Scheme	PMS	MSODB	PUMB
Key mobility parameters	direction	distance, direction and speed	distance, direction and speed
Calculating the *Cell Visiting Probability* (CVP)	YES	YES	YES
Defining the *Reservation Time Window* (RTW)	YES	YES	YES
Checking the *Resource Leasing Interval* (RLI)	YES	NO	YES
Estimating the *Expected Travel Distance* (ETD)	NO	YES	YES
Supporting handoff call that not in shadow cluster	YES	NO	YES
Adjusting the window size of shadow cluster	Considering only direction	NO	Considering direction and speed
Weighting reposes from all cells in the shadow cluster by considering the CVP	NO	NO	YES

The PUMB scheme is software which implemented on base station for controlling the network management. It composes of mobility model and CAC algorithm. In the mobility model, it estimates the parameters that are used in decision process of CAC algorithm these are CVP, RTW, and SC window size. MU's mobility parameters these are speed, distance, direction, and position are used to estimate these parameters very close to exact data. The estimated parameters in the mobility model are used in the CAC algorithm for the decision of call accepting or call rejecting, resource reservation, bandwidth borrowing and bandwidth allocation. If the estimated parameters are very close to real situations, the decision in the CAC algorithm is more accurate.

4.1.1. PUMB MODEL

In this research, a Global Positioning System (GPS) function is assumed to be embedded with each MU that is periodically transmitting mobility information to its current base station. The base station uses these information to calculate the probability that a MU may move from its current cell to a neighboring cell j or CVP, $P_{x,j}$. It can be calculated from MU's current position, mobility direction, moving speed, and travel distance to cell j, $\tilde{D}_{i,j}$.

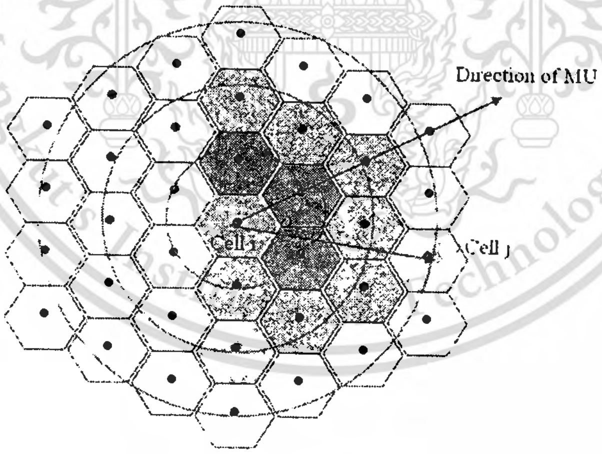

Figure 4.1 Graphical definition of $\delta_{x,j}$ and its SC which is depicted with the shaded area

We define v_x be the average moving speed of MU x and $\delta_{x,j}$ be the directional angle between the moving direction of MU x and a line joining the center of cell j with the position of MU x, as shown in Figure 4.1.

The CVP of MU x to visit cell j is assumed to have a value normalized over the virtual ring (V-ring) in which cell j resides as proposed in [14], and use the basic CVP properties in [18], we can calculated the CVP for MU x to visit cell j is found as shown in Equation (4.1).

$$P_{x,j} = \begin{cases} \dfrac{\dfrac{\cos\delta_{x,j}}{\tilde{D}_{i,j}}}{\sum\limits_{k\in R_{i,n} | j\in R_{i,n}} \dfrac{\cos\delta_{x,k}}{\tilde{D}_{i,k}}} & if\ \ \delta_{x,j} < \left|\dfrac{\pi}{2}\right| \ and\ v_x > 0 \\ 0 & Otherwise \end{cases} , \tag{4.1}$$

where $R_{i,0}$ is the current cell i and the summation is over the cell k that are in the same virtual ring as cell j.

4.1.1.1 FORMATION OF THE SHADOW CLUSTER

From the calculated $P_{x,j}$, we define the span of SC for a MU x to include all neighboring cells j such that $P_{x,j} \geq \psi$, where ψ is a *Shadow Custer Probability Threshold.* After that, it is to determine the *window size of the SC* (W_{SC}) which is the number of adjacent virtual rings of cells to be included in the SC. Let $Ring_{i,j}$ be the ring at which cell in the span of SC is located. In PUMB scheme, if users move within the predicted direction, their SC window sizes increase up to a maximum $R_{\max}$.

$$R_{\max} = \max[Ring_{i,j}] \quad \text{such that} \quad P_{x,j} \geq \psi \tag{4.2}$$

So that, if a MU moves along the current direction, increasing the W_{SC} by increases the virtual ring to support the MU's request. On the other hand, if a MU deviates from the current direction, decreasing the W_{SC}, as a MU may move out from the SC.

$$W_{SC} = \min(R_{\max}, \left\lfloor \left(1 - \frac{Dev_i}{\pi} T_x^{NC}\right)^2 \cdot R_{\max} \right\rfloor) \quad , \tag{4.3}$$

where T_x^{NC} is amount of continuous time that call x is prediction nonconforming call and Dev_i is deviation of call x at cell i. Let D_{Ai} is the direction of call x while moving to cell i and D_{Di} is the direction of call x while moving from cell i to cell j. The deviation of call x can then be calculated as:

$$Dev_i = \left| D_{Ai} - D_{Di} \right| \tag{4.4}$$

When MU deviates from the current direction, the W_{SC} is decreased by an amount proportional to the degree of deviation. The W_{SC} is recalculated at every handoff and MU's mobility behavior changing. Therefore, the W_{SC} decreases and increases follow the MU's moving behavior.

4.1.1.2 RESERVATION TIME WINDOW (RTW)

In the PUMB scheme, the RTW of a MU in each cell of the SC is estimated by considering expected travel distance and its standard deviation, moving speed, and MU's position for more accurate. The RTW of MU x when it arrives at cell j from cell i is considered in three terms of the time: *expected earliest arrival time* $\tilde{T}^{EA}_{i,j}(x)$, the *latest arrival time* $\tilde{T}^{LA}_{i,j}(x)$ and the *latest departure time* $\tilde{T}^{LD}_{i,j}(x)$. These time parameters can be determined by using the *maximum expected travel distance,* $\tilde{D}^{\max}_{i,j}$ and *the minimum expected travel distance,* $\tilde{D}^{\min}_{i,j}$ between MU's position in cell i and center of cell j, and by using normal distribution that has mean and standard deviation as $\tilde{D}_{i,j}$ and $\sigma_{i,j}$, respectively[18].

$$\tilde{T}^{EA}_{i,j}(x) = \tilde{D}^{\min}_{i,j} / v_x \tag{4.5}$$

$$\tilde{T}^{LA}_{i,j}(x) = \tilde{D}^{\max}_{i,j} / v_x \tag{4.6}$$

$\tilde{T}^{EA}_{i,j}(x)$ defines the lower end of RTW while $\tilde{T}^{LD}_{i,j}(x)$ is the higher end of RTW. $\tilde{T}^{LD}_{i,j}(x)$ can be found by adding the maximum of the expected cell residence time (CRT) to $\tilde{T}^{LA}_{i,j}(x)$. The expected CRT can be calculated by dividing the maximum trajectory of the cell by v_x. The details of calculating $\tilde{T}^{LD}_{i,j}(x)$ are given in Equation (4.7).

$$\tilde{T}^{LD}_{i,j}(x) = \tilde{T}^{LA}_{i,j}(x) + \frac{2R_j}{v_x}\ , \tag{4.7}$$

where R_j is the radius of cell j.

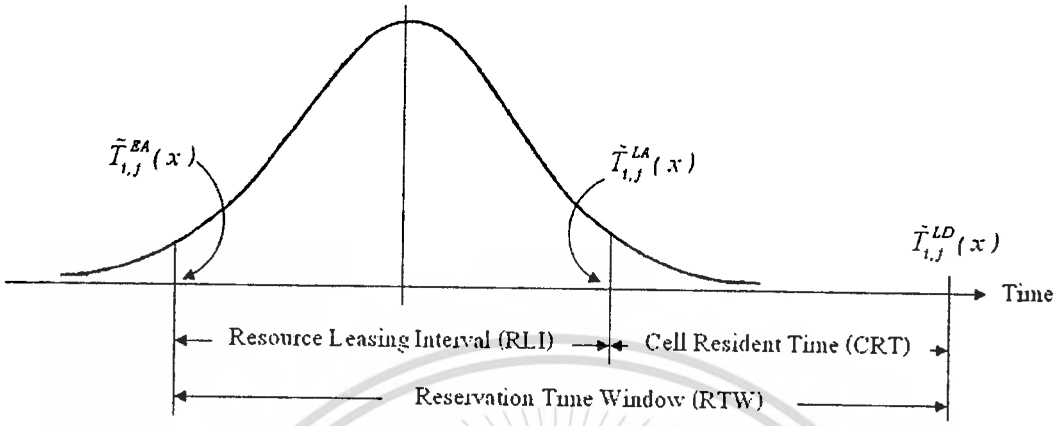

Figure 4.2 Graphical definition of Reservation Time Window

Figure 4.2 shows that the interval $\left[\tilde{T}_{i,j}^{EA}(x), \tilde{T}_{i,j}^{LD}(x)\right]$ is referred to as the *Reservation Time Window* (RTW), while the arrival interval $\left[\tilde{T}_{i,j}^{EA}(x), \tilde{T}_{i,j}^{LA}(x)\right]$ is referred to as the *Resource Leasing Interval* (RLI). The resources or bandwidths are reserved for the duration of RTW. However, if the MU does not arrive to cell j before RLI expires, all bandwidth are released and the reservation is canceled. This is necessary to prevent MU from holding resources unnecessarily.

The mechanism of reservation time window is shown in Figure 4.3. When MU is considered as prediction nonconforming call, the cell accepts the call if it has free bandwidth to support minimum bandwidth request and recalculates the MU's shadow cluster and adjust window size of shadow cluster as in Equation (4.3) and (4.4).

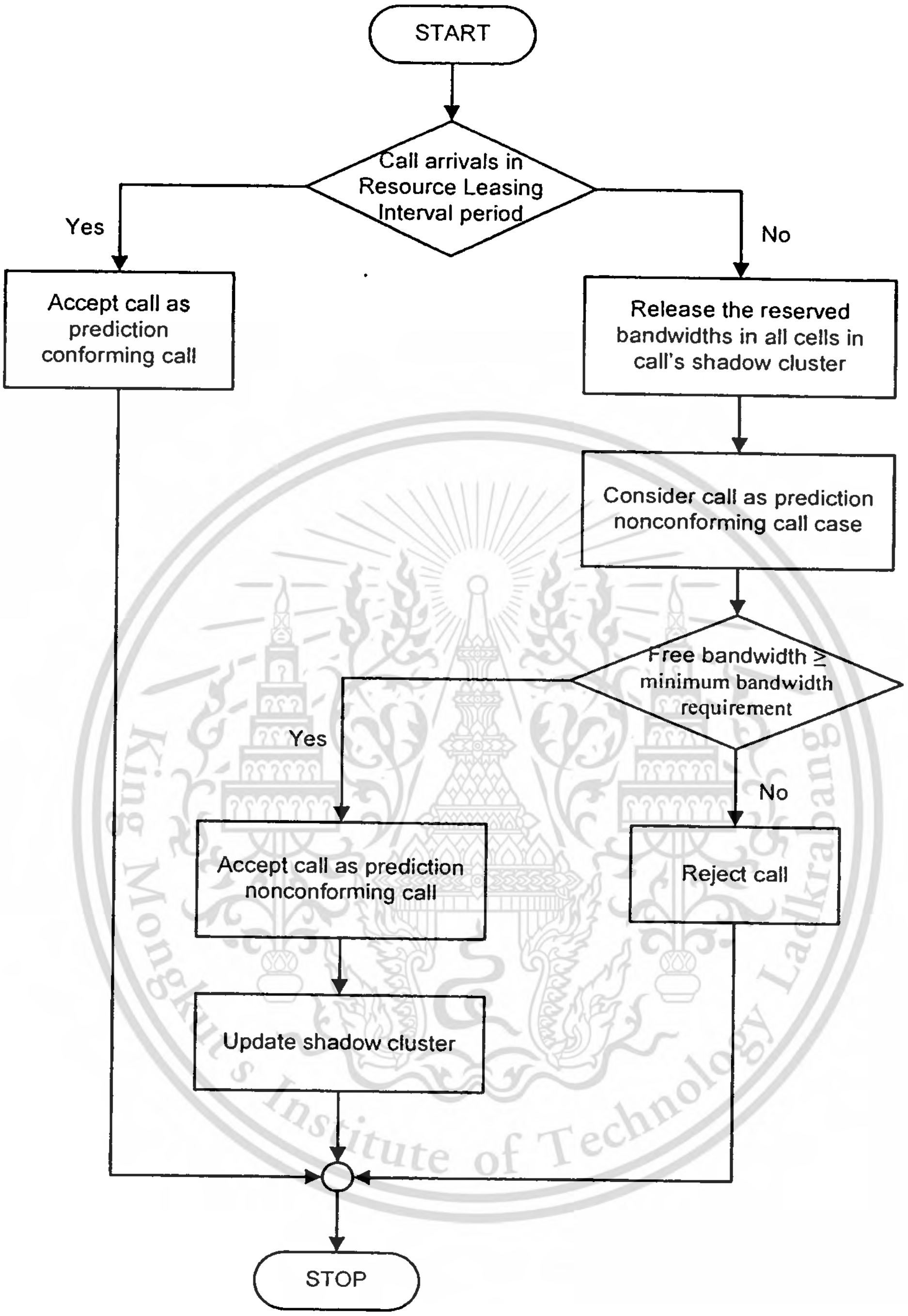

Figure 4.3 Reservation Time Window Mechanism

4.1.1.3 RESOURCE RESERVATION

PUMB scheme reserves an amount of bandwidth in a cell for a service proportional to the maximum bandwidth requirement of the service multiplied by the CVP for that cell in RTW as shown in Equation (4.8). The reservation of bandwidth in the different cells of the SC should be updated as the MU moves from its current position. The reservation in different cells within the SC is updated when the MU's direction goes beyond the angular span of the SC. When MU is an abrupt deviation in direction, the reservation is updated as well as the SC. When these cases occur, reserved resources in all cells in the SC are released while the MU's shadow cluster is recalculated. It used to support the new MU's direction and prevent unnecessary reserved bandwidth.

$$R_{y,j} = P_{x,j} B^{y}_{\max} \quad for \quad \tilde{T}^{I,A}_{i,j}(x) \le t \le \tilde{T}^{I,D}_{i,j}(x), \tag{4.8}$$

where $B^{y}_{\max}$ is the maximum requested bandwidth for service y.

Unlike other schemes, although the MU hands off from one cell to another, but it's not change mobility behavior, the SC is not recalculated. Consideration of this situation increases channel utilization, i.e., it reduces both the new call blocking probability (NCBP) and the handoff call dropping probability (HCDP), because it releases the resources reserved in those cells that lie outside the SC, while the overhead message transmission from SC recalculation is reduced.

4.1.2. PUMB CALL ADMISSION CONTROL ALGORITHM

In this section, we will present our proposed scheme called the *Predictive User Mobility Behavior* (PUMB) scheme. Firstly, it is necessary to define the traffic in cellular network into two classes: *Class I Partially elastic traffic* (such as audio stream and video stream) and *Class II Fully elastic traffic* (such as e-mail and File Transfer Protocol file (FTP-file)). If a class I call comes into a cell with insufficient bandwidth, some class II calls should be terminated, if necessary, for making space. From elastic definition, we can calculate elastic rate (ER) from Equation (4.9)

$$ER = \left(B^{y}_{\max} - B^{y}_{\min}\right) / B^{y}_{\max} , \tag{4.9}$$

where $B^{y}_{\max}$ is maximum requested bandwidth and $B^{y}_{\min}$ is minimum requested bandwidth. We can calculate the expected bandwidth $B^{y}_{\exp}$ for service y from elastic rate as [18]. The details of calculating $B^{y}_{\exp}$ are given in Equation (4.10).

$$B_{\exp}^{y} = B_{\max}^{y} - B_{\max}^{y} ER^{2}$$
$$= B_{\max}^{y} - \frac{(B_{\max}^{y} - B_{\min}^{y})^{2}}{B_{\max}^{y}} = 2B_{\min}^{y} - \frac{(B_{\min}^{y})^{2}}{B_{\max}^{y}} \qquad (4.10)$$

A service is accepted if it is possible to allocate an amount $B_{\min}^{y}$ of bandwidth. We separate borrowing bandwidth into two types: the fair borrowing bandwidth (FBB) and the maximum borrowing bandwidth (MBB) [18] are defined as:

$$FBB = \max\{B_{a}^{y}(t) - B_{\exp}^{y}, 0\} \qquad (4.11)$$

and

$$MBB = B_{a}^{y}(t) - B_{\min}^{y}, \qquad (4.12)$$

where $B_{a}^{y}(t)$ is the amount of currently allocated bandwidth to service y at a given time t. Each type of borrowing bandwidth is condition to accept or reject call. MBB is considered together with the reserved bandwidths and the free bandwidths for accepting handoff call, while FBB is considered together with the free bandwidths for accepting new call.

4.1.2.1. CALL FEASIBILITY AND SETUP PROCEDURE

Upon receive the reservation request; each cell in the SC decides whether it has sufficient bandwidth to reserve for the service. The base station sends positive response if it can support the service through reserving resources, and a negative response otherwise, as shown in Equation (4.13).

$$A_{i,j}^{x} = \begin{cases} 1, \; if \; C_{j}^{f}(t) \geq R_{y,j} \; for \; [\tilde{T}_{i,j}^{E,A}(x), \tilde{T}_{i,j}^{L,D}(x)] \\ 0, \; otherwise \end{cases}, \qquad (4.13)$$

where $C_{j}^{f}(t)$ is amount of free bandwidths in cell j at time t. The value of $A_{i,j}^{x}$ are collected for all cells j in the SC of the current cell i for the MU x. The decision to accept is taken if at least τ %of the cells in the shadow cluster can support an amount of reserved bandwidth in the RTW.

$$1 \geq \sum_{j \in SC} (P_{x,j} . A_{i,j}^{x}) \geq \tau . \sum_{j \in SC} P_{x,j} \geq 0 \;\; ; \;\; 0 \leq \tau \leq 1 \qquad (4.14)$$

The above feasibility test condition of the RTW and the CVP is checked so that more weight is given to support responses of the cells whose CVP is comparatively higher. When the current cell i accepts the call, it sends a message to all cells in SC, confirming that the reservation must now be performed. Every call reserved the required bandwidth for the RRI duration and updated its available bandwidth accordingly. However, notice that cell j cancels the reservation if the MU that does not arrive before the resource leasing interval period, RLI, expires.

4.1.2.2 PREDICTION CONFORMING AND NONCONFORMING CALL

Due to the changing behavior of the MUs in a cellular network, calls may hand off to cells that are not part of their SC and calls may not arrive within their RLIs. Therefore, we define the status of a call to be either *prediction conforming* or *prediction nonconforming* [14].

The CAC gives higher priority to prediction conforming calls over prediction nonconforming calls. When a prediction conforming call arrives and cannot be accommodated by the available bandwidth, a prediction nonconforming call is dropped. We borrow the predicted nonconforming call in order by the duration time decreasing for the purpose of increasing the CSP. The bandwidth allocation for prediction nonconforming call allocates only minimum bandwidth requested because of preventing NCBP and HCDP increasing.

4.1.2.3 CAC ALGORITHM FOR NEW CALL

The PUMB CAC algorithms consider Class I and Class II calls differently while admitting a new call in a cell. When a new Class I call arrives in the cell i, the base station calculates the maximum available bandwidth by adding the FBB of each existing call to free bandwidth. If the maximum available bandwidth is greater than or equal to B_{exp} of the MU, then the bandwidth reservation request is forwarded to all the cells in the SC to test condition of reserved bandwidth in RTW period and send these responses back, the admission decisions are taken based on their responses which weight by their CVP. However, if the maximum available bandwidth is not sufficient to meet the new call's bandwidth demand, the call is rejected. On the other hand, if the free bandwidth in the cell is more than zero, Class II calls are accepted. At first, after accepting a service, the minimum required bandwidth is allocated to each of the services, and then the remaining surplus bandwidth is redistributed among the services according to the proportion of their elastic rate. When new calls are accepted, it is admitted as predictive conforming call. The details of the CAC algorithms for new calls are show in Figure 4.4.

Class I

Step (1): IF $C_i^f(t) + \text{summation of } FBB \geq B_{\exp}^y$, THEN send reservation request to all the cells of the SC and receive response form each cell of the SC. Otherwise, reject the call.

Step (2): IF $\sum_{j \in SC} (P_{x,j} . A_{i,j}^x) \geq \tau . \sum_{j \in SC} P_{x,j}$, THEN accept the call and GOTO Step (3), otherwise, reject the call.

Step (3): IF $C_i^f(t) \geq B_{\max}^y$, THEN allocate an amount maximum requested bandwidth to the call. Otherwise, allocate free bandwidth to the call, redistribute the bandwidth through allocating first the minimum required to each and then surplus according to their elasticity limit.

Step (4): Admitted call as predicted conforming call. Send confirmation to each cell in SC to reserve an amount of bandwidth.

Class II

IF this cell has free bandwidth, THEN accept the call and admitted call as predicted conforming call. Otherwise, reject the call.

Figure 4.4 CAC algorithm of PUMB scheme for new calls

4.1.2.4 CAC ALGORITHM FOR HANDOFF CALL

The PUMB CAC algorithms discriminate prediction conforming call and prediction nonconforming call by using their RLI period condition and their SC cell. When prediction conforming call migrates to cell i, Class I class, the maximum available bandwidth for call is calculated by adding up free bandwidth $C_i^f(t)$, reserved bandwidth $C_i^r(t)$ and the summation of the MBB for each existing call in the cell i. If the maximum available bandwidth is greater than or equal to $B_{\min}^y$, then the call is accepted; otherwise it is rejected. For Class II handoff calls, if the maximum available bandwidth is zero, the transmission is stopped and the service waits until it gets bandwidth to start transmission again, because the Class II calls are offline and do not have any impact on user interaction. Unlike the MSODB, the PUMB supports the case of prediction nonconforming call, if the free bandwidth can support $B_{\min}^y$, the call is accepted, and otherwise, it is dropped. When bandwidth borrowing occurs, for making bandwidth a prediction nonconforming call is dropped before prediction conforming call. The details of the CAC algorithms for handoff calls are show in Figure 4.5.

Step (1): IF this cell is in SC and a call arrives to the cell during the lease period RLI, THEN GOTO Step (3), Otherwise, GOTO Step (2).

Step (2): IF $C_i^f(t) \geq B^y_{\min}$, THEN allocate free bandwidth to call, admitted call as predicted nonconforming call, compute new SC, Otherwise, reject the call.

Step (3): IF $C_i^f(t) + \text{summation of } MBB \geq B^y_{\min}$, THEN accept call, admitted call as predicted conforming call and GOTO Step (4), otherwise, reject the call.

Step (4): IF $C_i^f(t) + C_i^r \geq B^y_{\max}$, THEN allocate an amount of maximum requested bandwidth to call, Otherwise, GOTO Step (5).

Step (5): IF $C_i^f(t) + C_i^r \geq B^y_{\min}$, THEN allocate free bandwidth and reserved bandwidth to call, Otherwise, GOTO Step (6).

Step (6): IF call is non-rate adaptive call, THEN allocate free bandwidth and reserved bandwidth to call and GOTO Step (7). Otherwise, include the call in the list of existing call, redistribute the bandwidth among adaptive calls without effecting non-rate adaptive calls.

Step (7): IF bandwidth held by predicted nonconforming calls can be freed, THEN terminate then, allocate bandwidth to call. Otherwise, borrow bandwidth from existing rate-adaptive call.

Figure 4.5 CAC algorithm of PUMB scheme for handoff calls

4.2. QUALITY OF SERVICE PARAMETERS

In this research, we consider in four terms of QoS parameters: New Call Blocking Probability (NCBP), Handoff Call Dropping Probability (HCDP), Call Successful Probability (CSP) and Bandwidth Utilization (BU).

4.2.1. NEW CALL BLOCKING PROBABILITY

The new call dropping probability or NCBP is the probability of the situation when a MU attempts to connect to a cell in network, called new call, and if this cell cannot support the level of resources required by the MU, this connection is blocked. The probability of this situation is known as the *new call blocking probability* (NCBP). It equals the ratio of number of all new connection is denied into the network divided by number of all new connection in the network, as shown in Equation (4.15).

$$NCBP = \frac{N_{Block}}{N_{connect}}, \tag{4.15}$$

where $NCBP$ is new call blocking probability, N_{Block} is the number of all new connection which is denied from the network, and $N_{Connect}$ is the number of all new calls that connect to the network. Sometime, a mobile unit attempts to connect to a cell in network more than one time. So that $N_{Connect}$ in Equation (4.15) is cumulative frequency of the time of all connections request to the network.

4.2.2. HANDOFF CALL DROPPING PROBABILITY

The handoff call dropping probability or HCDP is the probability of the situation when a active connection in one cell attempts to migrate into a neighboring cell, called handoff call, and if this neighboring cell cannot support the level of resources required by the connection, this handoff is dropped. The probability of this situation is known as the *handoff call dropping probability* (HCDP). It equals the ratio of number of all handoff call is dropped from the network divided by number of all handoff calls in the network, as shown in Equation (4.16).

$$HCDP = \frac{N_{Drop}}{N_{Handoff}}, \tag{4.16}$$

where $HCDP$ is handoff call dropping probability, N_{Drop} is the number of all handoff call which is dropped from the network, and $N_{Handoff}$ is the number of all handoff calls which occur in the network. Each mobile unit can be handed off to neighboring cell more than one time. So that $N_{Handoff}$ in Equation (4.16) is cumulative frequency of the time of all handoff calls that occur in the network.

4.2.3. CALL SUCCESSFUL PROBABILITY

In addition to accepting a connection into the network, the amount of successful call is measured. It is expressed as the *call successful probability* (CSP), which is the probability that a connection request has not been dropped during its duration. It equals the ratio of number of all calls which terminate from the network divided by number of all calls which admit to the network, as shown in Equation (4.17).

$$CSP = \frac{N_{Terminate}}{N_{Admit}}, \qquad (4.17)$$

where CSP is call successful probability, $N_{Terminate}$ is the number of all calls which terminate from the network, and N_{Admit} is the number of all admitted calls in the networks.

4.2.4. BANDWIDTH UTILIZATION

When a call is accepted into the network, the cell will allocate bandwidth to the call. An important parameter is the degree to which the network makes an effective use of bandwidth. This parameter is called *bandwidth utilization*, which is found as shown in Equation (4.18).

$$BU = \frac{T_{used}}{min[T_{Request}, T_{Available}]}, \qquad (4.18)$$

where BU is bandwidth utilization, T_{Used} is the amount of all bandwidths used by various connections admitted into a network in currently time, $T_{Request}$ is the amount of all bandwidths requested by various connections send to a network in currently time, and $T_{Available}$ is the amount of all available bandwidths of all cells in currently time.

If the network can support the level of resources required by all connections then the $T_{Available}$ is more than the $T_{Request}$. As the result, $T_{Request}$ and T_{Used} are equal, and BU is the most value (is 1). Sometimes, the network cannot support the level of resources required by all connections because all requests in the network are very much and all available bandwidths are used to support the ongoing calls. So that, BU can be calculated from ratio of T_{Used} and $T_{Available}$ and the value is 1.

CHAPTER 5

PERFORMANCE EVALUATIONS

5.1. SIMULATION MODEL

In this section, we evaluate the performance of our proposed scheme "*Predictive User Mobility Behavior (PUMB)*", by means of the simulation. The considerations are focus on performance metrics such as New Call Blocking Probability (NCBP), Handoff Call Dropping Probability (HCDP), Call Successful Probability (CSP), and Bandwidth Utilization (BU).

Because the results in [18] show that the MSODB has better performance than PMS. So that, the performance is evaluated by comparing only between our proposed PUMB and Mobility Support On-Demand Borrowing (MSODB)[18]. The simulation results are demonstrated in three parts. The first part is the comparison between PUMB and MSODB when new call arrival rate is varied.

The second part is the comparison between PUMB and MSODB when the moving speed of mobile unit (MU) is varied and new call arrival rate is 6calls/min which is average congested networks. The final part is the comparison between PUMB and MSODB when shadow cluster probability threshold is varied while moving speed range is 0-40m/s or 0-144 km/hr and the new call arrival rate is considered into 3 ranges: low (1call/min), medium (5 calls/min) and high (10 calls/min).

Table 5.1 Traffic characteristics

Service ID	Service Class	$B^{y}_{\min}$ (Mbps)	$B^{y}_{\max}$ (Mbps)	Min. time(s)	Avg. time(s)	Max. time(s)	Example traffic contents
1	C1	0.03	0.03	60	180	600	Web browsing
2	C1	0.256	0.256	60	300	1800	Audio streams
3	C1	1.0	6.0	300	600	18000	Video Stream
4	C2	0.0	0.02	10	30	120	E-mail
5	C2	0.0	0.512	30	180	36000	FTP file downloads, e-mail attachments
6	C2	0.0	10.0	30	120	1200	FTP application download

In this simulation, the cellular network consists of cells. We assume all cell are homogeneous which have the same characteristics such as cell size and traffic pattern. Each cell contains a base station which is implemented CAC algorithm for the connection setup and teardown of new calls and handoff calls, as well as the bandwidth reservation in neighboring cells. In order to represent various multimedia applications, six different application groups are assumed based on the connection duration, bandwidth requirement, and class of service (Class I and Class II). The different application groups include constant bit rate, variable bit rate, and data traffic sources. Table 5.1 shows the traffic characteristics of six application groups used in the simulation. These are typical applications seen on existing networks, and their parameter values are chosen from [16,18]. Each of the six application groups occurs with equal probability.

The 39 cells with 1 km radius are used in the simulation. Each cell has maximum bandwidth capacity of 40 bandwidth units. The new call arrival rate has a Poisson distribution with arrival rate λ, while the call duration time was assumed to be described the time between events in a Poisson distribution with the mean $1/\mu$. Each simulation was carried out for 12 hours of real time cellular multimedia communications. Table 5.2 summarizes the various simulation parameters. The values for the simulation parameters are chosen carefully in order to closely present realistic scenario [14, 17, 18] and make the simulation feasible.

Table 5.2 Simulation parameters

Parameter	Value	Description of parameters
N	39	Number of cells simulated
R	13	Number of country roads and freeways
C_c^T	40	Cell capacity
J	10	Number of road junction
M	var	Number of mobiles in system
G_{out}	0.0001	Going out of network probability
λ	var	Mean call arrival rate
G_{off}	0.01	Mobile off probability
$1/\mu_{off}$	var	Mean MU off time
$1/\mu_{out}$	var	Mean out of network staying time
β	0.9	Confidence level
τ	0.8	Supported level from the cells in shadow cluster

5.2. SIMULATION RESULTS

5.2.1. PERFORMACNE METRICS FOR VARYING ARRIVAL RATES

In this part, the mobility parameters are shown in Table 5.3 [18]. The movements of the MU may be stationary or move, either towards a specific destination following the road networks, or randomly at walking speeds and the MU can start its itinerary from any location in the cellular network, with an appropriate state of movement. MUs were allowed to travel at speeds proportionate with the current road limits within 10% variations and the shadow cluster probability threshold is 0.2.

We separate simulation results for various arrival rates into three cases:

(1) Class I traffic (traffic ID 1, 2, and 3).

(2) Class II traffic (traffic ID 4, 5, and 6)

(3) Class I and Class II traffic.

Table 5.3 Mobility parameters

Parameter	Value	Description of parameters
P_c	0.15	Probability that the MU travels on a country road
P_f	0.1	Probability that the MU travels on a freeway
P_{walk}	0.4	Probability that the MU is walking or stationary
P_{s2m}	0.4	From stopping to moving probability
P_{m2s}	0.4	From moving to stopping probability
$V_{\max c}$	28	Maximum speed (m/s) on a country road
$V_{\max f}$	35	Maximum speed (m/s) on a freeway
$V_{\max r}$	18	Maximum speed (m/s) on local/city road
$V_{\max w}$	3	Maximum walking speed (m/s)

5.2.1.1. FOR CLASS I TRAFFIC

Figure 5.1 shows that the Class I NCBP of PUMB and MSODB are low during very low arrival rates, but increase steadily with the arrival rate increase. The improvements in Class I NCBP between both schemes are minimal at lower arrival rate. However, the improvements become important as the arrival rate increases. In the PUMB, it can adjust the window size of shadow cluster (SC) considering the typical behavior of mobile unit (MU) in order to avoid the unnecessary bandwidth reservation. As the result, the PUMB scheme is able to decrease the NCBP lower than MSODB about 10-19%.

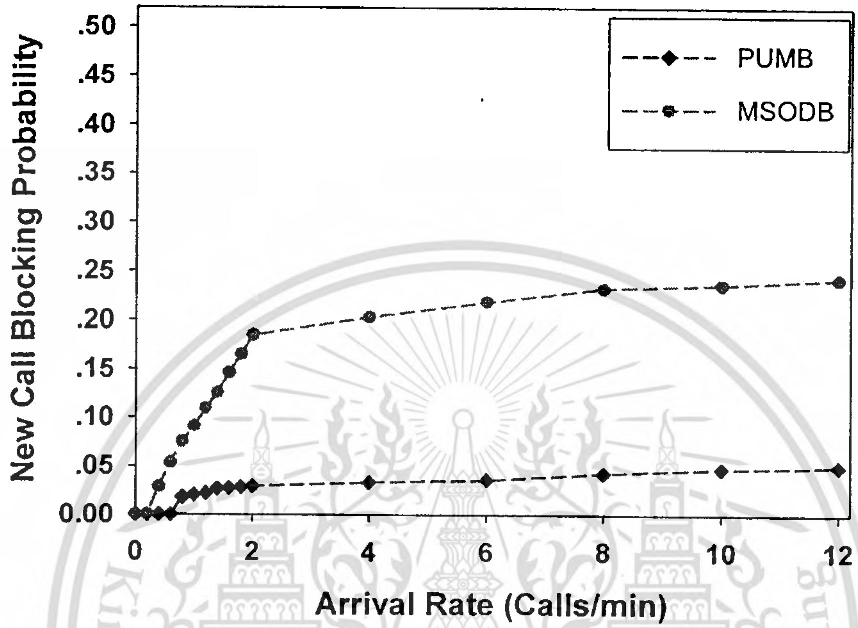

Figure 5.1 Comparison of Class I new call blocking probability for varying arrival rate

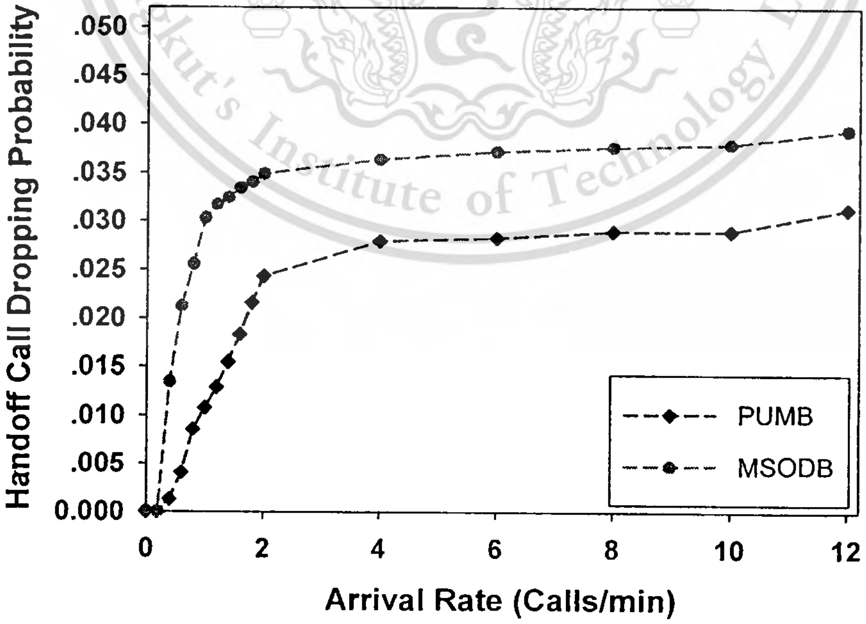

Figure 5.2 Comparison of Class I handoff call blocking probability for varying arrival rate

The Class I HCDP of PUMB and MSODB are shown in figure 5.2. While arrival rate increases, the Class I HCDP rises rapidly. In decision process of the PUMB, the responses from all cells in SC are weighted by their CVP. So that, the response from a cell with more CVP has higher priority than a cell with less CVP which is far the current cell. This may increase the decision accuracy for call accepting or call rejecting. As the result, it can guarantee an uninterrupted service for admitted call as they move from one cell to one of other cells. As the result, the PUMB scheme provides 8-19.5% improvements in handoff Class I HCDP compared with the MSODB scheme.

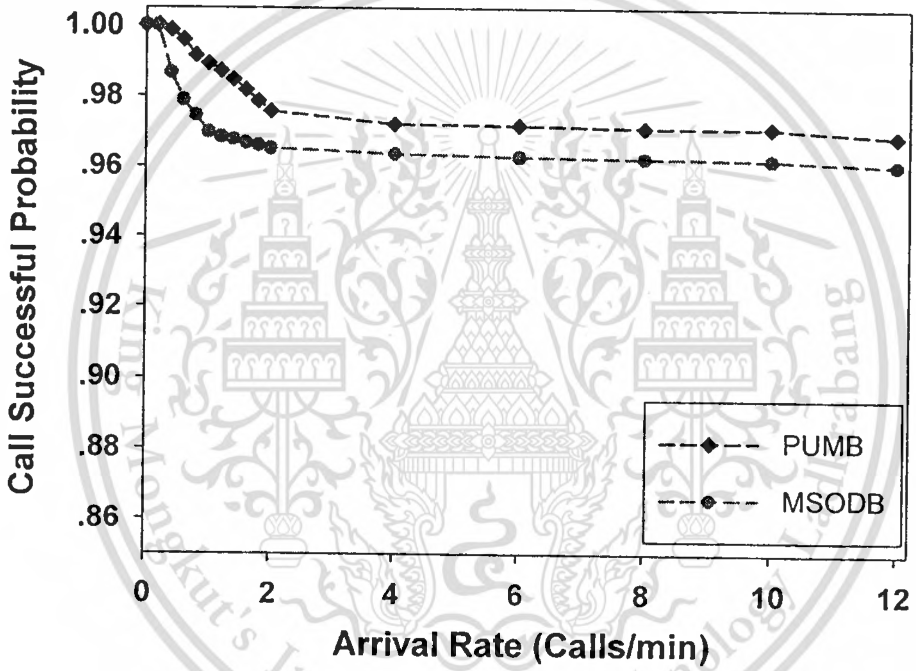

Figure 5.3 Comparison of Class I call successful probability for varying arrival rate

The Class I CSP of the PUMB and MSODB are presented in figure 5.3. The result shows that CSP decreases as the call arrival rate increases. Because the PUMB can increase the decision accuracy for call accepting or call rejecting. Therefore, it can guarantee an uninterrupted service for admitted call as they move from one cell to one of other cells. As the result, it can lead to decrease HCDP while increase CSP more than MSODB about 8-19.5 %.

The Class I bandwidth utilization of PUMB and MSODB is presented in figure 5.4. The result shows that as the arrival rate increases, the bandwidth utilization decreases. Due to the arrival rate increasing, reserved bandwidths of all shadow cluster increase. As the result, bandwidth utilization decreases. However, the PUMB can adjust the window size of shadow cluster in order to avoid the unnecessary bandwidth reservation. The PUMB achieves better bandwidth utilization than MSODB for each arrival rate. PUMB is able to increase the bandwidth utilization greater than MSODB about 8 %.

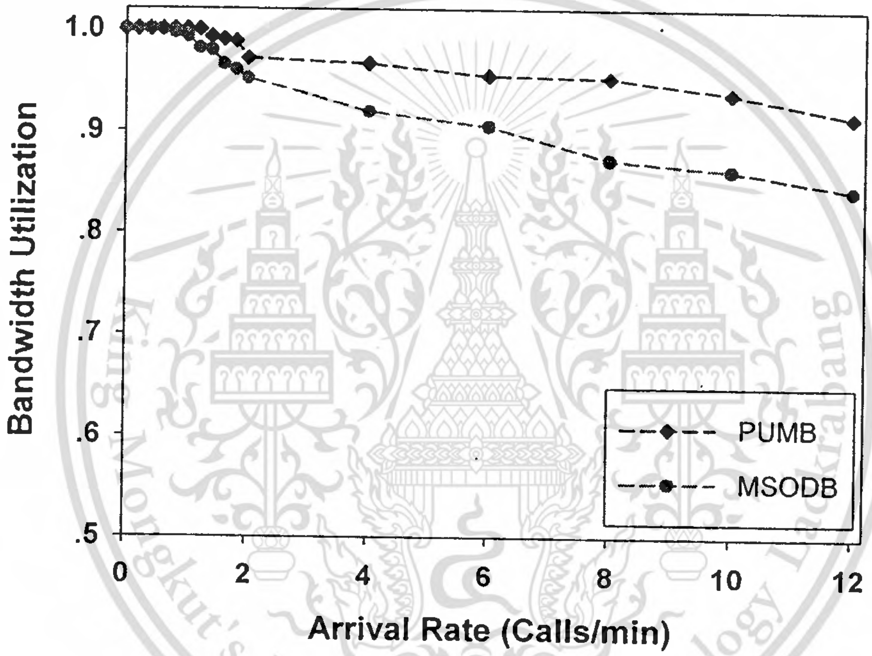

Figure 5.4 Comparison of Class I bandwidth utilization for varying arrival rate

5.2.1.2. FOR CLASS II TRAFFIC

The Class II NCBP is zero for both schemes at very low arrival rate, as shown in figure 5.5. However, although the differences in the Class II NCBP of both schemes are small at lower arrival rates, the differences increases as the arrival rate increases. The PUMB has better performance than MSODB. The Class II NCBP of PUMB is improved about 1-4 % compared with the MSODB.

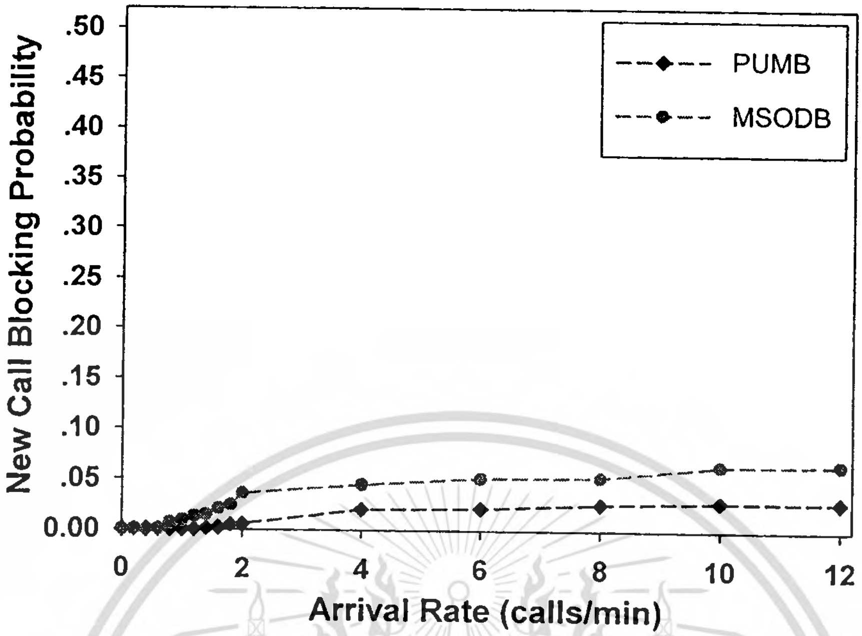

Figure 5.5 Comparison of Class II new call blocking probability for varying arrival rate

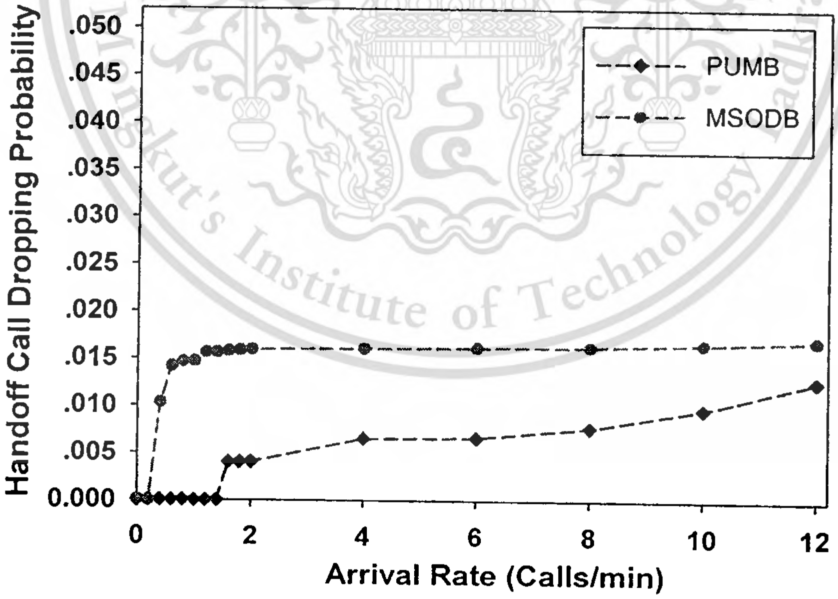

Figure 5.6 Comparison of Class II handoff call blocking probability for varying arrival rate

Figure 5.6 shows the Class II HCDP of PUMB and MSODB. The differences in the Class II HCDP of both schemes are more at lower arrival rates, the differences decrease as the arrival rate increases. The Class II HCDP of PUMB is improved about 4-15 % compared with the MSODB. The CSP of the PUMB and MSODB are presented in figure 5.7. The result shows that CSP decreases as the call arrival rate increases. However, the differences of the Class II CSP of both schemes are more at lower arrival rates, the differences decrease as the arrival rate increases. The PUMB scheme provides 4-15% improvements in Class II CSP compared with the MSODB.

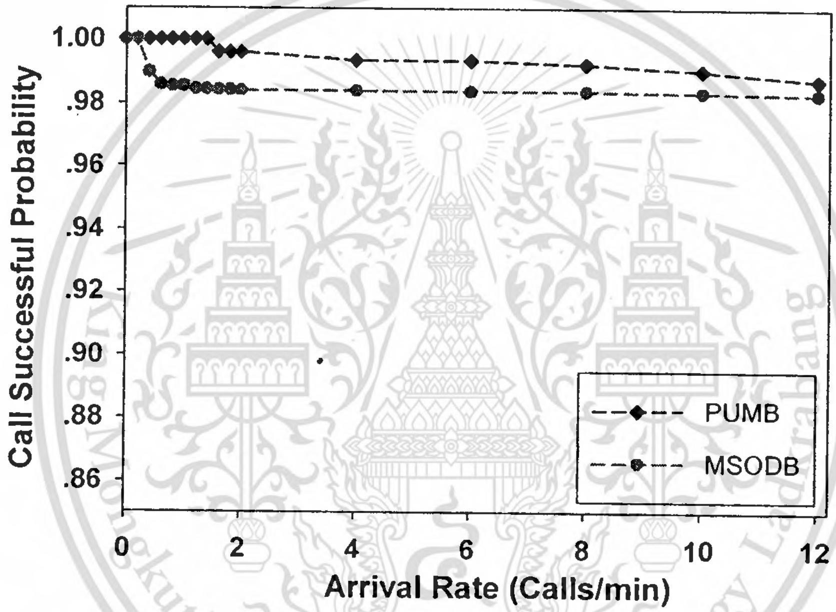

Figure 5.7 Comparison of Class II call successful probability for varying arrival rate

The Class II bandwidth utilization of PUMB and MSODB is presented in figure 5.8. The result shows that as the arrival rate increases, the bandwidth utilization decreases. MSODB achieves better bandwidth utilization than PUMB when arrival rate is more than 1. MSODB is able to increase the bandwidth utilization greater than PUMB up to 2 ~ 9 %.

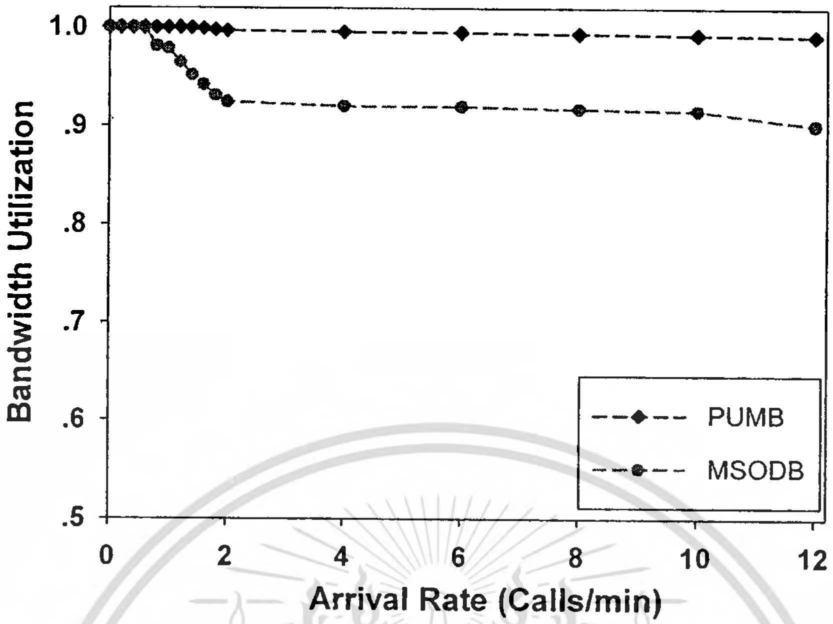

Figure 5.8 Comparison of Class II bandwidth utilization for varying arrival rate

5.2.1.3. FOR CLASS I AND CLASS II TRAFFICS

The NCBP of PUMB and MSODB are shown in figure 5.9. It is shown that the differences in the NCBP of both schemes are less at lower arrival rates, the differences increase as the arrival rate increases. The NCBP in PUMB is lower than MSODB for all of arrival rate. The NCBP in PUMB is reduced about 2~9 % compared with the MSODB. The PUMB can reduce the NCBP because if the MU does not arrive to its shadow cluster before RLI expires, the reserved bandwidths in MU's shadow cluster are released and used to support the other calls. Also the PUMB can adjust shadow cluster window size based on typical behavior of MU so that it can reduce unnecessary reserved bandwidth. As the result, cells have more bandwidth to support the other cells.

In figure 5.10, we present the HCDP of PUMB and MSODB. The result has shown that PUMB has better performance than MSODB while arrival rate increases. The HCDP of PUMB is improved about 9~23 % compared with the MSODB. The CSP of the PUMB and MSODB are presented in figure 5.11. The result shows that CSP decreases as the call arrival rate increases. However, the PUMB has better performance than MSODB. PUMB can reduce the HCDP while lead to increase CSP more than MSODB about 2 %. Because PUMB can guarantee an uninterrupted service for admitted calls as they move from one cell to one of other cells by weighting response from all cells in MU's shadow cluster by its CVP. This may increase the decision accuracy for call accepting or call rejecting. Thereby the HCDP of PUMB reduces while lead to increase CSP.

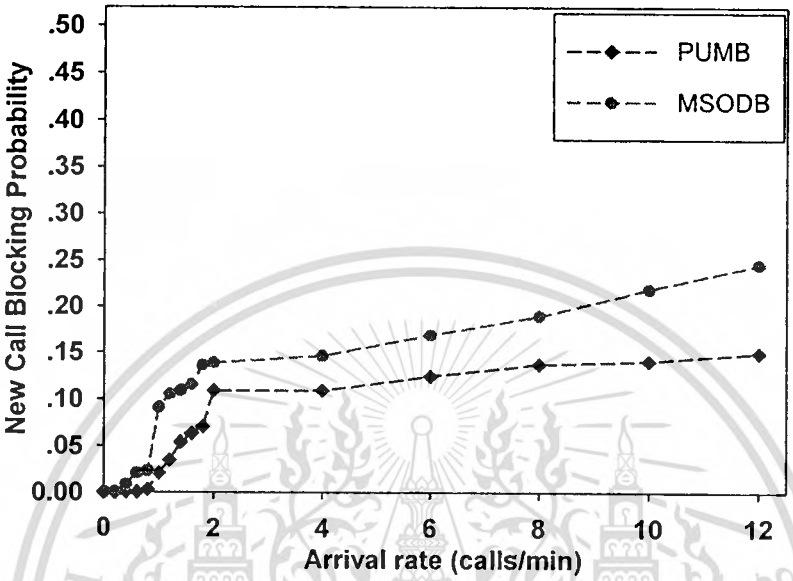

Figure 5.9 Comparison of new call blocking probability for varying arrival rate

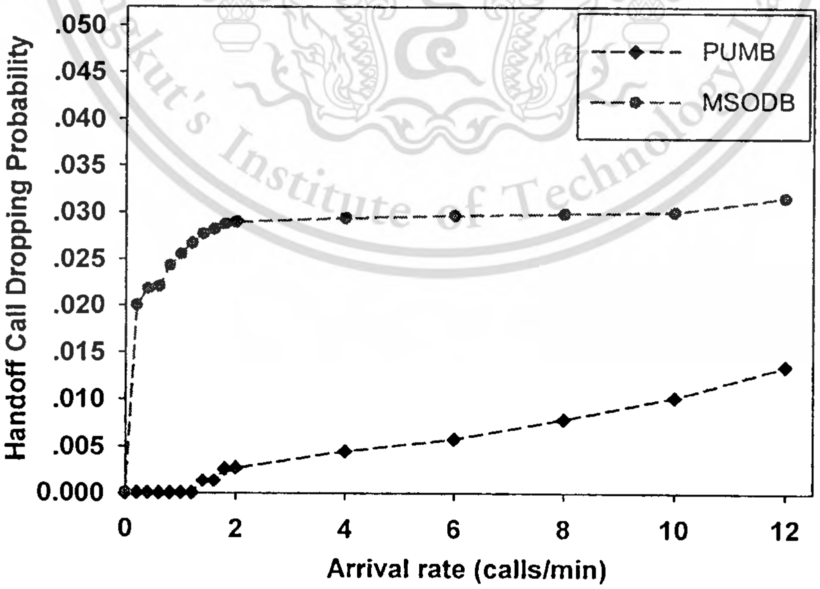

Figure 5.10 Comparison of handoff call blocking probability for varying arrival rate

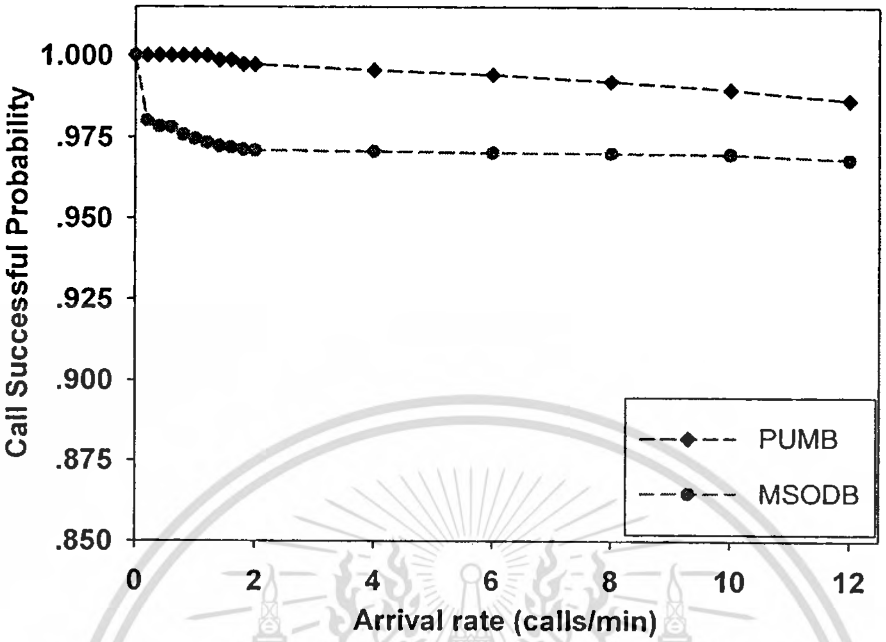

Figure 5.11 Comparison of call successful probability for varying arrival rate

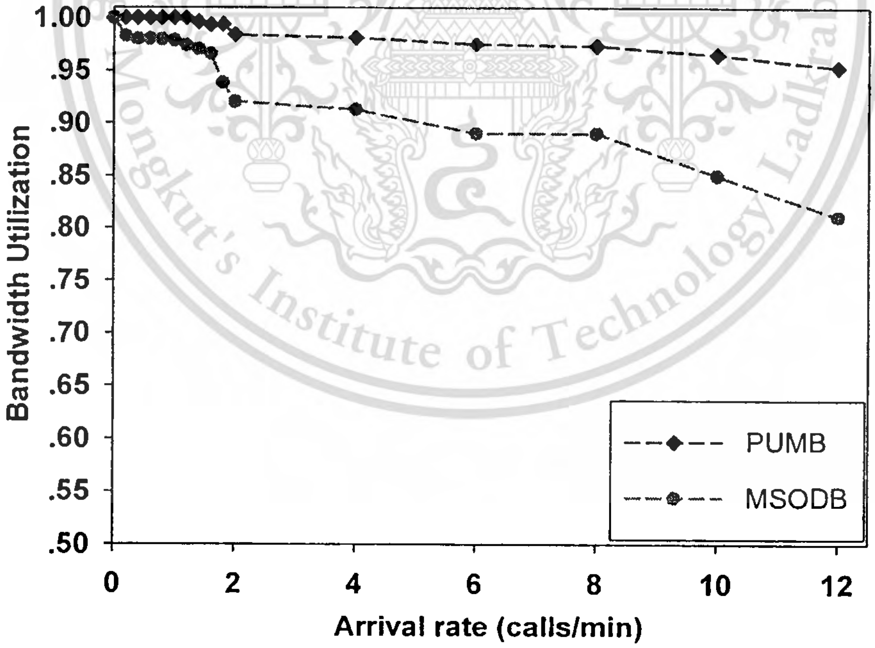

Figure 5.12 Comparison of bandwidth utilization for varying arrival rate

The bandwidth utilization of PUMB and MSODB are presented in figure 5.12. The result shows that as the arrival rate increases, the bandwidth utilization will decrease. However, PUMB achieves better bandwidth utilization than MSODB at all arrival rates. PUMB is able to increase the bandwidth utilization up to 2 ~ 14 % compared with the MSODB. In PUMB scheme if the MU does not arrive to cell j before RLI expires, all bandwidth are released and used to support the other calls. And PUMB can adjust SC window size based on typical behavior of MU so that it can reduce unnecessary reserved bandwidth and cells have more bandwidth to support the other calls. Therefore, bandwidths are used by considering the bandwidth utilization.

Figure 5.13 shows the overhead message transmission for various arrival rates. The graph clearly shows that overhead message increases as the call arrival rate increases. However, the PUMB has better performance than MSODB. PUMB decreases overhead message transmission less than MSODB about 2 ~ 6 %.

Because PUMB adjusts window size of SC based on typical behavior of MU so that it can reduce amount of cells in MU's shadow cluster. So that it can reduce overhead from message transmission for shadow cluster formation.

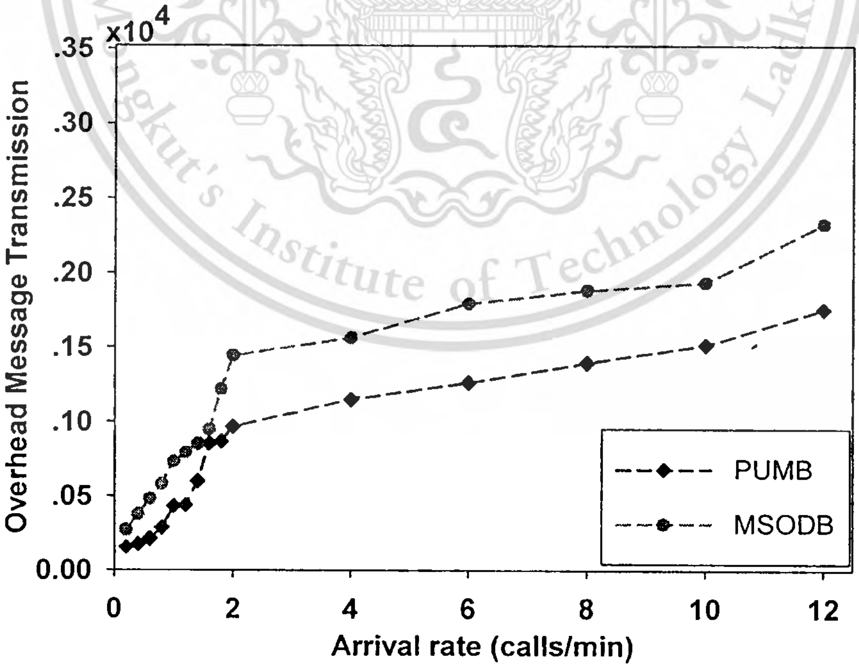

Figure 5.13 Comparison of overhead message transmission for varying arrival rates

5.2.1.4. DISCUSSIONS

From the results, PUMB can reduce the NCBP because if the MU does not arrive to cell j before Resource Leasing Interval expires, the reserved bandwidths are released and used to support the other calls. Also PUMB can adjust SC window size based on typical behavior of MU so that it can reduce unnecessary reserved bandwidth and cells have more bandwidth to support the other calls. Furthermore, PUMB can guarantee an uninterrupted service for admitted calls as they move from one cell to another by weighting reposes from all cells in the shadow cluster considering the CVP, thereby reducing the HCDP. This may increase the decision accuracy for call accepting or call rejecting.

In the PUMB scheme if the MU does not arrive to cell j before RLI expires, all bandwidth are released and used to support the other calls. And the PUMB can adjust SC window size based on typical behavior of MU so that it can reduce unnecessary reserved bandwidth and cells have more bandwidth to support the other calls. Therefore, bandwidths are used by considering the bandwidth utilization.

The performance metrics for varying arrival rates from figure 5.9-5.13, there are a phase change around arrival rate equal to 2 in both of PUMB and MSODB. Because in case of the arrival rate is less than 2, the available bandwidths in the current cell are used to support the handoff call as we can see in figure 5.10, and the HCDP in this range is very low. The remaining few available bandwidths can support the new call. This make the NCBP of new call increase rapidly as shown in figure 5.9. Figure 5.12 has shown that the available bandwidth in the current cell mostly used to support handoff call. For the overhead message transmission shown in figure 5.13, both new call and handoff call have to do the process for the SC formation. The overhead message transmission in this range also increases rapidly

In order to improve this situation, we need the scheme for balancing between NCBP and HCDP by using NCBP threshold and HCDP threshold in order to control and improve the quality of service. Another way is to consider the scheme for adjusting the shadow cluster window size depending on the situation in the networks.

5.2.2. PERFORMANCE METRICS FOR VARYING MOBILITY

In this part, we consider when arrival process has a Poisson distribution with new call arrival rate is 6 calls/min which is average congested networks. The moving speed of MU is varied for 5, 10, 15, 20, 25, 30, 35, 40, 45 m/s. The MU can start its itinerary from any location in the cellular network, with an appropriate state of movement.

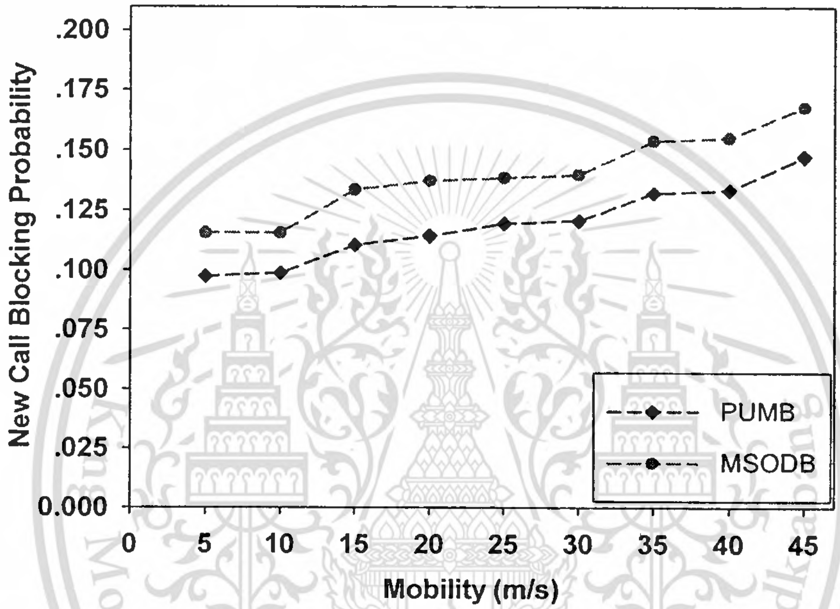

Figure 5.14 Comparison of new call blocking probability for varying mobility

The NCBP of PUMB and MSODB are shown in figure 5.14. It is shown that PUMB has better performance than MSODB while MU is moving faster. While MU is moving faster, the handoff also increases. As the result, the overhead message transmission from shadow cluster reformation increases, the NCBP increases. However, the PUMB can adjust the shadow cluster window size which can lead to decrease the unnecessary bandwidth reservation and the overhead message transmission. As the result, the PUMB can reduce the NCBP about 1~3 % compared with the MSODB.

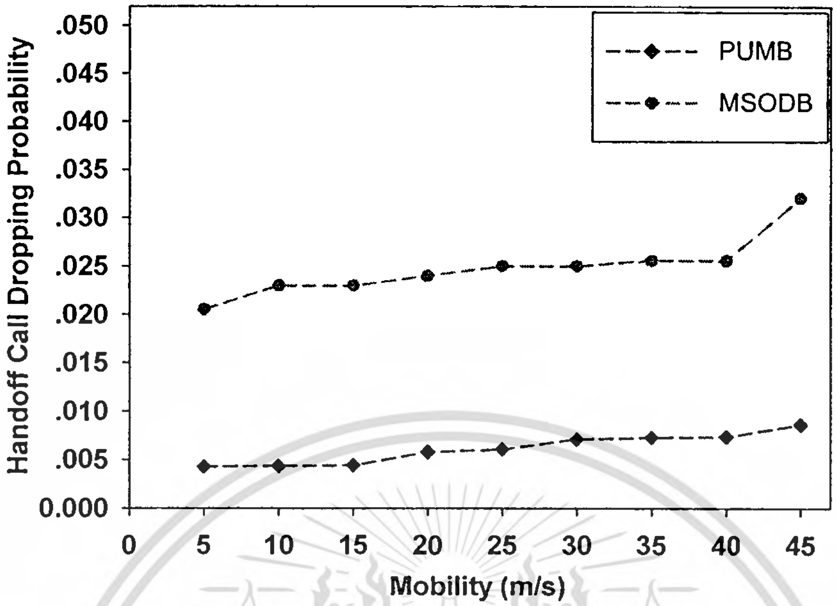

Figure 5.15 Comparison of handoff call blocking probability for varying mobility

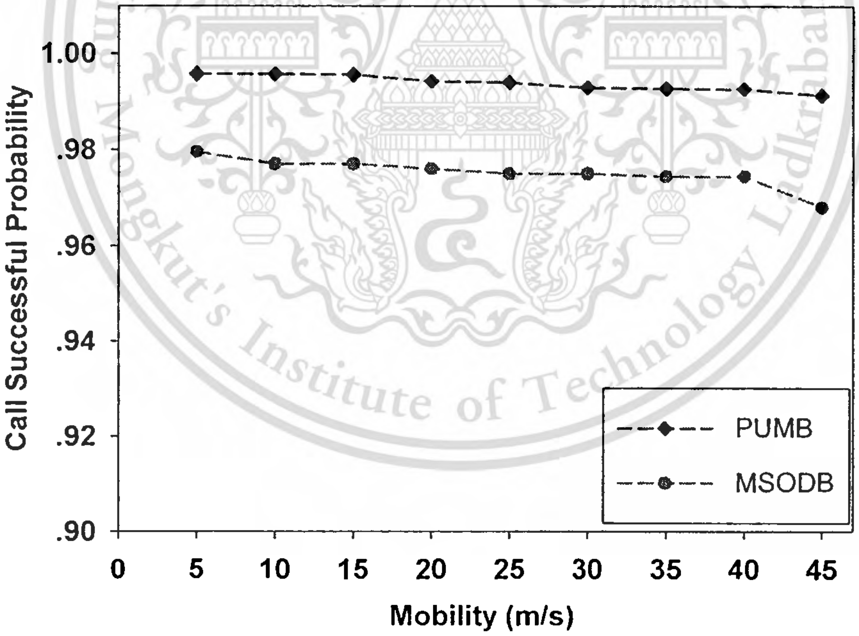

Figure 5.16 Comparison of call successful probability for varying mobility

The HCDP of PUMB and MSODB are presented in figure 5.15. The result has shown that PUMB has better performance than MSODB while MU is moving faster. Because the handoff increases as the moving speed increases. As the result, the overhead message increase which can lead to increase the HCDP. But the PUMB algorithm has the bandwidth borrowing algorithm and the decision process which weight all responses by their CVP for increasing the decision accuracy for call accepting. Therefore, it can guarantee an uninterrupted service and decrease HCDP less than MSODB about 1~3 %.

The CSP of PUMB and MSODB are presented in figure 5.16. The result shows that CSP of MSODB and PUMB slightly decrease when moving speed increases. Because the PUMB can increase the decision accuracy for call accepting or call rejecting. Therefore, it can guarantee an uninterrupted service for admitted call as they move from one cell to one of other cells. As the result, it can lead to decrease HCDP while increase CSP more than MSODB about 1-3 %.

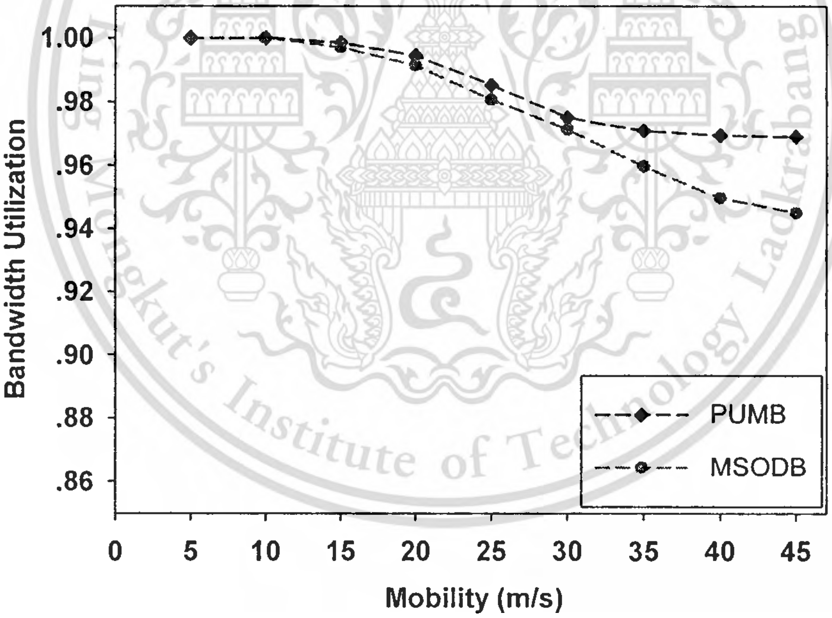

Figure 5.17 Comparison of bandwidth utilization for varying mobility

Figure 5.17 presents the bandwidth utilization of PUMB and MSODB. The result shows the trend of decreasing of bandwidth utilization as long as the moving speed of MU increases. However, PUMB achieves better bandwidth utilization than MSODB at all moving speed. PUMB is able to increase the bandwidth utilization up to 1 ~ 3 % compared with the MSODB.

Figure 5.18 shows the overhead message transmission for varying mobility. The results clearly show that as MU moves faster, the overhead message transmission increases. Because when the MU's moving speed is faster, the more chances of handoff increase. So that, the overhead message transmission from SC reformation increases. As the result, NCBP and HCDP increase while bandwidth utilization and CSP decrease. The PUMB has better performance than MSODB. It can reduce overhead message less than MSODB about 30 %.

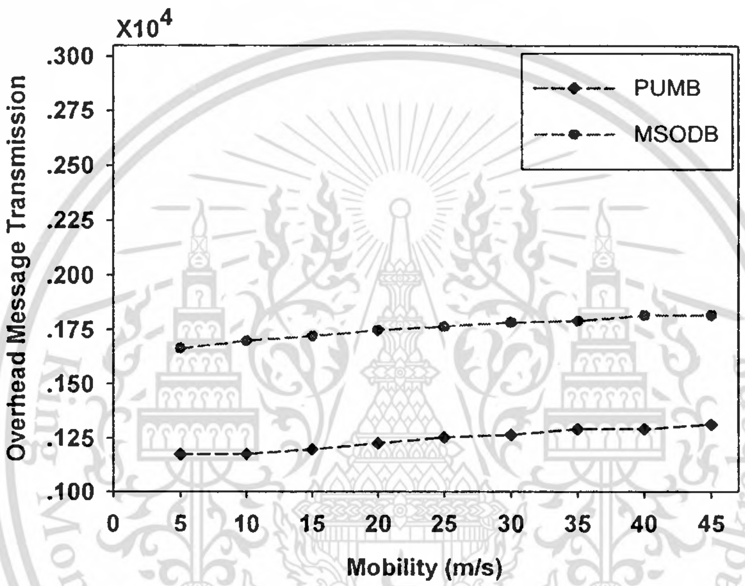

Figure 5.18 Comparison of overhead message transmission for varying mobility

From the result in Figure 5.14-17, there show that when the MU's moving speed increases, the performance of both schemes slightly change. So that, the moving speed of MU is not more effective for the PUMB and MSODB schemes. In addition to, the other values of arrival rate, the results are almost the same trend.

5.2.3. PERFORMANCE METRICS FOR VARYING SHADOW CLUSTER PROBABILITY THRESHOLD

In this section, the performance is evaluated by comparing between our proposed PUMB and traditional MSODB when the shadow cluster probability threshold, ψ is varied when moving speed range is 0-40m/s or 0-144 km/hr and the new call arrival rate is considered into 3 ranges: low (1 call/min), medium (5 calls/min) and high (10 calls/min).

5.2.3.1. FOR LOW ARRIVAL RATE

The NCBP of PUMB and MSODB in case of low arrival rate are shown in figure 5.19. When the shadow cluster probability threshold increases, NCBP of PUMB and MSODB decrease about 6% and 11% respectively. Because of the shadow cluster formation, the bandwidth is reserved only in a cell which has CVP higher than the shadow cluster probability threshold. So that, if the shadow cluster probability threshold is higher, amount of the cells in shadow cluster is lower. As the result, reserved bandwidth decreases and the cells have more bandwidth to support other calls. In the comparison of the NCBP between PUMB and MSODB, we found that the NCBP of PUMB is improved about 4.5-10% compared with the MSODB.

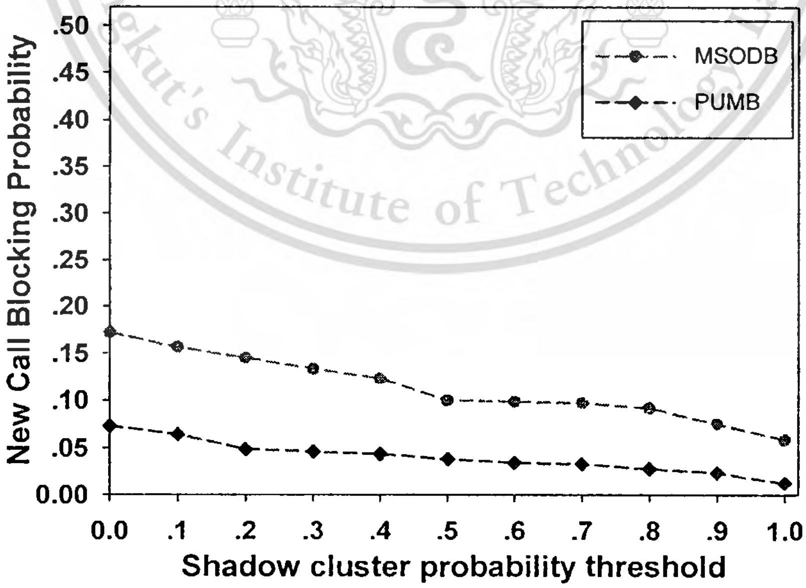

Figure 5.19 Comparison of new call dropping probability for varying shadow cluster probability threshold when arrival rate is 1 call/min

Figure 5.20 shows the HCDP of PUMB and MSODB. The results show that the HCDP of PUMB and MSODB increase as the shadow cluster probability threshold increases. Because when the shadow cluster probability threshold increases, the MU's shadow cluster size decreases. So that, amount of reserved bandwidths for each MU decreases. This causes effect to increase HCDP. When the shadow cluster probability threshold increases, the HCDP of PUMB and MSODB slightly increase 0.14% and 3.1% respectively. The HCDP of PUMB is improved about 2.7-3% compared with the MSODB.

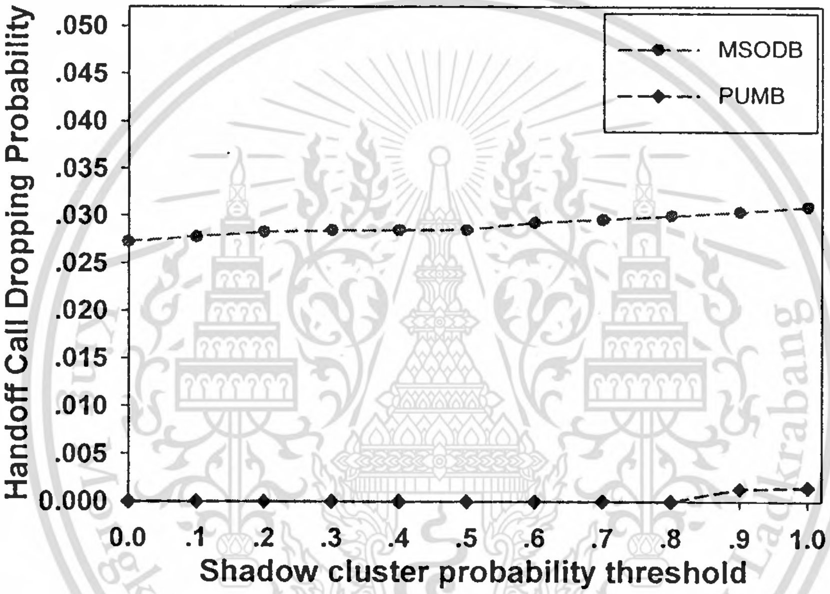

Figure 5.20 Comparison of handoff call dropping probability for varying shadow cluster probability threshold when arrival rate is 1 call/min

The CSP of PUMB and MSODB are presented in figure 5.21. The results show that the CSP of both schemes decrease as the shadow cluster probability threshold increases. If the shadow cluster probability threshold is higher, the shadow cluster size is less. As the result, the HCDP increases while lead to decrease CSP. When the shadow cluster probability threshold increases, the CSP of PUMB and MSODB decrease 0.14% and 3.1% respectively. The CSP of PUMB is more than MSODB about 2.7-3%.

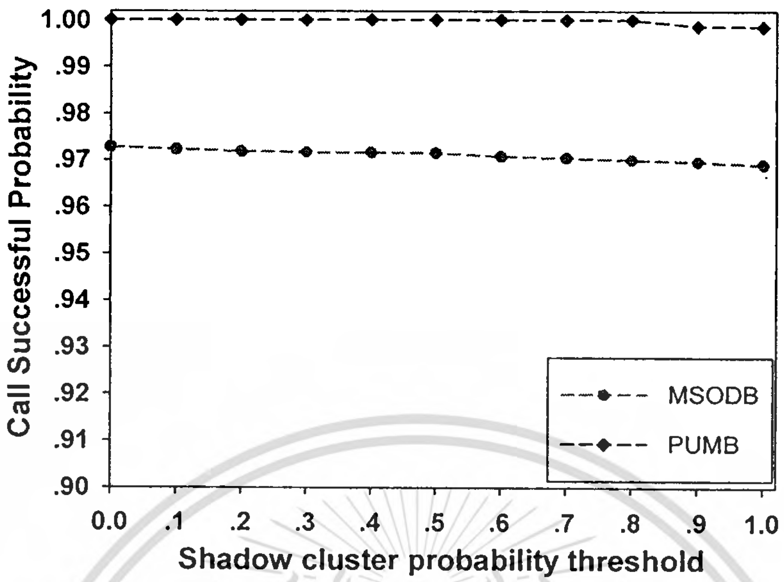

Figure 5.21 Comparison of call successful probability for varying shadow cluster probability threshold when arrival rate is 1 call/min

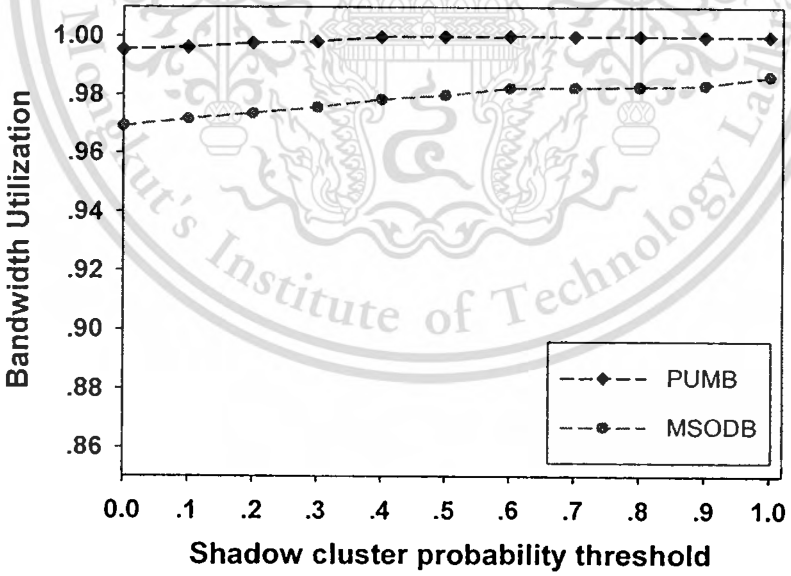

Figure 5.22 Comparison of bandwidth utilization for varying shadow cluster probability threshold when arrival rate is 1 call/min

Figure 5.22 presents the bandwidth utilization of PUMB and MSODB. The result shows the trend of increasing of bandwidth utilization as long as the shadow cluster probability threshold increases. Because of the shadow cluster formation, the bandwidth is reserved only in a cell which has CVP higher than the shadow cluster probability threshold. So that, if the shadow cluster probability threshold is higher, amount of the cells in shadow cluster is less. As the result, reserved bandwidth decreases and the cells have more bandwidth to support other calls. Therefore, bandwidth utilization increases. When the shadow cluster probability threshold increases, the bandwidth utilization of PUMB and MSODB increase 0.5% and 1.7% respectively. However, PUMB achieves better bandwidth utilization than MSODB about 1 ~ 2 %.

5.2.3.2. FOR MEDIUM ARRIVAL RATE

The NCBP of PUMB and MSODB in case of medium arrival rate are shown in figure5.23. When the shadow cluster probability threshold increases, the NCBP of PUMB and MSODB decrease. Because the shadow cluster probability threshold increases while lead to decrease the size of the shadow cluster. As the result, the reserved bandwidths decrease while the free bandwidths increase. So that, the NCBP of PUMB and MSODB decrease 6% and 6.5% respectively as the shadow cluster probability threshold increases. The differences in the NCBP of both schemes are more at lower arrival rates, the differences decrease as the shadow cluster probability threshold increases. The NCBP of PUMB is improved about 1.8-4.5% compared with the MSODB.

Figure 5.24 shows the HCDP of PUMB and MSODB. The results show that the HCDP of PUMB and MSODB increase as the shadow cluster probability threshold increases. In the shadow cluster formation, the bandwidth is reserved only in a cell which has CVP more than the shadow cluster probability threshold. So that, if the shadow cluster probability threshold is higher, the size of the shadow cluster is less. As the result, the HCDP increases. When the shadow cluster probability threshold increases, the HCDP of PUMB and MSODB increase 0.9% and 3.1% respectively. The HCDP of PUMB is improved about 2-2.6% compared with the MSODB.

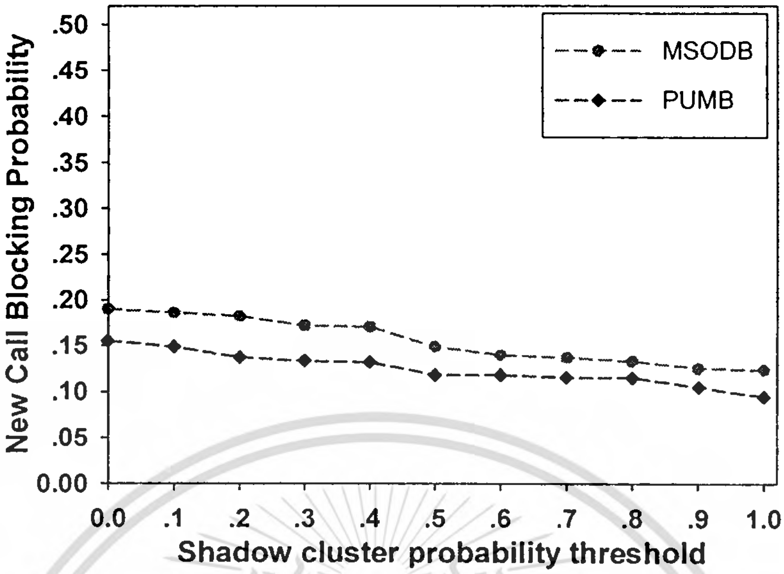

Figure 5.23 Comparison of new call dropping probability for varying shadow cluster probability threshold when arrival rate is 5 calls/min

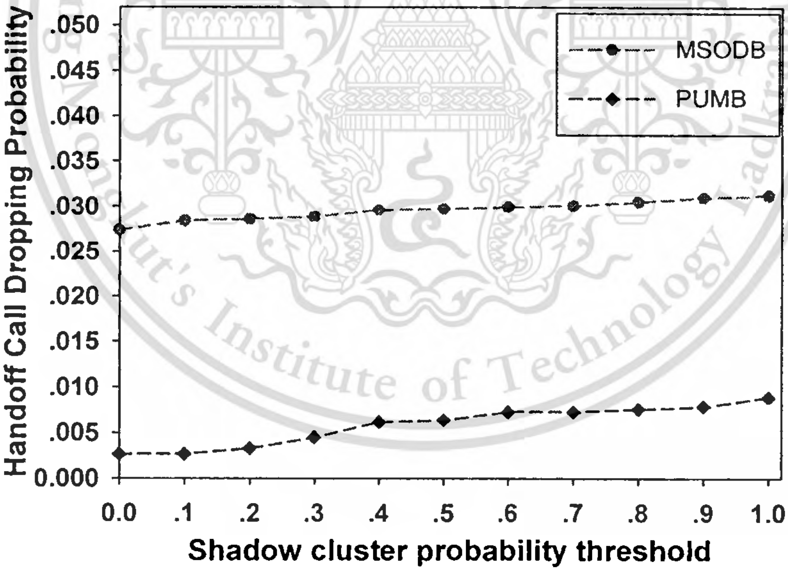

Figure 5.24 Comparison of handoff call dropping probability for varying shadow cluster probability threshold when arrival rate is 5 calls/min

The CSP of PUMB and MSODB are shown in figure 5.25. The results show that the CSP of PUMB and MSODB decrease as the shadow cluster probability threshold increases. If the shadow cluster probability threshold is higher, amount of reserved bandwidths is lower. As the result, the HCDP increases while lead to decrease the CSP. When the shadow cluster probability threshold increases, the HCDP of PUMB and MSODB decrease 0.9% and 3.1% respectively. The CSP of PUMB is improved about 2-2.6% compared with the MSODB.

Figure 5.26 presents the bandwidth utilization of PUMB and MSODB. The result shows the trend of increasing of bandwidth utilization as long as the shadow cluster probability threshold increases. When the shadow cluster probability threshold increases, the bandwidth utilization of MSODB and PUMB increase 2.5% and 1% respectively. Because amount of the reserved bandwidth decreases as the shadow cluster probability threshold increases. Therefore, cells have more bandwidth to support other calls. However, PUMB achieves better bandwidth utilization than MSODB about 1 ~ 2 %.

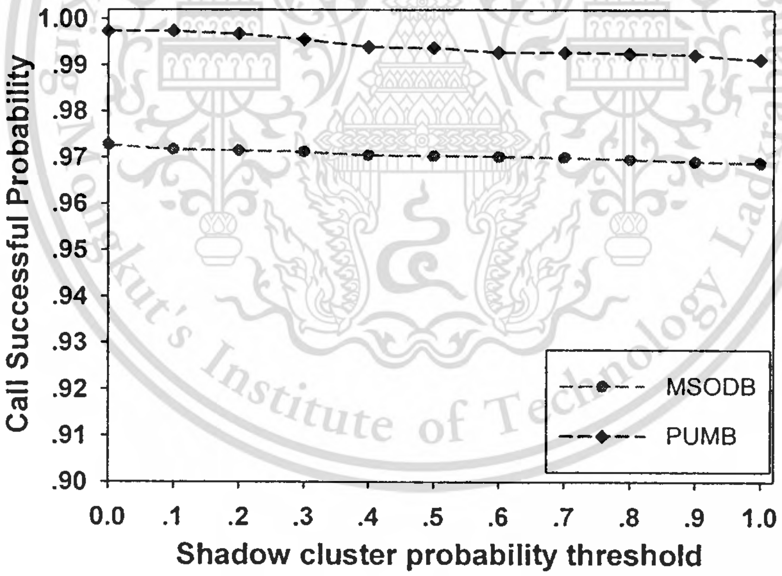

Figure 5.25 Comparison of call successful probability for varying shadow cluster probability threshold when arrival rate is 5 calls/min

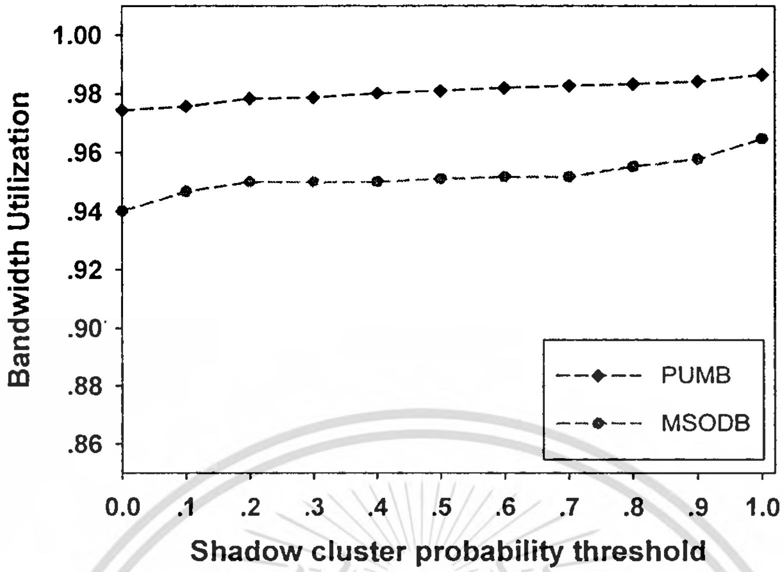

Figure 5.26 Comparison of bandwidth utilization for varying shadow cluster probability threshold when arrival rate is 5 calls/min

5.2.3.3. FOR HIGH ARRIVAL RATE

The NCBP of PUMB and MSODB in case of high arrival rate are shown in figure 5.27. When the shadow cluster probability threshold increases, the NCBP of PUMB and MSODB decrease. Because of the shadow cluster formation, the bandwidth is reserved only in a cell which has CVP higher than the shadow cluster probability threshold. So that, if the shadow cluster probability threshold is higher, amount of the cells in shadow cluster is lower. As the result, reserved bandwidth decreases and the cells have more bandwidth to support other calls. When the shadow cluster probability threshold increases, the NCBP of PUMB and MSODB decrease 6.5% and 7.5% respectively. The NCBP of PUMB is less than MSODB about 3.5-5.5%.

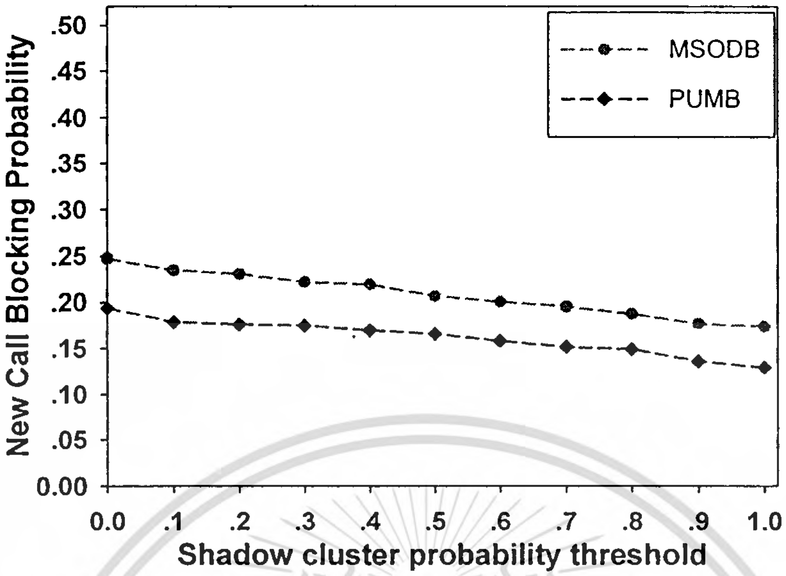

Figure 5.27 Comparison of new call dropping probability for varying shadow cluster probability threshold when arrival rate is 10 calls/min

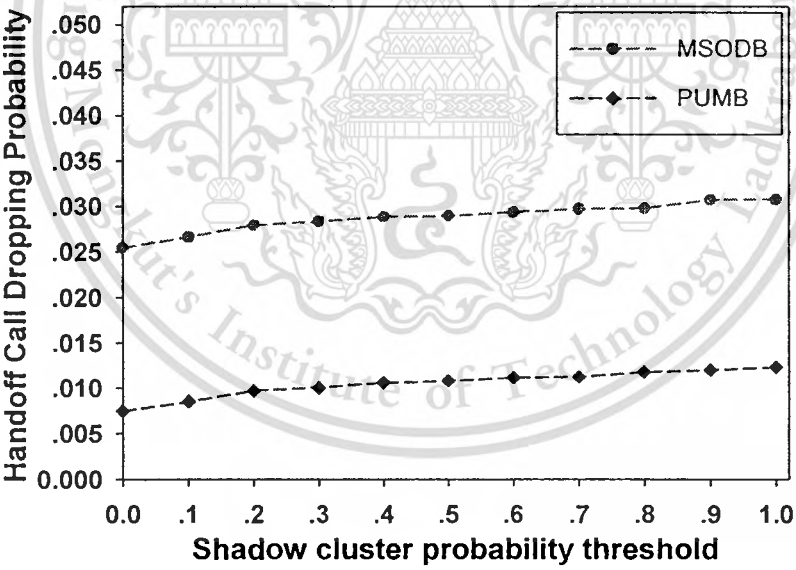

Figure 5.28 Comparison of handoff call dropping probability for varying shadow cluster probability threshold when arrival rate is 10 calls/min

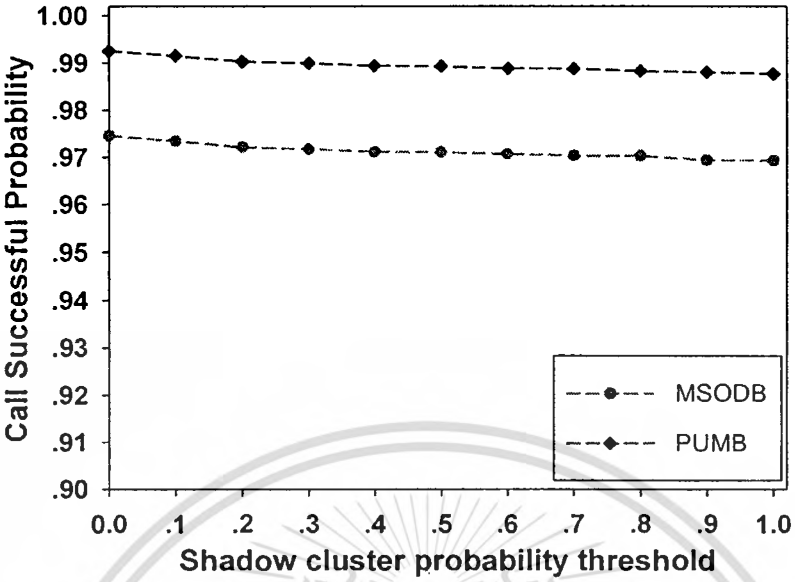

Figure 5.29 Comparison of call successful probability for varying shadow cluster probability threshold when arrival rate is 10 calls/min

Figure 5.28 shows the HCDP of PUMB and MSODB. The results show that the HCDP of PUMB and MSODB increase as the shadow cluster probability threshold increases. When the shadow cluster probability threshold increases, the HCDP of MSODB and PUMB increase 3.1% and 1.2% respectively. The HCDP of PUMB is less than MSODB about 1.7-2%. Increasing of the shadow cluster probability threshold can lead to decrease amount of reserved bandwidths. As the result, the HCDP increases and CSP decreases as shown in Figure 5.29. The results show that the CSP of PUMB and MSODB decrease about 1.2% and 3.1% respectively as long as the shadow cluster probability threshold increases. The CSP of PUMB is more than MSODB about 1.7-2%.

Figure 5.30 presents the bandwidth utilization of PUMB and MSODB. The result shows the trend of increasing of bandwidth utilization as long as the shadow cluster probability threshold increases. When the shadow cluster probability threshold increases, the bandwidth utilization of PUMB and MSODB increase 1.5% and 2.1% respectively. However, PUMB achieves better bandwidth utilization than MSODB about 1 ~ 2 %. Because the shadow cluster probability threshold increases, the shadow cluster size decreases. Therefore, the reserved bandwidths decrease while lead to increase the available bandwidths to support other calls. Also, the NCBP decreases and bandwidth utilization increases.

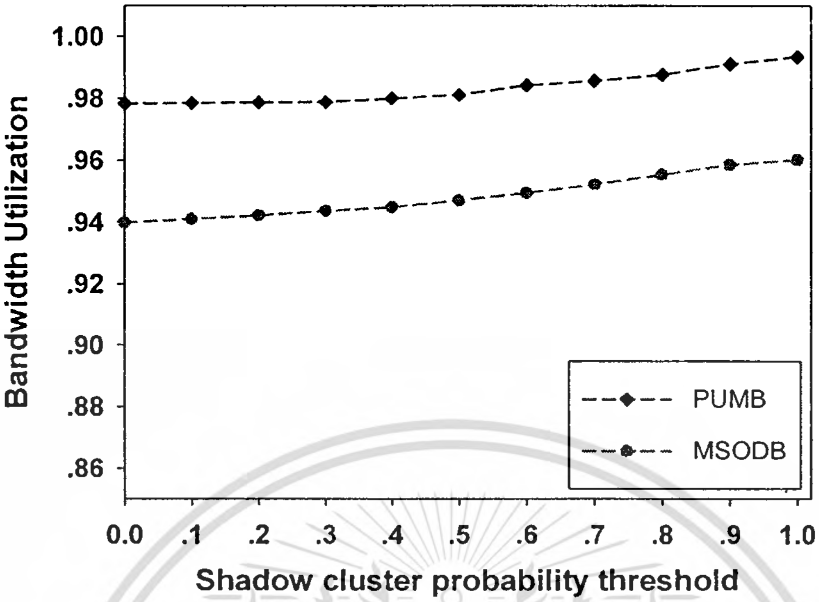

Figure 5.30 Comparison of bandwidth utilization for varying shadow cluster probability threshold when arrival rate is 10 calls/min

5.2.3.4. DISCUSSIONS

From the results, in case of arrival rate is low (1 call/min), the shadow cluster probability threshold has a little effect to HCDP value as shown in figure 5.20, HCDP values of the shadow cluster probability threshold between 0-0.8 don't vary. Because the traffic is low, the network can support bandwidth reservation of all calls. In the other hand, the shadow cluster probability threshold effects to NCBP value because the high shadow cluster probability threshold value effects to decrease the reserved bandwidth that can receive more new call. From the graphs, the suitable shadow cluster probability threshold value for low arrival rate is 0.8. When arrival rate is higher (5 and 10 calls/min), the shadow cluster probability threshold effects to HCDP value because the high shadow cluster probability threshold value effects to decrease the reserved bandwidth that can lead HCDP increasing while NCBP decreases due to the network can support more new call. From the results, the suitable shadow cluster probability threshold values for medium and high arrival rate are 0.2-0.3 and 0.1-0.3, respectively.

Table 5.4 Summary the shadow cluster probability threshold for each case of new call arrival rate

New call arrival rate (call/min)	**Shadow Cluster Probability Threshold**		
	New Call Blocking Probability (NCBP)	**Handoff Call Dropping Probability (HCDP)**	**Balance NCBP and HCDP (Optimal)**
1	0.8-1.0	0.0-0.8	0.8
5	0.2-1.0	0.0-0.3.	0.2-0.3
10	0.1-1.0	0.0-0.3	0.1-0.3

In the shadow cluster formation, the bandwidth is reserved only in a cell which has CVP more than the shadow cluster probability threshold. When shadow cluster probability threshold increases, the MU's shadow cluster size decreases. So that, amount of reserved bandwidths for each MU decrease. As the result, the reserved bandwidths in the network decrease and free bandwidths that used to support new call increase. This causes effect to increase HCDP and the unused reserved bandwidths increase due to the handoff call is dropped before it arrivals to these cells. Therefore, HCDP increases as long as shadow cluster probability threshold increases while NCBP and CSP decrease. On the other hand, when shadow cluster probability threshold is lower, amount of cell in each MU's shadow cluster is greater. The reserved bandwidths increase but the available bandwidths decrease.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

6.1. CONCLUSIONS

This thesis has proposed the scheme to improve the performance, called "Predictive User Mobility Behavior" (PUMB). The PUMB is extended or modified from Mobility Support On-Demand Borrowing (MSODB) and Predictive Mobility Support (PMS). The characteristics comparison of PMS, MSODB, and PUMB can be summarized as shown in Table 4.1. In PMS scheme [14], Cell Visiting Probability (CVP) was introduced to estimate the probability of an active MU visiting a neighboring cell. For each neighboring cell, a measure of directionality is obtained as the ratio of two angles: the one made by the line joining the centers of the current and neighboring cells with the predicted direction, and the other by the predicted direction with the line joining the centers of the current and immediate previous cells. The CVP for each neighboring cell is then calculated as its normalized directionality over a ring. Resource reservation time window (RTW) for each MU is estimated for each cell in the SC to reserve bandwidth. The PMS scheme allows a new call to be accepted only if its required bandwidth can be served and cells in the SC can reserve the necessary bandwidth for the call.

However, the PMS scheme is also restrictive for the following reasons. Firstly, PMS considers only the direction from the centers of the cells, and does not take other parameters such as position and speed into account. In the PMS scheme the CVPs of all the neighboring cells whose centers lie on along the same line as that of the current cell are equal for different positions of the cells which have the same SC. Secondly, CVP is not calculated if the MU has not encountered handoff, since PMS scheme calculates CVP from previous cell direction and estimated direction at the handoff.

In MSODB [18] scheme, all three key mobility parameters of distance, direction, and speed are used together to calculate the CVP normalized over a ring of cells similar to those presented in [14]. The MSODB scheme calculates CVP and RTW by incorporating the expected travel distance (ETD) in order to take into account the reserved resources and available bandwidth information for all of the cells in the SC.

However, the MSODB scheme is also restrictive for the following reasons. Firstly, in MSODB scheme, a call is not considered for prediction conforming call and prediction nonconforming call. When a call is accepted to the network, each cell in its SC will reserve bandwidth in all Reservation Time Window (RTW). Although when a call may arrive to a cell that is not a part of its SC, it may be dropped because bandwidths are not reserved for it while the reserved bandwidths in its SC are not released. As the result, the remaining available bandwidths for supporting the other calls decrease. When they arrive to the cell, they cannot use these bandwidths. This may cause the unnecessary blocking for new call and handoff call. Secondly, reposes from all cells in the SC have equal priority, irrespective of their distance to the current cell and their CVPs. As a result, sometimes handoff call may be dropped, due to the fact that the cell with less CVP which is far away from current cell can be supported while the cell which is near the current cell cannot be supported.

The main objectives of the CAC in PUMB upon accepting a connection request are as follows: 1) verifying the feasibility of accepting a new call into the system, 2) guaranteeing an uninterrupted service for admitted calls as they move from one cell to another, and 3) maximizing the utilization of the network resources. Two functions have been added into the PUMB. There are (1) adjusting the window size of Shadow Cluster (SC) by considering the typical behavior of mobile unit (MU) such as direction and speed, and (2) weighting reposes from all cells in the SC by considering the Cell Visiting Probability (CVP). The response from a cell with more CVP has higher priority than a cell with less CVP which is far the current cell. This may increase the decision accuracy for call accepting or call rejecting. As the result, it can guarantee an uninterrupted service for admitted call as they move from one cell to another.

The simulation has been performed in order to compare the achieved performance with the MSODB. The simulation results are demonstrated in three parts. The first part is the comparison between PUMB and MSODB when new call arrival rate is varied. The second part is the comparison between PUMB and MSODB when the moving speed of MU is varied and new call arrival rate is 6calls/min which is average congested network. The final part is the comparison between PUMB and MSODB when shadow cluster probability threshold is varied while moving speed rang is 0-40m/s or 0-144 km/hr and the new call arrival rate is considered into 3 ranges: low (1 call/min), medium (5 calls/min) and high (10 calls/min).

The simulation results demonstrated that our proposed scheme may have the better performance than MSODB even through the new call arrival rate or MU's moving speed or the shadow cluster probability threshold increases. The PUMB can reduce new call blocking probability and handoff call dropping probability while increasing bandwidth utilization and call successful probability.

In part of varying the shadow cluster probability threshold, when the shadow cluster probability threshold increases, new call blocking probability of MSODB and PUMB decrease while handoff call dropping probability of both schemes increases in all arrival rates. In case of the new call arrival rate is low, the suitable shadow cluster probability threshold value is 0.8. When the new call arrival rate is higher, the suitable shadow cluster probability threshold values for medium and high arrival rate are 0.2-0.3 and 0.1-0.3, respectively.

6.2. FUTURE WORK

The simulation results in the case of varying the shadow cluster probability threshold, they show that the shadow cluster probability threshold has effect to the network performance such as new call blocking probability and handoff call dropping probability. Because when the shadow cluster probability threshold increases, the *MU*'s shadow cluster size decreases. As the result, new call blocking probability decreases while handoff call dropping probability increases.

In addition to, the suitable shadow cluster probability threshold is varied follow the traffic environment such as cell size and traffic characteristics. For the low arrival rate, the suitable shadow cluster probability threshold is high. In the other hand, when arrival rate is higher, the suitable shadow cluster probability threshold is lower. Therefore, the suitable shadow cluster probability threshold can lead the suitable shadow cluster size.

For the future work, we plan to improve the performance of this scheme. We will adapt our scheme by adjusting the shadow cluster probability threshold depending on the situation in the networks for balancing between new call blocking probability and handoff call dropping probability.

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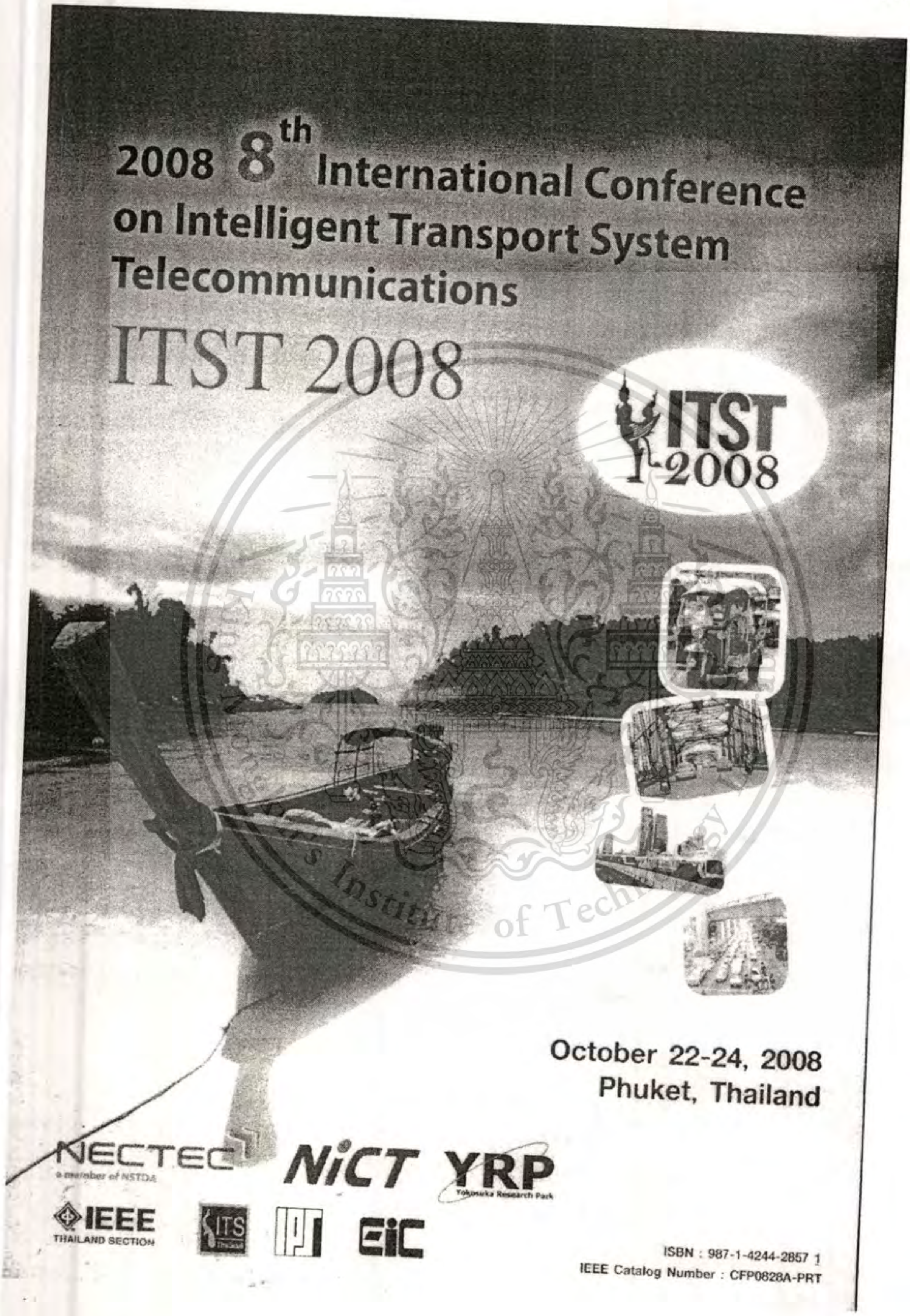
APPENDIX A PUBLISHED PAPERS



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Effect of Mobility on Predictive Mobility Support Dynamic Resource Reservation in Cellular Networks

SILADA INTARASOTHONCHUN, SAKCHAI THIPCHAKSURAT, AND
RUTTIKORN VARAKULSIRIPUNTH

Abstract— **In this paper, we propose a scheme for improved performance of resource reservation and call admission control for cellular networks called Predictive Mobility Support Demand (PMSD) scheme. This scheme is proposed in which bandwidth is allocated more efficiently to neighboring cells by key mobility parameters in order to provide QoS guarantees for transferring traffic. The probability is used to form a cluster of cell and the shadow cluster, where a mobile unit is likely to visit. Concomitantly, to ensure continuity of on-going calls with better utilization of resources, bandwidth is borrowed from prediction nonconforming calls and existing adaptive calls without affecting the minimum QoS guarantees. We evaluate the performance of PMSD scheme by means of the simulation. We measure several performance metrics such as the call blocking probability, call dropping probability ,and bandwidth utilization by comparing with the Mobility Support on Demand Borrowing (MSODB) scheme. The simulation results show that PMSD scheme provides the better performance that the one of MSODB.**

I. INTRODUCTION

CURRENTLY, mobile cellular networks are extending to support several types of traffics under diverse bandwidth requirements. These networks will serve multiple traffic classes with each class having different *quality of service* (QoS) requirements. In wireless networks, the scarcity of wireless bandwidth, the movements of users, and channel imperfections make QoS provisioning an extreme challenging task for wireless networks, in contrast to wired networks. The challenge is heightened further in cellular networks where an ongoing service can be dropped while handing-off to an adjacent cell if there are insufficient free resources to continue the service. *Call admission control* (CAC) is such a strategy to limit the number of call connection into the networks in order to reduce the network congestion and call dropping.

In cellular networks, an important QoS parameter is the *call blocking probability* (CBP), denoting the probability that a new connection request will be denied to admit into

the network. A similar situation arises when an active connection in one cell attempts to migrate into a neighboring cell and if this neighboring cell cannot support the level of resources required by the connection, this handoff is dropped. The probability of this situation is known as the *call dropping probability* (CDP). An additional important parameter is the degree to which the network makes an effective use of bandwidth. This parameter is called "*bandwidth utilization*", which equivalence to the ratio of the amount of bandwidth used by various connections admitted into a network divided by the minimum number between the total bandwidth requested and the total bandwidth available.

However, from the user's perspective, dropping an active call is more undesirable than blocking a new call. In order to support handoff call, any cellular network must implement a resource reservation algorithm within call admission control scheme. The concept of shadow cluster [1][3] is a predictive resource allocation scheme that provides high utilization of wireless network by dynamically reserving only those cells that the *mobile unit* (MU) may visit in the future. With the implementation of shadow cluster, the QoS can be improved by reducing the number of dropped calls and by disallowing the new calls that are highly likely result later in a dropped call.

The Mobility Support on Demand Borrowing (MSODB) scheme[5] used key mobility parameters such as distance, direction and speed together to calculate the *cell visiting probability* (CVP). CVPs and *Reservation Time Window* (RTW) were calculated by incorporating with the *expected travel distance* (ETD) in order to take into account on the reserved bandwidth and available bandwidth information for all of the cells in the shadow cluster.

In this paper, a new bandwidth reservation scheme is proposed using *Predictive Mobility Supported Demand* (PMSD) as the extended or modified scheme of MSODB. The main concept is that bandwidth is reserved in a cell only if the MU has higher probability of arriving in that cell based on key mobility parameters. However, if a cell that a MU arrives is no bandwidth currently reserved, then bandwidth is borrowed from the prediction nonconforming calls and the existing adaptive calls. If a call arrives to any cell before or after than the resource leasing interval, the reserved bandwidths are released and not reserved all RTWs like MSODB. Accordingly, unlike the MSODB scheme, PSMD can support prediction nonconforming calls and the

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shadow cluster window can adjust based on typical behavior of MU.

The rest of the paper is organized as follows. In Section II, we explain the proposed resource reservation model. We present our proposed scheme called Predictive Mobility Support Demand (PMSD) scheme in Section III. The simulation and results are provided in Section IV. Section V concludes our work.

II. PROPOSED RESOURCE RESERVATION MODEL

In order to support QoS guarantees efficiently, the cellular network must provide the required level of service, even if an active MU moves to a congested cell. This requires an exact future trajectory of the MU, so that required amount of resources can be reserved in advance, in those cells that will be visited by the MU. Since it is impossible to know the exact trajectory of all MUs in the network, a *shadow cluster* (SC) is formed by comprising the cells that are most likely to be visited by the MU, based on calculated CVP.

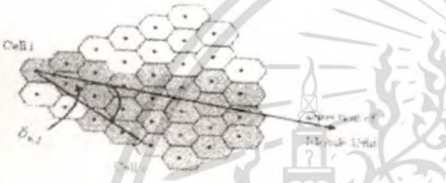

Fig. 1. Graphical definition of $\delta_{x,j}$ and formation of SC (The shaded area)

The CVP, $P_{x,j}$, is the probability that an active MU x may move from it's current cell to a neighboring cell j, and it can be derived from its current position, mobility direction, speed and the *Expected Travel Distance* (ETD), $D_{x,j}$ to arrive at cell j. Let v_x be the average moving speed of MU x and $\delta_{x,j}$ be the directional angle between the moving direction of MU x and a line joining the centre of cell j with the position of MU x, as shown in Fig. 1.

Fig. 2. Definition of virtual rings in heterogeneous cellular network

All the neighboring cells are clustered into different *virtual rings* (V-ring) centered about the centre of current cell i, as proposed in [1]. The radius of V-ring 1 ($R_{i,1}$) is equal to the distance from the centre of cell i to the centre of the bordered neighboring cell, whose centre is furthest away (see Fig. 2) from center of current cell i. Consequently, the radius of $R_{i,n}$ ($n = 1,2,3,\ldots$) is equal to n times the radius of $R_{i,1}$. Any cell that has its centre on the outer boundary of a V-ring is considered to be a member in that V-ring.

The CVP of MU x to visit cell j is assumed to have a value normalized over the V-ring in which cell j resides, the CVP for MU x to visit cell j is found as shown in (1)

$$P_{x,j} = \begin{cases} \dfrac{\dfrac{v_x^2 \cos\delta_{x,j}}{D_{x,j}}}{\displaystyle\sum_{k \in R_{i,n},\, n \neq R_{i,0}} \dfrac{v_x^2 \cos\delta_{x,k}}{D_{x,k}}}, & \delta_{x,j} \le \pi/2 \\ 0 & \text{, otherwise} \end{cases} \qquad (1)$$

Where, $R_{i,0}$ is the current cell i and the summation is over the cell k that are in the same V-ring as cell j.

A. Formation of the SC

Based on the calculated $P_{x,j}$, we define the SC for an active MU x to include all neighboring cells j such that $P_{x,j} \ge \psi$, where ψ is a ***predefined shadow probability threshold***, which can be set in a cellular network to achieve CDP under a predefined value by defining the forward span as the set of cell situated within the SC. After determining the forward span, the next step in the process of forming the SC is to decide on the *window size of the SC* (W_{sc}). The W_{sc} is defined as the number of adjacent V-rings of cells to be included in the SC.

The size of W_{sc} has a strong impact on the performance of the scheme. Increasing the W_{sc} by including more V-rings will increase the likelihood of supporting the required QoS if a MU moves along the current direction. On the other hand, if a MU deviates from the current direction, increasing the W_{sc} may not ensure the continued support of the call, as a MU may move out from the SC.

When MU deviates from the current direction, the W_{sc} is decreased by an amount proportional to the degree of deviation. W_{sc} is recalculated at every handoff. Therefore, the W_{sc} shrinks and grows depending on the MU's moving behavior.

B. Reservation Time Window (RTW)

The proposed scheme considers ETD and its standard deviation to estimate the RTW of a MU in each cell of the SC, in three terms of the time when MU x arrives at cell j from cell i, i.e., *expected earliest arrival time* $\hat{T}_j^{ea}(x)$, the *latest arrival time* $\hat{T}_j^{la}(x)$ and the *latest departure time* $\hat{T}_j^{ld}(x)$. These time parameters can be determined by using the *maximum ETD*, $D_{i,j}^{max}$ and the *minimum ETD*, $D_{i,j}^{min}$ between center of cell i and cell j, and by introducing normal distribution that has mean and standard deviation as $\bar{D}_j$ and $\sigma_{i,j}$, respectively. Then, by using the fact that distance = time × speed, we can obtained

$$\tilde{T}^{EA}_{i,j}(x) = \frac{\tilde{D}^{min}_{i,j}}{v_x} \quad \text{and} \quad \tilde{T}^{LA}_{i,j}(x) = \frac{\tilde{D}^{max}_{i,j}}{v_x} . \qquad (2)$$

$\tilde{T}^{EA}_{i,j}(x)$ is defined as the lower end of RTW whereas the higher end $\tilde{T}^{LD}_{i,j}(x)$ can be found by adding the maximum of the *expected call residence time* (CRT) to $\tilde{T}^{LA}_{i,j}(x)$ as shown in (3).

$$\tilde{T}^{LD}_{i,j}(x) = \tilde{T}^{LA}_{i,j} + CRT \quad , \qquad (3)$$

Where,

$$CRT = \frac{2R_j}{v_x}$$

and R_j is the radius of cell j.

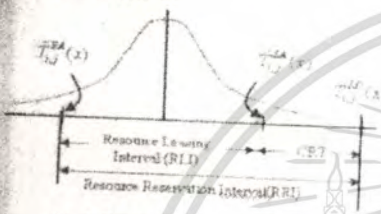

Fig. 3. Graphical definition of RTW

Figure 3 shows that the RTW is the expected residence time of a MU within cell j, $[\tilde{T}^{EA}_{i,j}(x), \tilde{T}^{LD}_{i,j}(x)]$. This interval is referred to as the *Resource Reservation Interval* (RRI) while the arrival interval $[\tilde{T}^{EA}_{i,j}(x), \tilde{T}^{LA}_{i,j}(x)]$ is referred to as the *Resource Leasing Interval* (RLI). Resources or bandwidth are reserved for the entire duration of RRI. However, if the MU does not arrive to cell j before RLI expires, all bandwidth are released and the reservation is canceled. This is necessary to prevent MU from holding resources unnecessarily.

C. Resource Reservation

The proposed scheme then reserves an amount of bandwidth in a cell for a service proportional to the maximum bandwidth requirement of the service multiplied by the CVP for that cell. Let $R_{y,j}$ be the amount of bandwidth reserved for a service y, such as handoff, on-going, new call. Therefore, for a given time t, where $\tilde{T}^{EA}_{i,j}(x) \le t \le \tilde{T}^{LD}_{i,j}(x)$, it can be obtained as below

$$R_{y,j} = P_{x,j} B^y_{max} \qquad (4)$$

Where B^y_{max} is the maximum bandwidth required for providing to service y.

III. THE PREDICTIVE MOBILITY SUPPORT DEMAND SCHEME

In this section, we will present our proposed scheme called the Predictive Mobility Support Demand (PMSD) scheme. Firstly, it is necessary to define the traffic in cellular network into two classes:

Class I: Real time traffic – These traffics are partially elastic and can degrade bandwidth in congested network such as interactive voice and video application.

Class II: Non real time traffic – These traffics are fully elastic and can use any of the minimum transmission rate such as web browsing and file transfer protocol.

If a *class I* call comes into a cell with insufficient bandwidth, some *class II* calls should be terminated, if necessary, for making space. The elastic nature of the service plays important role in deciding whether a service should be accepted in the system or not. A *Class II* service is accepted if any bandwidth greater than zero can be allocated to it. For *Class I* services, QoS becomes questionable if only the minimum bandwidth required for service y. The expected bandwidth B^y_{exp} for service y can be derived as below [5] when B^y_{min} is the minimum bandwidth required for service y.

$$B^y_{exp} = B^y_{min} + \frac{(B^y_{max} - B^y_{min})^2}{B^y_{max}} - 2B^y_{min} - \frac{(B^y_{min})^2}{B^y_{max}} \qquad (5)$$

A service is accepted if it is possible to allocate an amount B^y_{exp} of bandwidth, even after borrowing the amount of bandwidth from the existing service to meet the user's demands of reducing CDP. The *fair borrow able bandwidth* (FBB) is defined as the average amount of bandwidth that can be borrowed from a service, given by $\max\{B^y_a(t) - B^y_{exp}, 0\}$, while the *maximum borrow able bandwidth* (MBB) is defined as the maximum amount of bandwidth that can be borrowed from a service, i.e., $B^y_a(t) - B^y_{min}$, where $B^y_a(t)$ is the amount of currently allocated bandwidth to service y at a given time t.

A. Call Feasibility and Setup Procedure

Based on the guarantee of required service, a call is accepted if following two conditions are met. First, the bandwidth required to support the guaranteed requested service must be available in the cell where the call originates. Second, the required bandwidth must also be available for reservation in cells in shadow cluster at lease guaranteed service level. If the decision is to admit the call, the required bandwidth is allocated in the current cell and $R_{y,j}$ bandwidth is reserved in those cells for which it is agreed to reserve bandwidth during feasibility analysis.

Upon receive the reservation request, each cell in the SC decides whether it has sufficient bandwidth to reserve for the service. The base station sends positive response if it can support the service through receiving resources, and a negative response otherwise, as shown in

$$A^y = \begin{cases} 1, \text{ if } C^y(t) \ge R_{y,j} \text{ for } [\tilde{T}^{EA}_{i,j}(t), \tilde{T}^{LD}_{i,j}(t)] \\ 0, \text{ otherwise} \end{cases}$$

Where $C_i^f(t)$ is amount of free bandwidths in originating cell i at time t. The value of r are collected for all cells j in the SC of the originating cell i for the MU x. The decision to accept is taken if the following holds:

$$1 \geq \sum_{j\in SC}(P_{x,i,j}\cdot A^t_{i,j}) \geq r\cdot\sum_{j\in SC}P_{x,i,j} \geq 0\ ;\ 0\leq r\leq 1$$

The above feasibility test condition the RTW and the CVP, so that more weight is given to the support responses of the cells whose CVP is comparatively higher. When the originating cell i accepts the call, it sends a message to all cell in SC, indicating that the reservation must now be performed. Every call reserved the required bandwidth for the RRI duration and updated its available bandwidth accordingly. However, notice that cell j cancels the reservation if the MU that does not arrive prior to the expiration of the lease period RLI.

B. Prediction Conforming and Nonconforming Call

1) *Prediction conforming call:* When a call is accepted to the network, it is said to be prediction conforming call as long as it visits cells that belong to its SC and resides within each cell for the RRI period.

2) *Prediction nonconforming call:* A call is accepted to the network, but arrives to a cell earlier than its earliest arrival time, or arrives to a cell after its lease period RLI expires, or to a cell that is not part of its SC.

Notice that an early call remains prediction nonconforming up to the beginning of its RRI period after which it becomes prediction conforming. Furthermore, a call that remains within a cell beyond its RRI period is also considered prediction nonconforming. Consequently, a call may change status multiple times during its duration.

The CAC gives higher priority to prediction conforming calls over prediction nonconforming calls. When a prediction conforming call arrives and cannot be accommodated by the available bandwidth, a prediction nonconforming call is dropped.

C. Call Admission Control Algorithm for New Call

Class I

① IF $C_i^f(t)$ + summation of FBB $\geq B^i_{req}$, THEN send reservation request to all the cells of the SC and receive response form each cell of the SC. Otherwise, GOTO ⑤.

② IF $\sum_{j\in SC}(P_{x,i,j}\cdot A^t_{i,j}) \geq r\cdot\sum_{j\in SC}P_{x,i,j}$, THEN accept the call and GOTO ③, Otherwise, GOTO ⑤.

③ IF $C_i^f(t) \geq B^i_{max}$, THEN allocate an amount, B^i_{max}, of bandwidth to the call. Otherwise, allocate free bandwidth to the call, redistribute the bandwidth through allocating first the minimum required to each and then surplus according to their elasticity limit.

④ Admitted call as prediction conforming call. Send confirmation to each cell in SC to reserve an amount of bandwidth and GOTO ⑥.

⑤ Reject the call.

⑥ STOP

Class II

IF this cell has free bandwidth, THEN accept the call and admitted call as prediction conforming call. Otherwise, reject the call.

D. Call Admission Control Algorithm for Handoff Call

① IF this cell is in SC and a call arrives to the cell during the lease period RLI, THEN GOTO ③, Otherwise, GOTO ②.

② IF $C_i^f(t) \geq B^i_{min}$, THEN allocate an amount, B^i_{min}, of bandwidth to call, admitted call as prediction nonconforming call, compute new SC and GOTO ⑨, Otherwise, GOTO ③.

③ IF $C_i^f(t)$ + summation of MBB $\geq B^i_{min}$, THEN accept call, admitted call as prediction conforming call and GOTO ④, Otherwise, GOTO ⑧.

④ IF $C_i^f(t) + C_i^r(t) \geq B^i_{max}$, THEN allocate an amount, B^i_{max} of bandwidth to call. Otherwise, GOTO ⑤.

⑤ IF $C_i^f(t) + C_i^r(t) \geq B^i_{min}$, THEN allocate free bandwidth and reserved bandwidth to call and GOTO ⑨, Otherwise, GOTO ⑥.

⑥ IF call is non-rate adaptive call, THEN allocate free bandwidth and reserved bandwidth to call and GOTO ⑦. Otherwise, include the call in the list of existing call, redistribute the bandwidth among adaptive calls without effecting non-rate adaptive calls and GOTO ⑨.

⑦ IF bandwidth held by prediction non-conforming calls can be freed, THEN terminate then, allocate bandwidth to call and GOTO ⑨. Otherwise, borrow bandwidth from existing rate-adaptive call and GOTO ⑨.

⑧ Reject the call.

⑨ STOP

IV. PERFORMANCE EVALUATION EXPERIMENTS

In this section, the simulation results are presented call blocking probability, call dropping probability, and bandwidth utilization. The performance is evaluated by comparing between our proposed PMSD and traditional MSODB schemes. In this simulation, we assumed arrival process has a Poisson distribution with arrival rate ($\lambda=6$), while call duration time was assumed to be exponential distribution with mean call duration of $1/\mu$. The number of cells are 39 cells and each cell radius is 1 km. Table I summarizes the various simulation parameters [4][5] whose values were empirically chosen to present the most realistic scenario for the simulation. The traffic characteristics are shown in table II.

The call blocking probability of PMSD and MSODB are shown in Fig. 4. It is shown that PMSD has better performance than MSODB while speed increases. Because if the MU does not arrive to cell j before RLI expires, all bandwidth are released and used to support new call.

TABLE I
SIMULATION PARAMETERS

Parameter	Value	Description of parameters
N	39	Number of cells simulated
R	13	Number of country roads and freeways
C^i	40	Cell capacity
J	10	Number of road junction
M	var	Number of mobiles in system
G_{on}	0.0001	Going out of network probability
λ	var	Mean call arrival rate
G_{off}	0.01	Mobile off probability
$1/\mu_{off}$	var	Mean MU off time
$1/\mu_{out}$	var	Mean out of network staying time
β	0.9	Confidence level
ψ	0.2	Shadow cluster threshold

The call dropping probability of PMSD and MSODB is presented in Fig. 5. The result has shown that PMSD has better performance than MSODB while speed increased. This is because that PMSD has algorithm to support the prediction nonconforming call.

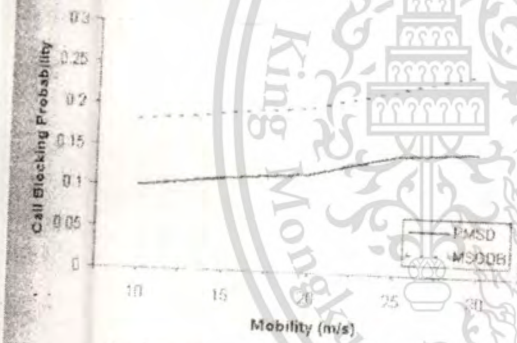

Fig. 4. Comparison of call blocking probability with different speed

In Fig. 6, we present the bandwidth utilization of PMSD and MSODB. The result has shown that the trend of reduces bandwidth utilization in all cases as the speed is increased. However, PMSD achieves better bandwidth utilization than MSODB at all arrival rates. When CBP and CDP decrease, PMSD can lead to increase bandwidth utilization.

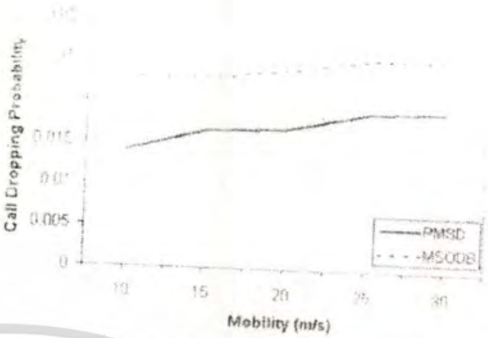

Fig. 5. Comparison of call dropping probability with different speed.

Fig. 6. Comparison of bandwidth utilization with different speed.

V. CONCLUSIONS

We study a resource reservation problem for support the mobility handoff. Such problems are presented in cellular networks as well as in several other applications. We propose the Predictive Mobility Support Demand (PMSD) scheme and compare the performance of PMSD to the traditional MSODB scheme. According to the simulation results, they demonstrate that the PMSD scheme has appeared to be better performance ratio than the MSODB scheme. The PMSD can maintain the dropping probability of handoff calls, reduces the blocking probability of new call, and increases bandwidth utilization, that is, the PMSD can improve the efficiency of this problem.

TABLE II
TRAFFIC CHARACTERRISTICS

Service ID	Service Class	B'_{min} (Mbps)	B'_{max} (Mbps)	Min time(s)	Avg time(s)	Max time(s)	Example traffic contents
1	C1	0.03	0.03	60	180	600	Web browsing
2	C1	0.256	0.256	60	300	1800	Audio streams
3	C1	1.0	6.0	300	600	18000	Video Stream
4	C2	0.0	0.02	10	30	120	E-mail
5	C2	0.0	0.512	30	180	36000	FTP file downloads, e-mail attachments
6	C2	0.0	10.0	30	120	1200	FTP application download

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PAPER *Special Section on Multi-dimensional Mobile Information Networks*

Dynamic Call Admission Control Scheme Based on Predictive User Mobility Behavior for Cellular Networks

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SUMMARY In this paper, we propose a modified scheme of MSODB and PMS, called Predictive User Mobility Behavior (PUMB) to improve performance of resource reservation and call admission control for cellular networks. This algorithm is proposed in which bandwidth is allocated more efficiently to neighboring cells by key mobility parameters in order to provide QoS guarantees for transferring traffic. The probability is used to form a cluster of cells and the shadow cluster, where a mobile unit is likely to visit. When a mobile unit may change the direction and migrate to the cell that does not belong to its shadow cluster, we can support it by making efficient use of predicted nonconforming call. Concomitantly, to ensure continuity of on-going calls with better utilization of resources, bandwidth is borrowed from predicted nonconforming calls and existing adaptive calls without affecting the minimum QoS guarantees. The performance of the PUMB is demonstrated by simulation results in terms of new call blocking probability, handoff call dropping probability, bandwidth utilization, call successful probability, and overhead message transmission when arrival rate and speed of mobile units are varied. Our results show that PUMB provides the better performances comparing with those of MSODB and PMS under different traffic conditions.

key words: *resource reservation, call admission control, shadow cluster, cellular networks*

1. Introduction

In a wireless network, the bandwidth is perhaps the most precious and scarce resource of the entire communication system. It is of great importance to use this resource in the most efficient manner. Sometimes, a base station may need to reserve resources, even if this means denying access to a mobile unit (MU) requesting admission to the network. Call admission control (CAC) is such a strategy to limit the number of call connection into the networks in order to reduce the network congestion and call dropping.

An important QoS parameter is the new call blocking probability (CBP), denoting the probability that a new connection request will be denied to admit into the network. A similar situation arises when an active connection in one cell attempts to migrate into a neighboring cell, called handoff call, and if this neighboring cell cannot support the level of resources required by the connection, this handoff is dropped. The probability of this situation is known as the handoff call dropping probability (CDP). An additional important parameter is the degree to which the network makes an effective use of bandwidth. This parameter is called bandwidth utilization, which is equal to the ratio of the amount of bandwidth used by various connections admitted into a network to the total bandwidth available. In addition to accepting a connection into the network, the amount of successful call is measured. It is expressed as the call successful probability (CSP), which is the probability that a connection request has not been dropped during its duration. It is one of the greatest challenges faced by mobile protocol designers to maintain CDP and CBP as low as possible while maximizing the bandwidth utilization under the strenuous condition of continuous mobile connection.

Levine et al. [2] proposed the shadow cluster (SC) concept, which is a predictive resource allocation scheme that provides high wireless network utilization by dynamically reserving only those resources that are needed to maintain the requested CBP by the connection. The SC scheme profiles user mobility information at regular intervals to estimate its handoff probability density function (pdf) and uses the pdf to estimate time-dependent active mobile probability (AMP) for the MU to visit neighboring cells. For reserving resources, a SC of cells for the each active MU is then formed using these AMPs for each time interval. This SC comprises the neighboring cells that the MU is likely to visit. In the CAC scheme, each cell reserves the required bandwidth proportional to the AMP for each active MU whose SC includes this cell for the corresponding time interval.

Aljadhai and Znati [1] proposed a parametric mobility model known as the predictive mobility support (PMS) scheme. Cell Visiting Probability (CVP) was introduced to estimate the probability of an active MU visiting a neighboring cell. For each neighboring cell, a measure of directionality is obtained as the ratio of two angles: the one made by the line joining the centers of the current and neighboring cells with the predicted direction, and the other by the predicted direction with the line joining the centers of the current and immediate previous cells. The CVP for each neighboring cell is then calculated as its normalized directionality over a tier. Resource reservation time window (RTW) for each MU is estimated for each cell in the SC to reserve bandwidth. The PMS scheme allows a new call to be accepted

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only if its required bandwidth can be served and cells in the SC can reserve the necessary bandwidth for the call.

However, the PMS scheme is also restrictive for the following reasons. Firstly, PMS considers only the direction from the centers of the cells, and does not take other parameters such as position and speed into account. In the PMS scheme the CVPs of all the neighboring cells whose centers lie on along the same line as that of the current cell are equal for different positions of the cells which have the same SC. Secondly, CVP is not calculated if the MU has not encountered handoff, since PMS scheme calculates CVP from previous cell direction and estimated direction at the handoff.

Islam et al. extended the on-demand borrowing (ODB) [4] scheme to propose the mobility support on-demand borrowing (MSODB) [5] scheme, where all three key mobility parameters of distance, direction, and speed are used together to calculate the CVP normalized over a ring of cells similar to those presented in [1]. The MSODB scheme calculates CVP and RTW by incorporating the expected travel distance (ETD) in order to take into account the reserved resources and available bandwidth information for all of the cells in the SC.

However, the MSODB scheme is also restrictive for the following reasons. Firstly, in MSODB scheme, a call is not considered for prediction conforming call and prediction nonconforming call. When a call is accepted to the network, each cell in its SC will reserve bandwidth in all Reservation Time Window (RTW). Although when a call may arrive to a cell that is not a part of its SC, it may be dropped because bandwidths are not reserved for it while the reserved bandwidths in its SC are not released. As the result, the remaining available bandwidths for supporting the other calls decrease. When they arrive to the cell, they cannot use these bandwidths. This may cause the unnecessary blocking for new call and handoff call. Secondly, reposes from all cells in the SC have equal priority, irrespective of their distance to the current cell and their CVPs. As a result, sometimes handoff call may be dropped, due to the fact that the cell with less CVP which is far away from current cell can be supported while the cell which is near the current cell can not be supported.

In this paper, a new bandwidth reservation scheme is proposed using Predictive User Mobility Behavior (PUMB) as the extended or modified scheme of MSODB and PMS. The main objectives of the CAC in PUMB upon accepting a connection request are as follows: 1) verifying the feasibility of accepting a new call into the system, 2) guaranteeing an uninterrupted service for admitted calls as they move from one cell to another, and 3) maximizing the utilization of the network resources. In order to achieve our objectives, the advantages of PMS and MSODB are integrated together into PUMB scheme including the following our proposed extended functions: 1) adjusting the window size of SC considering the typical behavior of MU such as direction and speed, and 2) weighting reposes from all cells in the SC by considering the CVP. The characteristics comparison of PMS, MSODB, and PUMB can be summarized as shown in Table 1. The main concept is that the bandwidth is reserved only in a cell which has higher probability of MU's migrating to that cell for RTW based on key mobility parameters. The most difficult points are to predict the cell that MU will migrate in order to estimate the handoff time to that cell. From these points, we use the key mobility parameters such as position, direction, speed and ETD, to estimate the CVP and RTW of neighboring cells for predicting the MU's mobility behavior, which was not incorporated in the MSODB scheme. These estimated parameters are used for making decision in our proposed scheme called PUMB algorithm. The call in our consideration is classified into two types as presented in PMS: the prediction conforming call and the prediction nonconforming call. The prediction conforming call has the higher priority than the one of prediction nonconforming call. If a prediction conforming call comes into a cell with insufficient bandwidth, some prediction nonconforming call should be terminated, if necessary, for making space. From the resource reservation interval point of view, the PUMB scheme and the PMS scheme, if a call arrives to any cell without the resource leasing interval, the reserved bandwidths are released in order to avoid the unnecessary bandwidth reservation. Also, in the PUMB scheme, the SC window can be adjusted based on the typical behavior of MU, but the PMS scheme considers only direction. Furthermore, the PUMB algorithm weights reposes from all cells in the SC by considering the CVP. The response from a cell with more CVP has higher priority than a cell with less CVP which is far the current cell. This may increase the decision accuracy for call accepting or call rejecting. As the result, it can guarantee an uninterrupted service for admitted call as they move from one cell to another.

Table 1 Characteristics comparison of PMS, MSODB, and PUMB

[illegible]	PMS	MSODB	PUMB
Key mobility parameters	direction	distance, direction and speed	position, direction and speed
[illegible]	YES	YES	YES
[illegible]	YES	YES	YES
[illegible]	YES	NO	YES
Estimating the expected travel distance (ETD)	NO	YES	YES
[illegible]	YES	NO	YES
Adjusting the window size of shadow cluster	Considering with direction	NO	Considering direction and speed
[illegible] by considering the CVP	NO	NO	YES

The rest of the paper is organized as follows. In Sect. 2, we explain our proposed scheme called Predictive User Mobility Behavior (PUMB) scheme. The simulation and results are provided in Sect. 3. Section 4 concludes our work.

2. PUMB

PUMB scheme composes of mobility model and CAC algorithm. In the mobility model, it estimates the parameters that are used in decision process of CAC algorithm such as CVP, RTW, and SC window size. MU's mobility parameters such as speed, distance, direction, and position are used to estimate these parameters very close to exact data. The estimated parameters in the mobility model are used in the CAC algorithm for the decision of call accepting or call rejecting, resource reservation, bandwidth borrowing and bandwidth allocation. If the estimated parameters are very close to real situations, the decision in the CAC algorithm is more accurate.

2.1 PUMB Model

In this paper, a GPS (Global Positioning System) function is assumed to be embedded with each MU that is periodically transmitting mobility information to its current base station. The base station uses these information to calculate the probability that a MU x may move from its current cell to a neighboring cell j or CVP, $P_{x,j}$. It can be calculate from MU's current position, mobility direction, moving speed, and travel distance to cell j, $D_{x,j}$.

We define v_x be the average moving speed of MU x and $\delta_{x,j}$ be the directional angle between the moving direction of MU x and a line joining the center of cell j with the position of MU x, as shown in Fig. 1.

The CVP of MU x to visit cell j is assumed to have a value normalized over the virtual ring (V-ring) in which cell j resides as proposed in [1], and use the SC concept in [2], we can calculated the CVP for MU x to visit cell j is found as shown in (Eq. (1)).

$$P_{x,j} = \begin{cases} \dfrac{\frac{\cos\delta_{x,j}}{D_{x,j}}}{\sum\limits_{k\in R_{i,0}\to R_{j,k}} \frac{\cos\delta_{x,k}}{D_{x,k}}}, & \delta_{x,j} \le \pi/2,\ v_x \ne 0 \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

where, $R_{i,0}$ is the current cell i and the summation is over the cell k that are in the same V-ring as cell j.

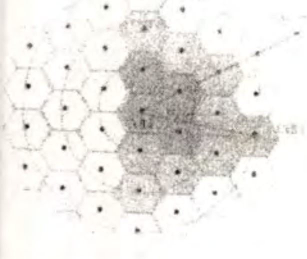


Fig. 1 Graphical definition of and its SC which is depicted with the shaded area.

2.1.1 Formation of the Shadow Cluster

From the calculated $P_{x,j}$, we define the span of SC for a MU x to include all neighboring cells j such that $P_{x,j} \ge \psi$, where ψ is a SC probability threshold. After that, it is to determine the window size of the SC (W_{SC}) which is the number of adjacent V-rings of cells to be included in the SC. Let $Ring_{i,j}$ be the ring at which cell in the span of SC is located. In PUMB scheme, if users move within the predicted direction, their SC window sizes increase up to a maximum R_{max}.

$$R_{max} = \max\left\{Ring_{i,j}\right\} \text{ such that } P_{x,j} \ge \psi \tag{2}$$

So that, if a MU moves along the current direction, increasing the W_{SC} by increases the V-ring to support the MU's request. On the other hand, if a MU deviates from the current direction, decreasing the W_{SC}, as a MU may move out from the SC.

$$W_{SC} = \min\left(R_{max}, \left\lceil\left(1 - \frac{Dev_i}{\pi} T_i^{NC}\right) R_{max}\right\rceil\right) \tag{3}$$

where T_i^{NC} is amount of continuous time that call x is prediction nonconforming call and Dev_i is deviation of call x at cell i. Let D_{Xi} is the direction of call x while moving to cell i and D_{Dj} is the direction of call x while moving from cell i to cell j. The deviation of call x can then be calculated as:

$$Dev_i = |D_{Xi} - D_{Dj}| \tag{4}$$

When MU deviates from the current direction, the W_{SC} is decreased by an amount proportional to the degree of deviation. The W_{SC} is recalculated at every handoff and MU's mobility behavior changing. Therefore, the W_{SC} decreases and increases follow the MU's moving behavior.

2.1.2 Reservation Time Window (RTW)

In the PUMB scheme, the RTW of a MU in each cell of the SC is estimated by considering travel distance, its standard deviation, moving speed, and MU's position for more accurate. The RTW of MU x when it arrives at cell j from cell i is considered in three terms of the time: expected earliest arrival time $\hat{T}_{i,j}^{EA}(x)$, the latest arrival time $\hat{T}_{i,j}^{LA}(x)$ and the latest departure time $\hat{T}_{i,j}^{LD}(x)$. These time parameters can be determined by using the maximum travel distance, $\hat{D}_{i,j}^{max}$ and the minimum travel distance, $\hat{D}_{i,j}^{min}$ between MU's position in cell i and center of cell j, and by using normal distribution that has mean and standard deviation as $D_{i,j}$ and $\sigma_{i,j}$, respectively [5].

The mechanism of reservation time window is as Fig. 2. The interval $[\hat{T}_{i,j}^{EA}(x), \hat{T}_{i,j}^{LD}(x)]$ is referred to as the Resource Reservation Interval (RRI), while the arrival interval $[\hat{T}_{i,j}^{EA}(x), \hat{T}_{i,j}^{LA}(x)]$ is referred to as the Resource Leasing Interval (RLI) [1]. The resources or bandwidths are reserved for the duration of RRI. However, if the MU does not arrive in cell j before RLI expires, all bandwidth are released and

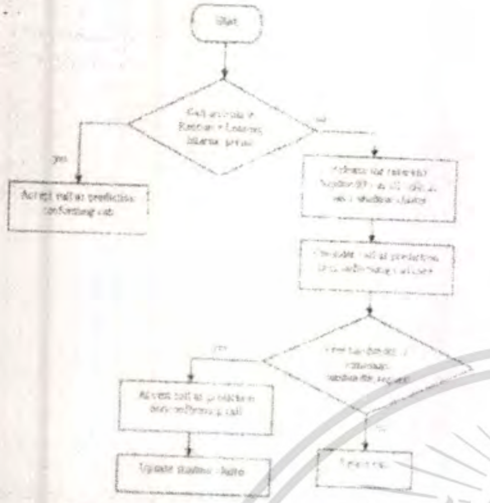


Fig. 2 Reservation time window mechanism

the reservation is canceled. This is necessary to prevent MU from holding resources unnecessarily. When MU is considered as prediction nonconforming call, the cell accepts the call if it has free bandwidth to support minimum bandwidth request and recalculates the MU's shadow cluster and adjust window size of shadow cluster as in Eq.(3).

2.1.3 Resource Reservation

The proposed scheme then reserves an amount of bandwidth in a cell for a service proportional to the maximum bandwidth requirement of the service multiplied by the CVP for that cell in RTW. The reservation of bandwidth in the different cells of the shadow cluster should be updated as the MU moves from its current position. The reservation in different cells within the shadow cluster is updated when the MU's direction goes beyond the angular span of the shadow cluster. When MU is an abrupt deviation in direction, the reservation is updated as well as the shadow cluster. When these cases occur, reserved resources in all cells in the shadow cluster are released while the MU's shadow cluster is recalculated. It used to support the new MU's direction and prevent unnecessary reserved bandwidth.

Unlike other schemes, although the MU hands off from one cell to another, but its not change mobility behavior, the shadow cluster is not recalculated. Consideration of this situation increases channel utilization, i.e., it reduces both the CDP and the CBP, because it releases the resources reserved in those cells that lie outside the shadow cluster, while the overhead message transmission from shadow cluster recalculation is reduced.

2.2 PUMB Call Admission Control Algorithm

The main objectives of the CAC in PUMB upon accepting a connection request are as follows:

1) to verify the feasibility of accepting a new call into the system,

2) to guarantee an uninterrupted service for admitted calls as they move from one cell to another, and

3) to maximize the utilization of the network resources.

These objectives can be achieved by reserving resources only where needed and within the expected residence time interval. Based on a balance between these extremes, the PUMB scheme can guarantee with high probability an uninterrupted service without unnecessarily sacrificing the network resource utilization by using algorithm for supporting prediction nonconforming call and releasing reserved bandwidth when MU's behavior changes.

In this section, we will present our proposed scheme called the Predictive User Mobility Behavior (PUMB) scheme. Firstly, it is necessary to define the traffic in cellular network into two classes: Class I Partially elastic traffic and Class II Fully elastic traffic. If a class I call comes into a cell with insufficient bandwidth, some class II calls should be terminated, if necessary, for making space. From elastic definition, we can calculate elastic rate (ER) from $(B^u_{max} - B^u_{min})/B^u_{max}$ where B^u_{max} is maximum bandwidth request and B^u_{min} is minimum bandwidth request. We can calculate the expected bandwidth B^u_{exp} for service u from elastic rate as [5]. A service is accepted if it is possible to allocate an amount B^u_{min} of bandwidth. We separate borrowing bandwidth into two types: the fair borrowing bandwidth FBB and the maximum borrowing bandwidth MBB [5].

2.2.1 Call Feasibility and Setup Procedure

Upon receive the reservation request, each cell in the SC decides whether it has sufficient bandwidth to reserve for the service. The base station sends positive response if it can support the service through reserving resources, and a negative response otherwise, as shown in

$$A^x_{i,j} = \begin{cases} 1, & \text{if } C^f_j \ge R_{u,j} \text{ for } \left[T^{EA}_{i,j}(x), T^{LD}_{i,j}(x)\right] \\ 0, & \text{otherwise} \end{cases}$$

where $C^f_j(t)$ is amount of free bandwidths in cell j at time t. The value of $A^x_{i,j}$ are collected for all cells j in the SC of the current cell i for the MU x. The decision to accept is taken if the following holds:

$$1 \ge \sum_{j \in SC} \left(P_{x,j} A^x_{i,j}\right) \ge \tau . \sum_{j \in SC} P_{x,j} \ge 0 \; ; \; 0 \le \tau \le 1$$

The above feasibility test condition of the RTW and the CVPs is checked so that more weight is given to support responses of the cells whose CVP is comparatively higher. When the current cell i accepts the call, it sends a message to all cells in SC, confirming that the reservation must now be performed. Every call reserved the required bandwidth for the RRI duration and updated its available bandwidth accordingly. However, notice that cell j cancels the reservation if the MU that does not arrive before the resource leasing interval period, RLI, expires.

2.2.2 Prediction Conforming and Nonconforming Call

Due to the changing behavior of the mobile units in a cellular network, calls may hand off to cells that are not part of their Shadow Cluster and calls may not arrive within their resource leasing interval periods, RLIs. Therefore, we define the status of a call to be either prediction conforming or prediction nonconforming [1].

The CAC gives higher priority to prediction conforming calls over prediction nonconforming calls. When a prediction conforming call arrives and cannot be accommodated by the available bandwidth, a prediction nonconforming call is dropped. We borrow the predicted nonconforming call in order by the duration time decreasing for the purpose of increasing the CSP. The bandwidth allocation for prediction nonconforming call allocates only minimum bandwidth requested because of preventing CBP and CDP increasing.

2.2.3 CAC Algorithm for New Call

The PUMB CAC algorithms consider Class I and Class II calls differently while admitting a new call in a cell. When a new Class I call arrives in the cell i, the base station calculates the maximum available bandwidth by adding the FBB of each existing call to free bandwidth. If the maximum available bandwidth is greater than or equal to B^r_{req} of the MU, then the bandwidth reservation request is forwarded to all the cells in the shadow cluster to test condition of reserved bandwidth in RTW period and send these responses back, the admission decisions are taken based on their responses which weight by their CVP. However, if the maximum available bandwidth is not sufficient to meet the new calls bandwidth demand, the call is rejected. On the other hand, if the free bandwidth in the cell is more than zero, Class II calls are accepted. At first, after accepting a service, the minimum required bandwidth is allocated to each of the services, and then the remaining surplus bandwidth is redistributed among the services according to the proportion of their elastic rate. When new calls are accepted, it is admitted as predictive conforming call. The details of the CAC algorithms for new calls are show in Fig. 3.

2.2.4 CAC Algorithm for Handoff Call

The PUMB CAC algorithms discriminate prediction conforming call and prediction nonconforming call by using the RLI period condition and shadow cluster cell. When prediction conforming call migrates to cell i, Class I class, the maximum available bandwidth for call is calculated by adding up free bandwidth $C^f_i(t)$, reserved bandwidth $C^r_i(t)$ and the summation of the MBB for each existing call in the cell i. If the maximum available bandwidth is greater than or equal to B^r_{min}, then the call is accepted; otherwise it is rejected. For Class II handoff calls, if the maximum available bandwidth is zero, the transmission is stopped and the service waits until it gets bandwidth to start transmission again because the Class II calls are offline and do not have any impact on user interaction. Unlike the MSODB, the PUMB supports the case of prediction nonconforming call, if the free bandwidth can support B^r_{min}, the call is accepted, and otherwise, it is dropped. When bandwidth borrowing occurs for making bandwidth a prediction nonconforming call is dropped before prediction conforming call. The details of the CAC algorithms for handoff calls are show in Fig. 4.

```
Step (1) IF [illegible] + summation of FBB ≥ $B^r_{req}$ THEN send reservation request
         to all the cells of the SC and receive response from each cell of the
         SC. Otherwise, reject the call
Step (2) IF $\sum$ [illegible] $C$ [illegible] ≥ $\sum_{j \in SC}$ [illegible] THEN accept the call and GOTO Step
         (3). Otherwise, reject the call
Step (3) IF [illegible] ≥ $B^r_{max}$ THEN allocate an amount maximum requested
         bandwidth to the call. Otherwise, allocate free bandwidth to the call
         redistribute the bandwidth through allocating first the minimum
         required to each and then surplus according to their elasticity level
Step (4) Admitted call as predicted conforming call. Send confirmation to each
         cell in SC to reserve an amount of bandwidth.
Class 2
IF this cell has free bandwidth, THEN accept the call and admitted call as
predicted conforming call. Otherwise, reject the call.
```

Fig. 3 CAC algorithm of PUMB scheme for new calls.

```
Step (1) IF this cell is in SC and a call arrives to the cell during the leased
         RLI, THEN GOTO Step (3). Otherwise, GOTO Step (2).
Step (2) IF [illegible] ≥ $B^r_{min}$ THEN allocate free bandwidth to call, admitted
         call as predicted nonconforming call, compute new SC. Otherwise,
         reject the call.
Step (3) IF [illegible] + summation of MBB ≥ $B^r_{min}$ THEN accept
         call, admitted call as predicted conforming call and GOTO Step (4).
         Otherwise, reject the call.
Step (4) IF [illegible] ≥ $B^r_{max}$ THEN allocate an amount of maximum
         requested bandwidth to call. Otherwise, GOTO Step (5).
Step (5) IF [illegible] ≥ $B^r_{min}$ THEN allocate free bandwidth and
         reserved bandwidth to call. Otherwise, GOTO Step (6).
Step (6) IF call is [illegible] adaptive call, THEN allocate free bandwidth and
         reserved bandwidth to call and GOTO Step (7). Otherwise, include
         the call in the list of existing call, redistribute the bandwidth among
         [illegible] existing rate adaptive calls.
Step (7) IF bandwidth held the predicted nonconforming calls can be freed,
         THEN terminate them, allocate bandwidth to call. Otherwise, borrow
         bandwidth from existing rate-adaptive call
```

Fig. 4 CAC algorithm of PUMB scheme for handoff calls.

3. Performance Evaluation

In this section, we evaluate the performance of our proposed scheme PUMB, by means of the simulation. We consider for performance metrics such as CBP, CDP, CSP and bandwidth utilization. The performance is evaluated by comparing between our proposed PUMB and traditional MSODB. The simulation results are demonstrated in two parts. The first part is the comparison between PUMB and MSODB when arrival rate of new calls, λ, is varied. The second part is the comparison between PUMB and MSODB when the moving speed of MU is varied and arrival rate of new calls is at $\lambda = 6$ which is average congested network. In this simulation,

Table 2 Simulation parameters [5].

Parameter	Value	Description of parameters
N	39	Number of cells simulated
R	13	Number of country roads and freeways
C_c^t	40	Cell capacity
J	10	Number of road junction
M	var	Number of mobiles in system
G_{out}	0.0001	Going out of network probability
λ	var	Mean call arrival rate
G_{off}	0.01	Mobile off probability
$1/\mu_{off}$	var	Mean MU off time
$1/\mu_{out}$	var	Mean out of network staying time
β	0.9	Confidence level
ψ	0.2	Shadow cluster probability threshold

Table 3 Traffic characteristics [5].

Traffic ID	Class ID	B_{min}^t (Mbps)	B_{max}^t (Mbps)	Min Time (s)	[illegible] Time (s)	Max Time (s)
1	C1	0.03	0.03	60	180	600
2	C1	0.256	0.256	60	300	1800
3	C1	1.0	6.0	300	600	18000
4	C2	[illegible]	0.02	10	40	120
5	C2	[illegible]	0.512	[illegible]	180	[illegible]
6	C2	[illegible]	10.0	30	120	1200

Table 4 Mobility parameters [5].

Parameter	Value	Description of parameters
[illegible]	0.1	Probability that the MU travels on a country road
[illegible]	0.2	Probability that the MU travels on a freeway
[illegible]	0.4	Probability that the MU is walking on [illegible]
[illegible]	0.4	From stopping to moving probability
[illegible]	0.1	From moving to stopping probability
[illegible]	22	Maximum speed (m/s) on a country road
[illegible]	25	Maximum speed (m/s) on a freeway
[illegible]	16	Maximum speed (m/s) on local city road
[illegible]	3	Maximum walking speed (m/s)

we assumed arrival process has a Poisson distribution with arrival rate λ, while call duration time was assumed to be exponential distribution with the mean $1/\mu$. The number of cells is 39 cells and each cell radius is 1 km. The shadow cluster probability threshold is 0.2 as used in MSODB. Table 2 summarizes the various simulation parameters [4], [5] whose values were empirically chosen to present the most realistic scenario for the simulation. The traffic characteristics are shown in Table 3, which was used in [2], [3], [5]. Each of the six types of traffic occurs with equal probability.

3.1 Performance Metrics for Varying Arrival Rates

In this part, the mobility parameters are shown in Table 4 [5]. The movements of the MU may be stationary or move, either towards a specific destination following the road networks, or randomly at walking speeds and the MU can start its itinerary from any location in the cellular network, with an appropriate state of movement. MU's were allowed to travel at speeds proportionate with the current road limits within 10% variations.

We separate simulation results for various arrival rates into three cases: 1) Class I traffic (traffic ID 1, 2, and 3), 2) Class II traffic (traffic ID 4, 5, and 6), and 3) Class I and Class II traffic.

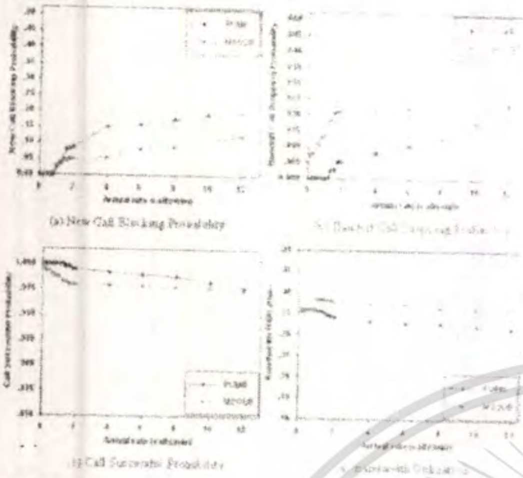
3.1.1 For Class I Traffic

Figure 5(a) shows that the Class I CBP of PUMB and MSODB are low during very low arrival rates, but increase steadily with the arrival rate increase. This presents a 29.6% improvement by the PUMB scheme compared with the MSODB scheme. The improvements in Class I CBP between both schemes are minimal at lower arrival rate. However, the improvements become important as the arrival rate increases.

Fig. 5 Comparison of Class I performance for varying arrival rate.

The Class I CDP of PUMB and MSODB are shown in Fig. 5(b). While arrival rate increases, the Class I CDP rises rapidly. The PUMB scheme provides 11.5 - 19.8% improvements in handoff Class I CDP compared with the MSODB scheme. The Class I CSP of the PUMB and MSODB are presented in Fig. 5(c). The result shows that CSP decreases as the call arrival rate increases. However, PUMB has better performance than MSODB. It can reduce CDP and increase CSP more than MSODB about 2% up.

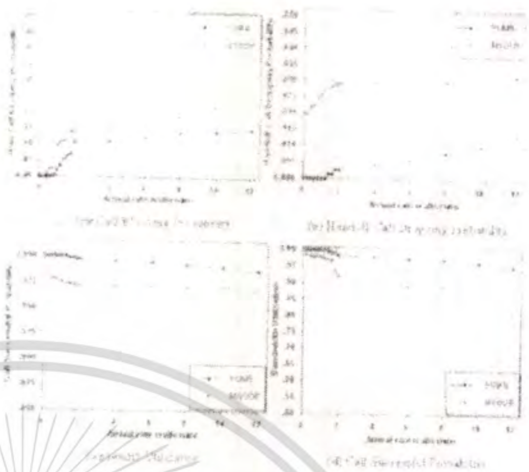
The Class I bandwidth utilization of PUMB and MSODB is presented in Fig. 5(d). The result shows that as the arrival rate increases, the bandwidth utilization decreases. However, PUMB achieves better bandwidth utilization than MSODB for each arrival rate. PUMB is able to increase the bandwidth utilization greater than MSODB up to 2 ~ 18%.



(a) New Call Blocking Probability (b) Handoff Call Dropping Probability

(c) Call Successful Probability (d) Bandwidth Utilization

Fig. 6 Comparison of Class II performance for varying arrival rate



(a) New Call Blocking Probability (b) Handoff Call Dropping Probability

(c) Bandwidth Utilization (d) Call Successful Probability

Fig. 7 Comparison of performance for varying arrival rate

3.1.2 For Class II Traffic

The Class II CBP is zero for both schemes at very low arrival rate, as shown in Fig. 6(a). However, although the differences in the Class II CBP of both schemes are small at lower arrival rates, the differences increases as the arrival rate increases. The MSODB has better performance than PUMB. The Class II CBP of MSODB is improved about 3~9% from PUMB.

Figure 6(b) shows the Class II CDP of PUMB and MSODB. The differences in the Class II CDP of both schemes are more at lower arrival rates, the differences decrease as the arrival rate increases. The Class II CDP of PUMB is improved about 3.1~17.9% from MSODB. The CSP of the PUMB and MSODB are presented in Fig. 6(c). The result shows that CSP decreases as the call arrival rate increases. However, the differences of the Class II CSP of both schemes are more at lower arrival rates, the differences decrease as the arrival rate increases. The PUMB scheme provides 2% improvements in Class II CSP compared with the MSODB.

The Class II bandwidth utilization of PUMB and MSODB is presented in Fig. 6(d). The result shows that as the arrival rate increases, the bandwidth utilization decreases. MSODB achieves better bandwidth utilization than PUMB when arrival rate is more than 2. MSODB is able to increase the bandwidth utilization greater than PUMB up to 2 ~ 4%.

3.1.3 For Class I and Class II Traffics

The CBP of PUMB and MSODB are shown in Fig. 7(a). It is shown that the CBP in PUMB is lower than MSODB for all of arrival rate. The CBP in PUMB is reduced about 2~9% form MSODB. In Fig. 7(b), we present the CDP of PUMB and MSODB. The result has shown that PUMB has better performance than MSODB while arrival rate increases. The CDP of PUMB is improved about 9~23% from MSODB. The CSP of the PUMB and MSODB are presented in Fig. 7(c). The result shows that CSP decreases as the call arrival rate increases. However, the PUMB has better performance than MSODB. PUMB can reduce the CDP while lead to increase CSP more than MSODB about 2% up.

PUMB can reduce the CBP because if the MU does not arrive to cell *j* before RLI expires, the reserved bandwidths are released and used to support the other calls. Also PUMB can adjust SC window size based on typical behavior of MU so that it can reduce unnecessary reserved bandwidth and cells have more bandwidth to support the other calls. Furthermore, PUMB can guarantee an uninterrupted service for admitted calls as they move from one cell to another by weighting reposes from all cells in the SC considering the CVP, thereby reducing the CDP. This may increase the decision accuracy for call accepting or call rejecting.

The bandwidth utilization of PUMB and MSODB are presented in Fig. 7(d). The result shows that as the arrival rate increases, the bandwidth utilization will decrease. However, PUMB achieves better bandwidth utilization than MSODB at all arrival rates. PUMB is able to increase the bandwidth utilization up to 2 ~ 14% from MSODB. Because in PUMB algorithm if the MU does not arrive to cell *j* before RLI expires, all bandwidth are released and used to support the other calls. And PUMB can adjust SC window size based on typical behavior of MU so that it can reduce unnecessary reserved bandwidth and cells have more bandwidth to support the other calls. Therefore, bandwidths are used by considering the bandwidth utilization.

Figure 8 shows the overhead message transmission for various arrival rates. The graph clearly shows that overhead message increases as the call arrival rate increases. However, the PUMB has better performance than MSODB, because PUMB adjusts window size of SC, so that it can reduce overhead from message transmission and decreases

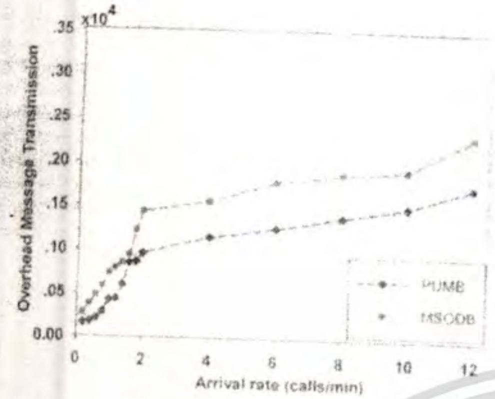
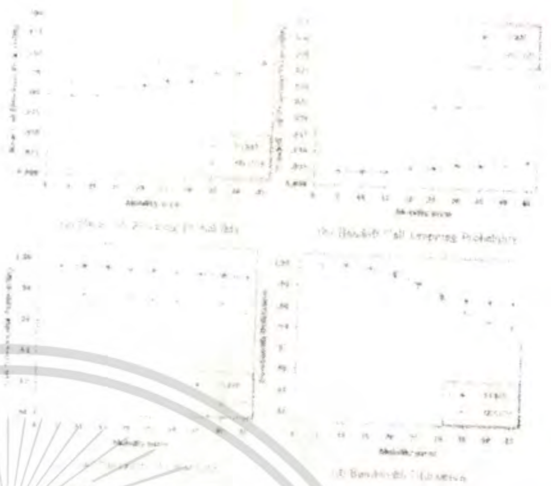


Fig. 8 Comparison of overhead message transmission for varying arrival rates.



(a) New Call Blocking Probability (b) Handoff Call Dropping Probability (c) [illegible] (d) Bandwidth Utilization

Fig. 9 Comparison of performance for varying mobility.

Fig. 10 Comparison of overhead message transmission for varying mobility ($\lambda = 6$).

overhead message transmission less than MSODB about 2~6%.

In case of the arrival rate is less than 2, the available bandwidths in the current cell are used to support the handoff call as we can see in Fig. 7(b), and the CDP in this range is very low. The remaining few available bandwidths can support the new call. This make the CBP of new call increase rapidly as shown in Fig. 7(a). Figure 7(d) has shown that the available bandwidth in the current cell mostly used to support handoff call. For the overhead message transmission shown in Fig. 8, both new call and handoff call have to do the process for the SC formation. The overhead message transmission in this range also increases rapidly.

In order to improve this situation, we need the mechanism for balancing between CBP and CDP by using CBP threshold and CDP threshold in order to control and improve the quality of service. Another way is to consider the mechanism for adjusting the size of the SC window depending on the situation in the networks.

3.2 Performance Metrics for Varying Mobility

In this part, we consider when arrival process has a Poisson distribution with arrival rate of $\lambda = 6$, while the moving speed of MU is varied for 5, 10, 15, 20, 25, 30, 35, 40, 45 m/s. The MU can start its itinerary from any location in the cellular network, with an appropriate state of movement.

The CBP of PUMB and MSODB are shown in Fig. 9(a). It is shown that PUMB has better performance than MSODB while MU is moving faster. The CBP of PUMB is reduced about 1~3% form MSODB. The CDP of PUMB and MSODB are presented in Fig. 9(b). The result has shown that PUMB has better performance than MSODB while MU is moving faster. The CDP of PUMB is improved about 1~3% from MSODB. The CSP of PUMB and MSODB are presented in Fig. 9(c). The result shows that CSP of MSODB and PUMB slightly decrease. The PUMB has better performance than MSODB. It can reduce CDP and increase CSP more than MSODB about 1~3%.

Figure 9(d) presents the bandwidth utilization of PUMB and MSODB. The result shows the trend of decreasing of bandwidth utilization as long as the moving speed of MU increases. However, PUMB achieves better bandwidth utilization than MSODB at all moving speed. PUMB is able to increase the bandwidth utilization up to 1 ~ 3% from MSODB.

Figure 10 shows the overhead message transmission for varying mobility. The results clearly show that as MU moves faster, the overhead message transmission increases. Because when the MU's moving speed is faster, the more chances of handoff increase. So that, the overhead message transmission from SC reformation increases. As the result, CBP and CDP increase while BU and CSP decrease.

In the other values of arrival rate, the results are almost the same trend. So that, the results show that the mobility is not more effective for the MSODB and PUMB algorithm.

4. Conclusions

We have proposed the new approach to improve the performance, i.e., PUMB. The PUMB algorithm can guarantee an uninterrupted service for admitted calls as they move from one cell to another by weighting reposes from all cells in the shadow cluster considering their CVF so that more accurate decisions of accepting or rejecting calls can be realized. The simulation has been performed in order to compare the achieved performance with the traditional MSODB. The simulation results demonstrated that our proposed mechanism may have the better performance than MSODB even through the call arrival rate or MU's moving speed increases. PUMB can reduce CBP and CDP while increasing bandwidth utilization and CSP. Although, for some new Class II call cases, PUMB may cause CBP higher than MSODB, but in general case PUMB keeps CBP less than MSODB. And we plan to explore method to balance between two traffic classes of new call for reduce new Class II call blocking probability.

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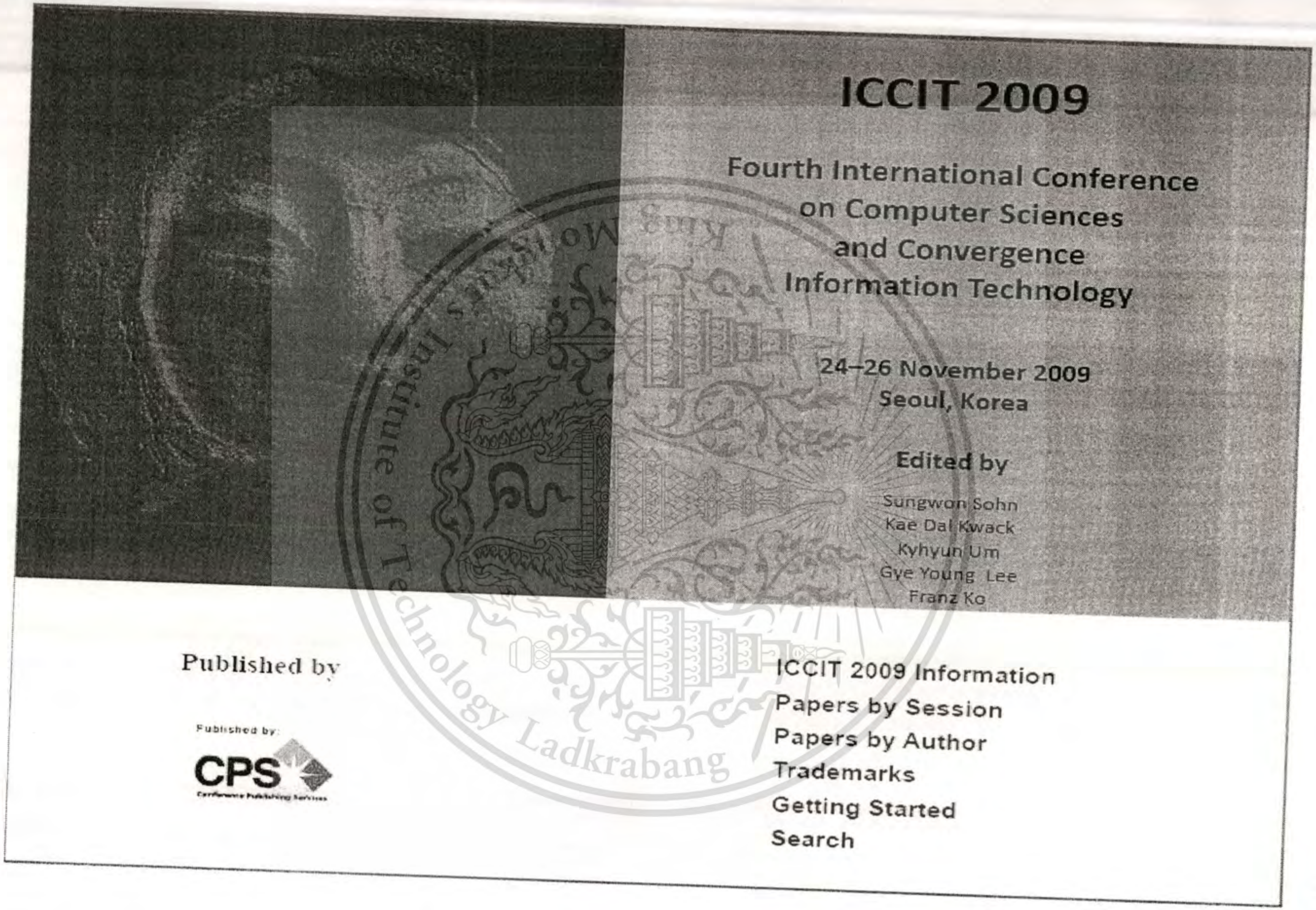

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Effect of Shadow Cluster on Predictive User Mobility Behavior Scheme in Cellular Networks

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Abstract— **In this paper, we propose a scheme for improved performance of resource reservation and call admission control for cellular networks called *Predictive User Mobility Behavior* (PUMB) scheme. This algorithm is proposed in which bandwidth is allocated more efficiently to neighboring cells by key mobility parameters in order to provide Quality of Service (QoS) guarantees for transferring traffic. The cell visiting probability (CVP) is used to form the shadow cluster cell, where a mobile unit is likely to visit, by comparing with shadow cluster probability threshold. We are interested in the effect of the shadow cluster probability threshold in PUMB because when shadow cluster probability threshold increases, the *MU*'s shadow cluster size decreases so that the suitable shadow cluster probability threshold can define the suitable shadow cluster size for increasing network performance. The performance of the PUMB is demonstrated by simulation results in terms of new call blocking probability and handoff call dropping probability when new call arrival rate and the shadow cluster threshold are varied. Our results show that when shadow cluster probability threshold increases, CBP of MSODB and PUMB decrease while CDP of both schemes increases in all arrival rates. However, PUMB is better than MSODB under different traffic conditions.**

Keywords: ***Shadow Cluster, Cellular Network, Resource Reservation***

I. INTRODUCTION

Currently, mobile cellular networks are expected to support several types of traffics under diverse bandwidth requirements. These networks will serve multiple traffic classes with each class having different *quality of service* (QoS) requirements. *Call admission control* (CAC) is such a strategy to limit the number of call connection into the networks in order to reduce the network congestion and call dropping. In cellular networks, an important QoS parameter is the *new call blocking probability* (CBP), denoting the probability that a new connection request will be denied to admit into the network. A similar situation arises when an active connection in one cell attempts to migrate into a neighboring cell and if this neighboring cell cannot support the level of resources required by the connection, this handoff is dropped. The probability of this situation is known as the *handoff call dropping probability* (CDP).

In this paper, a new bandwidth reservation scheme is proposed using *Predictive User Mobility Behavior* (PUMB) as the extended or modified scheme of MSODB[5] and *predictive mobility support* (PMS)[1]. The main concept is that bandwidth is reserved only in a cell which has higher probability of *MU's* migrating to that cell for *Reservation Time Window* (RTW) based on key mobility parameters. We use the key mobility parameters to calculate the *Call Visiting Probability* (CVP) of neighboring cells for predicting the *MU's* mobility direction and use these parameters for decision in PUMB algorithm. Also we separate the call into prediction conforming call and prediction nonconforming call which is lower priority than first type. If the bandwidth borrowing occurs, bandwidth is borrowed from the prediction nonconforming calls and the existing adaptive calls. If a call arrives to any cell before or after than the resource leasing interval, the reserved bandwidths are released and not reserved all RTW like MSODB. Accordingly, unlike the MSODB scheme, PUMB can support prediction nonconforming calls and the SC window can be adjusted based on typical behavior of MU.

In shadow cluster formation, a cell is included to shadow cluster if it has CVP more than shadow cluster probability threshold. So that, shadow cluster probability threshold is greater, amount of cell in each *MU's* shadow cluster is lower. This causes effect to increase CDP and the unused reserved bandwidths increase due to the handoff call is dropped before it arrivals to these cells. On the other hand, when the shadow cluster probability threshold is lower, amount of cell in each *MU's* shadow cluster is greater. The reserved bandwidths increase but the available bandwidths decrease. Therefore, the suitable shadow cluster probability threshold can lead the suitable shadow cluster size. We are interested in the effect of the shadow cluster probability threshold in PUMB because when shadow cluster probability threshold increases, the *MU*'s shadow cluster size decreases so that the suitable shadow cluster probability threshold can define the suitable shadow cluster size for increasing network performance.

The rest of the paper is organized as follows. In Section II, we explain our proposed scheme called Predictive User Mobility Behavior (PUMB) scheme. The simulation and results are provided in Section III. Section IV discusses the results and section V concludes our work.

II. PREDICTIVE USER MOBILITY BEHAVIOR (PUMB)

A. PUMB Model

In this paper, a GPS (*Global Positioning System*) function is assumed to be embedded with each *MU* that is

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periodically transmitting mobility information to its current base station. The base station uses this information to calculate the probability that a *MU* x may move from its current cell to a neighboring cell j or CVP, $P_{x,j}$. It can be calculate from *MU's* current position, mobility direction, moving speed, and travel distance to cell j, $\bar{D}_{i,j}$. We define v_x be the average moving speed of *MU* x and $\delta_{x,j}$ be the directional angle between the moving direction of *MU* x and a line joining the center of cell j with the position of *MU* x, as shown in Fig.1.

Figure 1 Graphical definition of $\delta_{x,j}$ and its SC which is depicted with the shaded area

The CVP of *MU* x to visit cell j is assumed to have a value normalized over the virtual ring (V-ring) in which cell j resides as proposed in [1], and use the SC concept in [2], we can calculated the CVP for *MU* x to visit cell j is found as shown in (1).

$$P_{x,j} = \begin{cases} \dfrac{\dfrac{\cos\delta_{x,j}}{\bar{D}_{i,j}}}{\sum\limits_{k \in R_{i,n} | i \in R_{i,0}} \dfrac{\cos\delta_{x,k}}{\bar{D}_{i,k}}}, & \delta_{x,j} \le \pi/2 \text{ , } v > 0 \\ 0 & \text{, } otherwise \end{cases} \tag{1}$$

where, $R_{i,0}$ is the current cell i and the summation is over the cell k that are in the same V-ring as cell j.

1) Formation of Shadow Cluster

From the calculated $P_{x,j}$, we define the span of SC for a *MU* x to include all neighboring cells j such that $P_{x,j} \ge \psi$, where ψ is a SC *probability threshold.* After that, it is to determine the *window size of the SC* (W_{sc}) which is the number of adjacent V-rings of cells to be included in the SC. Let $Ring_{i,j}$ be the ring at which cell in the span of SC is located. In PUMB scheme, if users move within the predicted direction, their SC window sizes increase up to a maximum $R_{\max}$.

$$R_{\max} = \max[Ring_{i,j}] \quad \text{such that} \quad P_{x,j} \ge \psi \tag{2}$$

So that, if a MU moves along the current direction, increasing the W_{sc} by increases the V-ring to support the *MU's* request. On the other hand, if a MU deviates from the current direction, decreasing the W_{sc}, as a MU may move out from the SC.

$$W_{sc} = \min(R_{\max}, \left\lfloor \left(1 - \frac{Dev_i}{\pi} T_x^{NC}\right)^2 R_{\max} \right\rfloor) \tag{3}$$

where T_x^{NC} is amount of continuous time that call x is prediction nonconforming call and Dev_i is deviation of call x at cell i. Let D_{Ai} is the direction of call x while moving to cell i and D_{Di} is the direction of call x while moving from cell i to cell j. The deviation of call x can then be calculated as:

$$Dev_i = |D_{Ai} - D_{Di}| \tag{4}$$

When MU deviates from the current direction, W_{sc} is decreased by an amount proportional to the degree of deviation. W_{sc} is recalculated at every handoff and *MU's* mobility behavior changing. Therefore, W_{sc} decreases and increases follow the *MU's* moving behavior.

2) Reservation Time Window (RTW)

In the PUMB scheme, the RTW of a MU in each cell of the SC is estimated by considering travel distance, its standard deviation, moving speed, and *MU's* position for more accurate. The RTW of *MU* x when it arrives at cell j from cell i is considered in three terms of the time: *expected earliest arrival time* $\bar{T}_{i,j}^{EA}(x)$, the *latest arrival time* $\bar{T}_{i,j}^{LA}(x)$ and the *latest departure time* $\bar{T}_{i,j}^{LD}(x)$. These time parameters can be determined by using the *maximum travel distance*, $\bar{D}_{i,j}^{\max}$ and *the minimum travel distance*, $\bar{D}_{i,j}^{\min}$ between *MU's* position in cell i and center of cell j, and by using normal distribution that has mean and standard deviation as $\bar{D}_{i,j}$ and $\sigma_{i,j}$, respectively [5].

The interval $[\bar{T}_{i,j}^{EA}(x), \bar{T}_{i,j}^{LD}(x)]$ is referred to as the *Resource Reservation Interval* (RRI), while the arrival interval $[\bar{T}_{i,j}^{EA}(x), \bar{T}_{i,j}^{LA}(x)]$ is referred to as the *Resource Leasing Interval* (RLI) [1]. The bandwidths are reserved for the duration of RRI. However, if the MU does not arrive to cell j before RLI expires, all bandwidth are released and the reservation is canceled. This is necessary to prevent *MU* from holding resources unnecessarily. When *MU* is considered as prediction nonconforming call, the cell accepts the call if it has free bandwidth to support minimum bandwidth request and recalculates the *MU's* shadow cluster and adjust window size of shadow cluster as shown in (3).

3) Resource Reservation

The proposed scheme then reserves an amount of bandwidth in a cell for a service proportional to the maximum bandwidth requirement of the service multiplied by the CVP for that cell in RTW. The reservation of bandwidth in the different cells of the shadow cluster should be updated as the *MU* moves from its current position. The reservation in different cells within the shadow cluster is updated when the *MU's* direction goes beyond the angular span of the shadow cluster. When there is an abrupt deviation in direction, the reservation is updated as well as the shadow cluster. When these cases occur, reserved resources in all cells in the shadow cluster are released while the *MU's* shadow cluster is recalculated. It used to support the new *MU's* direction and prevent unnecessary reserved bandwidth.

Unlike other schemes, although the MU hands off from one cell to another, but it's not change mobility behavior, the shadow cluster is not recalculated. Consideration of this situation increases channel utilization, i.e., it reduces both the CDP and the CBP, because it releases the resources reserved in those cells that lie outside the shadow cluster, while the overhead message transmission from shadow cluster recalculation is reduced.

B. PUMB Call Admission Control Algorithm

The main objectives of the CAC in PUMB upon accepting a connection request are as follow:

(a) to verify the feasibility of accepting a new call into the system,

(b) to guarantee an uninterrupted service for admitted calls as they move from one cell to another, and

(c) to maximize the utilization of the network resources.

These objectives can be achieved by reserving resources only where needed and within the expected residence time interval. Based on a balance between these extremes, the PUMB scheme can guarantee with high probability an uninterrupted service without unnecessarily sacrificing the network resource utilization by using algorithm for supporting prediction nonconforming call and releasing reserved bandwidth when *MU's* behavior changes.

In this section, we will present our proposed scheme called the Predictive User Mobility Behavior (PUMB) scheme. Firstly, it is necessary to define the traffic in cellular network into two classes: *Class I Partially elastic traffic* and *Class II Fully elastic traffic*. If a class I call comes into a cell with insufficient bandwidth, some class II calls should be terminated, if necessary, for making space. From elastic definition, we can calculate elastic rate (ER) from $\left(B_{\max}^{y} - B_{\min}^{y}\right)/B_{\max}^{y}$ where $B_{\max}^{y}$ is maximum bandwidth request and $B_{\min}^{y}$ is minimum bandwidth request. We can calculate the expected bandwidth B_{exp}^{y} for service y from elastic rate as [5]. A service is accepted if it is possible to allocate an amount $B_{\min}^{y}$ of bandwidth. We separate borrowing bandwidth into two types: the fair borrowing bandwidth FBB and the maximum borrowing bandwidth MBB [5].

1) Call Feasibility and Setup Procedure

Upon receive the reservation request, each cell in the SC decides whether it has sufficient bandwidth to reserve for the service. The base station sends positive response if it can support the service through reserving resources, and a negative response otherwise, as shown in

$$A_{i,j}^{t} = \begin{cases} 1, \ if \ C_j^f(t) \ge R_{y,j} \ for \ [\bar{T}_{i,j}^{ZA}(x), \bar{T}_{i,j}^{LD}(x)] \\ 0, \ otherwise \end{cases} \tag{5}$$

where $C_j^f(t)$ is amount of free bandwidths in cell j at time t. The value of $A_{i,j}^{t}$ are collected for all cells j in the SC of the current cell i for the $MU\,x$. The decision to accept is taken if the following holds:

$$1 \ge \sum_{j \in SC} (P_{x,j} . A_{i,j}^{t}) \ge \tau . \sum_{j \in SC} P_{x,j} \ge 0 \ ; \ 0 \le \tau \le 1 \tag{6}$$

The above feasibility test condition of the RTW and the CVPs is checked so that more weight is given to support responses of the cells whose CVP is comparatively higher. When the current cell i accepts the call, it sends a message to all cells in SC, confirming that the reservation must now be performed. Every call reserved the required bandwidth for the RRI duration and updated its available bandwidth accordingly. However, notice that cell j cancels the reservation if the *MU* that does not arrive before the resource leasing interval period, RLI, expires.

2) Prediction Conforming and Nonconforming Call

Due to the changing behavior of the mobile units in a cellular network, calls may hand off to cells that are not part of their Shadow Cluster and calls may not arrive within their resource leasing interval periods, RLIs. Therefore, we define the status of a call to be either *prediction conforming* or *prediction nonconforming* [1].

The CAC gives higher priority to prediction conforming calls over prediction nonconforming calls. When a prediction conforming call arrives and cannot be accommodated by the available bandwidth, a prediction nonconforming call is dropped. We borrow the predicted nonconforming call in order by the duration time decreasing for the purpose of increasing the call successful probability. The bandwidth allocation for prediction nonconforming call allocates only minimum bandwidth requested because of preventing CBP and CDP increasing.

3) CAC Algorithm for New Call

The PUMB CAC algorithms consider Class I and Class II calls differently while admitting a new call in a cell. When a new Class I call arrives in the cell i, the base station calculates the maximum available bandwidth by adding the FBB of each existing call to free bandwidth. If the maximum available bandwidth is greater than or equal to B_{exp} of the MU, then the bandwidth reservation request is forwarded to all the cells in the shadow cluster to test condition of reserved bandwidth in RTW period and send these responses back, the admission decisions are taken based on their responses which weight by their CVP. However, if the maximum available bandwidth is not sufficient to meet the new call's bandwidth demand, the call is rejected. On the other hand, if the free bandwidth in the cell is more than zero, Class II calls are accepted. At first, after accepting a service, the minimum required bandwidth is allocated to each of the services, and then the remaining surplus bandwidth is redistributed among the services according to the proportion of their elastic rate. When new calls are accepted, it is admitted as predictive conforming call. The details of the CAC algorithms for new calls are shown in Fig.2.

```
Class I
Step (1): IF $C_i^f(t)$ + summation of FBB ≥ $B^r_{exp}$, THEN send reservation
          request to all the cells of the SC and receive response form
          each cell of the SC. Otherwise, reject the call.
Step (2): IF $\sum_{j \in SC} (P_{i,j} A^t_{i,j}) \geq \tau_i \sum_{j \in SC} P_{i,j}$, THEN accept the call and GOTO
          Step (3). Otherwise, reject the call
Step (3): IF $C_i^f(t) \geq B^r_{max}$, THEN allocate an amount maximum
          requested bandwidth to the call. Otherwise, allocate free
          bandwidth to the call. Redistribute the bandwidth through
          allocating first the minimum required to each and then surplus
          according to their elasticity limit.
Step (4): Admitted call as predicted conforming call. Send confirmation to
          each cell in SC to reserve an amount of bandwidth
Class II
    IF this cell has free bandwidth, THEN accept the call and admitted call
    as predicted conforming call. Otherwise, reject the call
```

Figure 2.CAC algorithm of PUMB scheme for new calls

4) *CAC Algorithm for Handoff Call*

The PUMB CAC algorithms discriminate prediction conforming call and prediction nonconforming call by using the RLI period condition and shadow cluster cell. When prediction conforming call migrates to cell i, Class I class, the maximum available bandwidth for call is calculated by adding up free bandwidth $C_i^f(t)$, reserved bandwidth $C_i^r(t)$ and the summation of the MBB for each existing call in the cell i. If the maximum available bandwidth is greater than or equal to B^r_{min}, then the call is accepted; otherwise it is rejected. For Class II handoff calls, if the maximum available bandwidth is zero, the transmission is stopped and the service waits until it gets bandwidth to start transmission again, because the Class II calls are offline and do not have any impact on user interaction. Unlike the MSODB, the PUMB supports the case of prediction nonconforming call, if the free bandwidth can support B^r_{min}, the call is accepted, and otherwise, it is dropped. When bandwidth borrowing occurs, for making bandwidth a prediction nonconforming call is dropped before prediction conforming call. The details of the CAC algorithms for handoff calls are shown in Fig.3.

```
Step (1)  IF this cell is in SC and a call arrives to the cell during the lease
          period RLI, THEN GOTO Step (3). Otherwise, GOTO Step (2)
Step (2)  IF $C_i^f(t) \geq B^r_{min}$, THEN allocate free bandwidth to call, admitted
          call as predicted nonconforming call, compute new SC.
          Otherwise, reject the call
Step (3)  IF $C_i^f(t) + C_i^r(t)$ + summation of MBB ≥ $B^r_{min}$, THEN accept
          call, admitted call as predicted conforming call and GOTO Step
          (4). Otherwise, reject the call
Step (4)  IF $C_i^f(t) + C_i^r(t) \geq B^r_{max}$, THEN allocate an amount of maximum
          requested bandwidth to call. Otherwise, GOTO Step (5)
Step (5)  IF $C_i^f(t) + C_i^r(t) \geq B^r_{min}$, THEN allocate free bandwidth and
          reserved bandwidth to call, Otherwise, GOTO Step (6)
Step (6)  IF call is non-rate adaptive call, THEN allocate free bandwidth
          and reserved bandwidth to call and GOTO Step (7). Otherwise,
          include the call in the list of existing call, redistribute the
          bandwidth among adaptive calls without effecting non-rate
          adaptive calls
Step (7)  IF bandwidth held by predicted nonconforming calls can be freed,
          THEN terminate them, allocate bandwidth to call. Otherwise,
          borrow bandwidth from existing rate-adaptive call
```

Figure 3.CAC algorithm of PUMB scheme for handoff calls

III. PERFORMANCE EVALUATION

In this section, the simulation results are presented CBP and CDP. The performance is evaluated by comparing between our proposed PUMB and traditional MSODB when the shadow cluster probability threshold, ψ is varied when moving speed rang is 0-40m/s or 0-144 km/hr and the new call arrival rate is considered into 3 rang: low (1call/min), medium (5 calls/min) and high (10 calls/min).

In this simulation, we assumed arrival process has a Poisson distribution with arrival rate λ, while call duration time was assumed to be exponential distribution with the mean $1/\mu$. The number of cells is 39 cells and each cell radius is 1 km. Table 1 summarizes the various simulation parameters [4,5] whose values were empirically chosen to present the most realistic scenario for the simulation. The traffic characteristics are shown in Table 2, which was used in [2,3,5]. Each of the six types of traffic occurs with equal probability.

TABLE I. SIMULATION PARAMETERS [5]

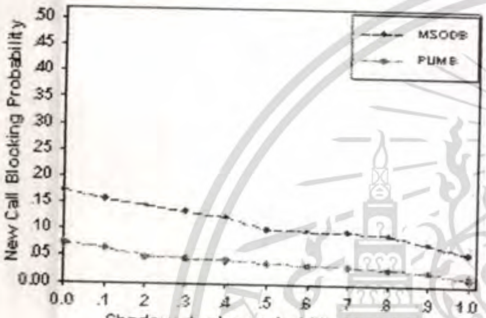
Parameter	Value	Description of parameters
N	39	Number of cells simulated
R	13	Number of country roads and freeways
C	40	Cell capacity
J	10	Number of road junction
M	var	Number of mobiles in system
G_{out}	0.0001	Going out of network probability
λ	var	Mean call arrival rate
v_i	0-144	Moving speed (km/hr)
G_{off}	0.01	Mobile off probability
$1/\mu_{off}$	var	Mean MU off time
$1/\mu_{out}$	var	Mean out of network staying time
β	0.9	Confidence level

TABLE II. TRAFFIC CHARACTERISTICS [5]

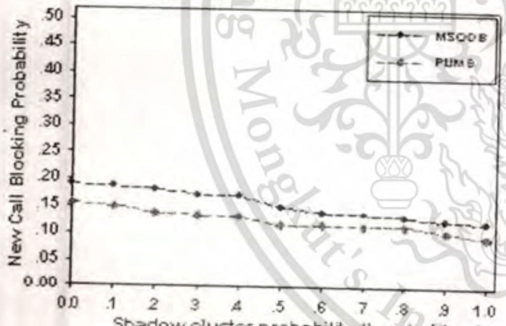
Traffic ID	Class ID	B^i_{min} (Mbps)	B^i_{max} (Mbps)	Min Time (s)	Avg Time (s)	Max Time (s)
1	C1	0.03	0.03	60	150	600
2	C1	0.256	0.256	60	300	1800
3	C1	1.0	6.0	300	600	18000
4	C2	0.0	0.02	10	30	120
5	C2	0.0	0.512	30	180	36000
6	C2	0.0	10.0	30	120	1200

The CBP of PUMB and MSODB are shown in Fig.4. When shadow cluster probability threshold increases, CBP of MSODB and PUMB decrease in all arrival rates. At arrival rate is 1 call/min, the CBP of PUMB is improved about 4.5-10% from MSODB and when shadow cluster probability threshold increases, the CBP of MSODB and PUMB decrease 11% and 6% respectively. In case of medium arrival rate, the CBP of PUMB is improved about 1.8-4.5% from MSODB and when shadow cluster probability threshold increases, the CBP of MSODB and PUMB decrease 6.5% and 6% respectively. The CBP of PUMB is less than MSODB about 3.5-5.5% and when shadow cluster probability threshold increases, the CBP of MSODB and PUMB decrease 7.5% and 6.5% respectively when arrival rate is 10 calls/min.

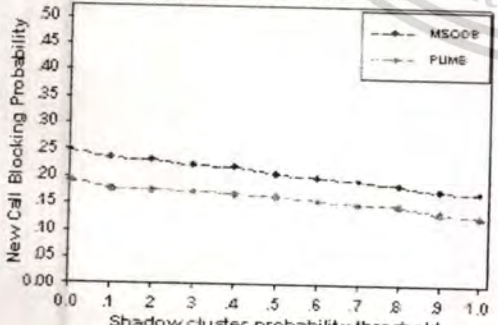
Fig. 5 shows the CDP of MSODB and PUMB. The results show that the CDP of MSODB and PUMB increase as shadow cluster probability threshold increases in all arrival rates. The CDP of PUMB is improved about 2.7-3% from MSODB and when shadow cluster probability threshold increases, the CDP of MSODB and PUMB increase 3.1% and 0.14% respectively at arrival rate is 1 call/min. In case of medium arrival rate, the CDP of PUMB is improved about 2-2.6% from MSODB and when shadow cluster probability threshold increases, the CDP of MSODB and PUMB increase 3.1% and 0.9% respectively. The CDP of PUMB is less than MSODB about 1.7-2% and when shadow cluster probability threshold increases, the CDP of MSODB and PUMB increase 3.1% and 1.2% respectively when arrival rate is 10 calls/min.



(a) arrival rate = 1 call/min

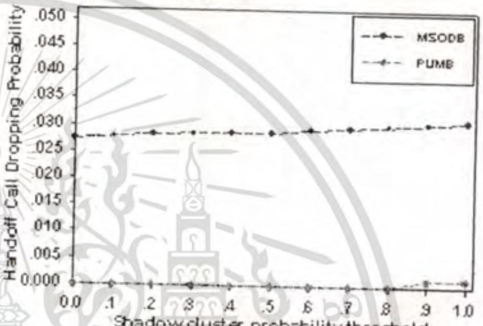


(b) arrival rate = 5 calls/min



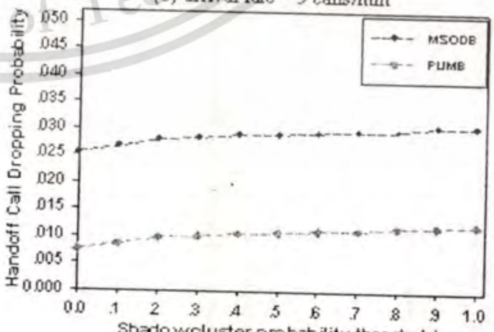
(c) arrival rate = 10 calls/min

Figure 4. Comparison of new call dropping probability for varying shadow cluster probability threshold



(a) arrival rate = 1 call/min

(b) arrival rate = 5 calls/min



(c) arrival rate = 10 calls/min

Figure 5. Comparison of handoff call dropping probability for varying shadow cluster probability threshold.

IV. DISCUSSION

From the results, in case of arrival rate is low (1 call/min), the shadow cluster probability threshold has a little effect to CDP value as shown in Fig.5 (a), CDP values of the shadow cluster probability threshold between 0-0.8 don't vary. Because the traffic is low, the network can support bandwidth reservation of all calls. In the other hand, the shadow cluster probability threshold effects to CBP value because the high shadow cluster probability threshold value effects to decrease the reserved bandwidth that can receive more new call. From the graphs, the suitable shadow cluster probability threshold value for low arrival rate is 0.8. When arrival rate is higher (5 and 10 calls/min), the shadow cluster probability threshold effects to CDP value because the high shadow cluster probability threshold value effects to decrease the reserved bandwidth that can lead CDP increasing while CBP decreases due to the network can support more new call. From the results, the suitable shadow cluster probability threshold values for medium and high arrival rate are 0.2-0.3 and 0.1-0.3, respectively.

Because when shadow cluster probability threshold increases, the *MU*'s shadow cluster size decreases. So that, amount of reserved bandwidths for each *MU* decrease. As the result, the reserved bandwidths in the network decrease and free bandwidths that used to support new call increase. This causes effect to increase CDP and the unused reserved bandwidths increase due to the handoff call is dropped before it arrivals to these cells. Therefore, CDP increases as long as shadow cluster probability threshold increases while CBP decreases. On the other hand, when shadow cluster probability threshold is lower, amount of cell in each *MU's* shadow cluster is greater. The reserved bandwidths increase but the available bandwidths decrease.

V. CONCLUSIONS

We have proposed the new approach to improve the performance, PUMB. The PUMB algorithm can guarantee an uninterrupted service by creating shadow cluster from considering CVP compares with shadow cluster probability threshold, so that the suitable shadow cluster probability threshold can increase network performance. The simulation has been performed in order to compare the achieved performance with the MSODB. The simulation results demonstrated that when shadow cluster probability threshold increases, CBP of MSODB and PUMB decrease while CDP of both schemes increases in all arrival rates. In case of arrival rate is low, the suitable shadow cluster probability threshold value is 0.8. When arrival rate is higher, the suitable shadow cluster probability threshold values for medium and high arrival rate are 0.2-0.3 and 0.1-0.3, respectively. However, PUMB may have the better performance than MSODB even through the shadow cluster probability threshold for all arrival rates.

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