Adaptive Location Update Schemes for
Continuous Cell Zooming Algorith in
Wireless Networks

By

Ms. Khin Cho Tun

Submitted in Partial Fulfillment of the
Requirement for the Degree of
Master of Science in Communication
and Computer Network Technology
Assumption University

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Master Thesis Approval

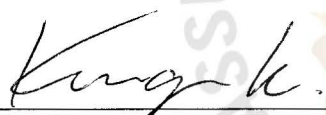|	
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April 2015

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LIST OF PUBLICATIONS

Under the supervision of her advisor, Dr. Kunagorn Kunavut, the author has published the following research papers that are related to this research.

[1]   K. C. Tun and K. Kunavut, Performance evaluation of dynamic cell zooming algorithms in omni-directional and sector-based cells, in Proc. International Joint Conference on Computer Science and Software Engineering (JCSSE-IEEE), pp.556–560, 2014.

[2]   K. C. Tun and K. Kunavut, An overview of cell zooming algorithms and power saving capabilities in wireless networks, KMUTNB: International Journal of Advanced Science and Technology, vol.7, no.3, pp. 1–13, 2014. (TCI)

[3]   K. C. Tun and K. Kunavut, Adaptive location update schemes for continuous cell zooming algorithm in wireless networks, in Proc. International Conference on Knowledge and Smart Technology (KST-IEEE), pp.155–160, 2015. (Best Paper Award)
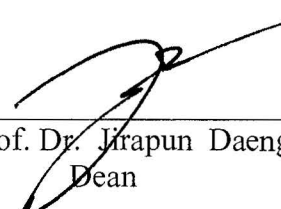
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ABSTRACT

Continuous cell zooming algorithm is a potential dynamic cell zooming algorithm for energy-efficient operation of mobile wireless networks. In this algorithm, location management strategy (location update process) is required to know the location of the farthest user in each cell to perform cell zooming. However, the application of conventional periodic update scheme in continuous cell zooming algorithm can lead to a high signaling cost. Therefore, in this research, two adaptive location update schemes, namely, Time-Adaptive Periodic Update (TAPU) and Location-Adaptive Periodic Update (LAPU) are proposed aiming to reduce the number of update messages in cell zooming operation. The performances of the proposed adaptive location update schemes are compared with that of Convention Periodic Update (CPU) scheme. Their performances are evaluated in terms of power saving capability, outage ratio and the number of update messages in cell zooming operation in different scenarios in both omni-directional and sector-based cell networks. The results show that the TAPU and LAPU have no significant effect on power saving capability of continuous cell zooming algorithm, however they give less number of update messages in cell zooming operation compared to CPU scheme. However, outage occurs in cell zooming operation with TAPU scheme because it has longer update intervals. Meanwhile the LAPU scheme can eliminate outage in cell zooming operation as CPU scheme does. In the scenario with the variation of total number of users in the network, the results depict that the transmitted power ratio and the total number of update messages in each update scheme increase with the increment of total number of users in the network. Meanwhile, the outage ratio in TAPU has a declined trend with the increase of total number of users in the network.

In the scenario with the variation of average moving speed, the transmitted power ratio achieved by each update scheme has no consistent (increasing or decreasing) trend with the increment of average moving speed due to inconsistent moving behaviour. The outage ratio in TAPU increases with the enhancement of average moving speed of users in the network. The numbers of update messages in both CPU and TAPU are constant and the number of update messages in LAPU has the same trend with transmitted power ratio. In sector-based cell network, larger power saving can be attained. Consequently, a lager outage ratio also occurs in sector-based cell network. Compared to CPU, the total number of update messages is reduced about 50% by TAPU and LAPU in both omni-directional and sector-based cell networks.

CHAPTER 1

Introduction

This chapter introduces the emergence of the cell zooming concept as a potential strategy to develop green communication in wireless networks.

1.1 The Growth of Cellular Networks and Subscribers

Since many decades ago, human society has been upgraded through modernized telecommunication networks. Here, being an integral part of modern telecommunication system, cellular phone technology has brought a great impact on different perspectives of human since its first appearance in the late 1970s. Since around 2006, in some countries such as India, the number of cellular phone subscribers has far exceeded the number of wired phone subscribers [6]. According to the prediction of GSMA (Groupe Speciale Mobile Association), in Asia Pacific, 3G coverage will increase by approximately 20% between 2014 and 2018 to reach 90% of the region's population [45]. It was also foreseen that the majority of future growth in mobile phone connection would come from the markets of developing regions because most developed world markets are close to 100% penetration. Meanwhile, mobile subscribers have also been able to access the Internet via their mobile phones (devices) for online communication services such as web browsing, emails and file transfers since the birth of 3G (Third Generation) and at the current era of 4G (Fourth Generation) communication technologies. This take-up of broadband services in mobile communication also has brought the substantial growth of 3G traffic volume from 300 % to 700 % yearly [2]. Such increasing number of subscribers and enlarging

traffic volume necessitate the tremendous increment of the communication infrastructure year by year. Figure 1-1 depicts the growth of global network convergence area with respect to world's population [45]. It is understandable that the yearly growth of convergence area highlights the increment of mobile networks in the world with increasing number of subscribers.
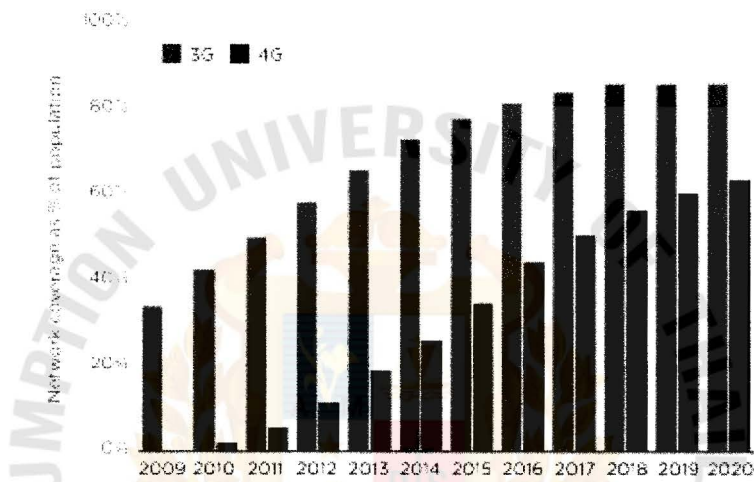
Figure 1-1 Growth of global network convergence 2009-2020 [45]

1.2 Global Issues

On one hand, it is to see such growth of communication networks as a gain in human society. On the other hand, two issues come up with this gain are larger and larger energy demand to supply these communication networks and the footprints of CO_2 emission from massive energy production. Today, these global issues are being critically discussed since the incoming energy crisis due to fossil fuel depletion is the major worry of human society and the footprints of CO_2 emission such as global warming and climate change have been obviously sensed in the environment.

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A study reported that the power consumption of telecommunication networks was almost 160 TWh in 2007 and it will sustainably grow by a rate of 10.2 % per year [28]. By this rate, it was estimated to be 315 TWh by 2015. As a consequence, the contribution of CO_2 emission from global telecommunication systems (mobile and fixed communication devices) is approximately 230 $MtCO_2e$, which is about 29 % of the total carbon footprint of ICT (Information and communication technology), 800 MtCO2e [14]. This statistic shows that the telecommunication networks are partially responsible for the critical global issues.

At this point, a research noticed that future networks with wireless technologies will continue to consume at least ten times more power than that with wired technologies when providing comparable access rates and traffic volumes [3-6]. This fact prompted research society to get started to initiate a new research area called "*Green Cellular Networks*". At the same time, the corresponding organizations also started projects aiming at "*Green Wireless Communication*". For example, the European Commission included projects such as "*Energy Aware Radio and NeTwork TecHnologies (EARTH)*", "*Towards Real Energy-efficient Network Design (TREND)*" and "*Cognitive Radio and Cooperative strategies for Power saving in multi-standard wireless devices (C2POWER)*" within its seventh framework program to address the energy efficiency of mobile communication systems [21].

1.3 Power Consumption in Base Station and Feasible Management

If the power consumption in a wireless mobile network is analyzed by breaking down into different categories as shown in Figure 1-2, it can be found that the base

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station consumes more than 50% of entire network's power consumption [21]. Then a research also stated that the group of base stations is responsible for two-third of CO_2 emission from a cellular network [8]. For this reason, management of energy consumption of wireless base stations by means of advanced technologies or operational strategies has become an essential topic of discussion and important mission of research society [1].
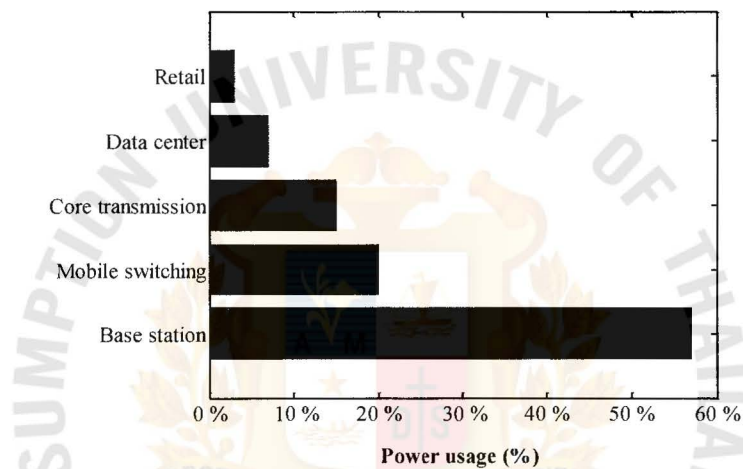
Figure 1-2 Cellular network power consumption [21]

The feasible management of base stations that should be performed in a holistic approach that integrates many different aspects from which energy efficiency can be improved is shown in Figure 1-3. More specifically, the energy efficiency of a network can be increased by using a more efficient power amplifier, renewable energy, agile (moveable and small) base station such as femtocells, smart grid, cognitive radio, newer protocols in medium access control (MAC) and so on. Here, it can be noticed that switching off a portion of the network (site level-turn off) during low traffic hours is also a feasible solution to reduce power consumption or to increase energy efficiency.

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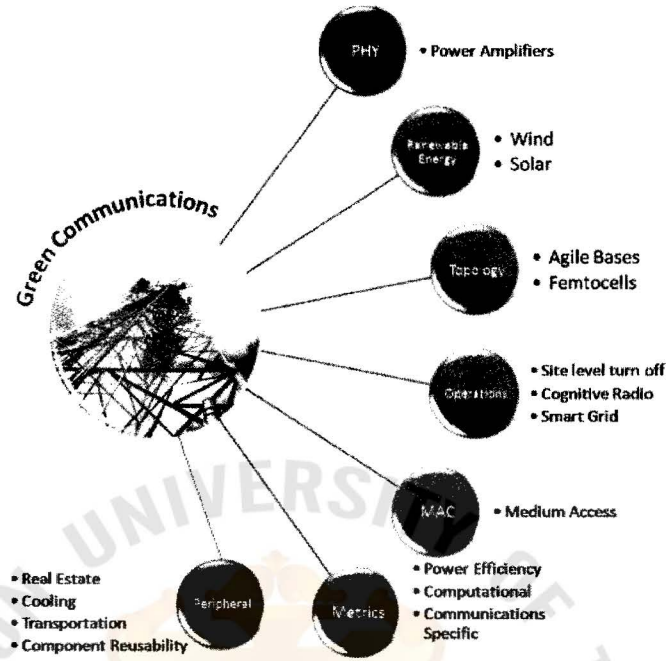
Figure 1-3 Holistic green communications research vision [1]

1.4 Cell Zooming in Cellular Network

As explained above, taking management on base stations to reduce power consumption in cellular networks from a single aspect is not adequate yet. For example, the energy efficiency of a cellular network can be increased by deploying MIMO (Multiple Input Multiple Output) antennas instead of SISO (Single Input Single Output) antennas [53]. However, it still finds that the static operation of base stations regardless of traffic arrival and users' location in a particular network lead to unnecessary energy usage. This practical experience bears a compatible strategy called *cell zooming* to optimize the energy consumption of the base stations in a network.

Firstly, it should be known that there is a conceptual diversity of *"cell zooming"* in a cellular network. It can be explained as follows.

1.4.1 Relay-assisted cell zooming

In this concept, the originally designed cell size is not zoomed in/out. At the edge of original cell, a moveable or fixed relay station is applied as shown in Figure 1-4 so that the transmitted power of the main base station is amplified and retransmitted at the same frequency to further distance. Sometimes, relaying is performed by mobile station [25]. Thus, this concept is also seen as "cell zooming" although the original cell is not zoomed out in reality [25, 39, 53].
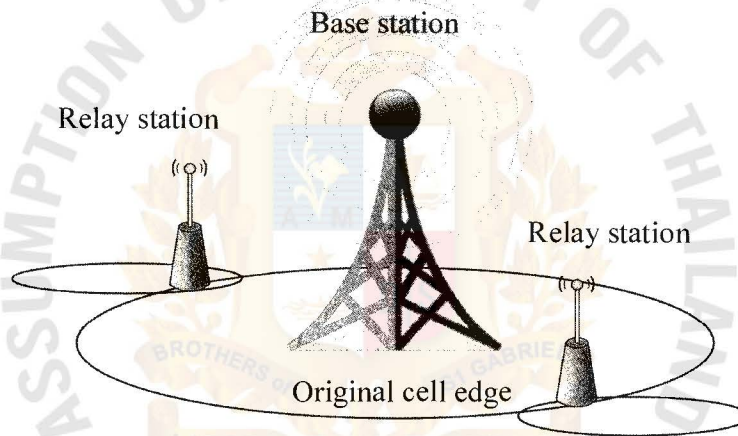
Figure 1-4 Relay-assisted cell zooming

1.4.2 Multi-point coordinated cell zooming

This concept also brings "cell zooming" without resizing the original cell size of each base station. Figure 1-5 helps to explain this concept in which the designated mobile station is served by multi base stations at the same time. Thus, from the perspective of a mobile station, the cell size is virtually magnified although the actual cell sizes of base stations do not change. Thus, this concept is also termed as "virtual cell zooming" or "virtual MIMO system" [19, 22, 53].

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• Mobile station
——— Real cell edge
– – – – Virtual cell edge
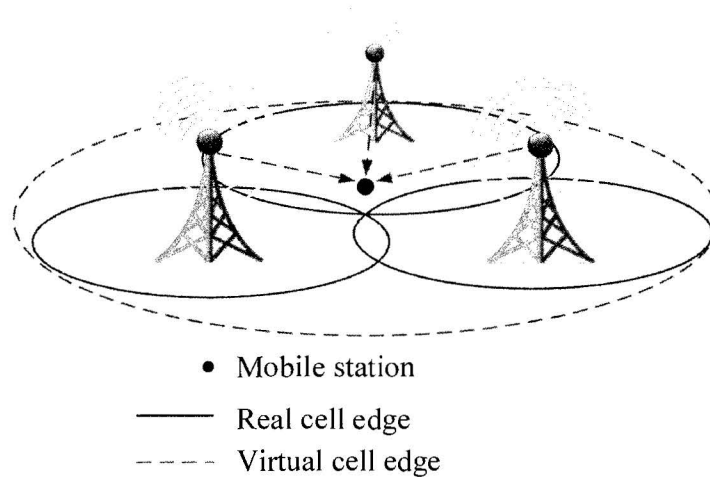
Figure 1-5 Multi-point coordinated cell zooming

1.4.3 Physically adjusted cell zooming

In this concept, the original cell size is actually reformed by adjusting the parameters such as antenna height or transmitted power [33, 35, 53]. As shown in Figure 1-6, the cell edge of the base station can be changed by adjusting the antenna height. It also should be noted that setting sleep mode and switching the cell off are included in this concept. At the same time, it should be noted that some authors [32] alternatively use "switch-off" and "sleep mode" because energy consumption in sleep mode is negligible and it is the nearly same as switching-off.

——— Original cell edge
– – – – – Zoomed cell edge
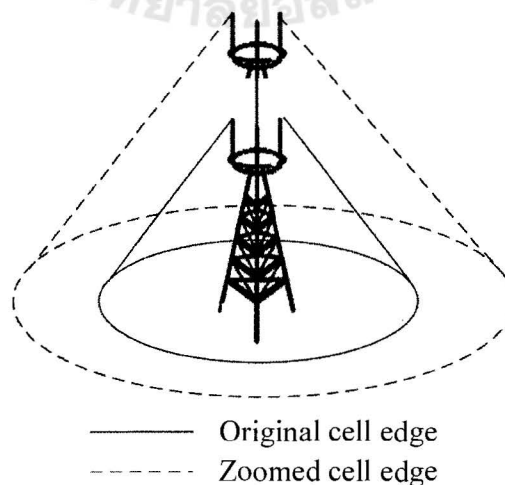
Figure 1-6 Physically adjusted cell zooming

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1.5 Challenges in Physically Adjusted Cell Zooming

Physically adjusted cell zooming is alternatively termed as "cell breathing" [34]. To the best of the author's knowledge, "cell breathing" was firstly introduced as a load balancing method in CDMA and WCDMA networks in earlier works [23, 41, 43]. At that time, most researchers mainly focused on the impact of "cell breathing" on the soft handoff margin shifting and call quality rather than power saving [23].

Then, the "sleep mode" concept was introduced as a power saving mechanism for wireless access network in IEEE 802.11 and IEEE802.16e specifications [50, 26, 48]. Although "sleep mode" was intended only for mobile stations (MTs), it has also been adopted for power saving in base stations (BSs). Setting base stations into sleep mode also can be seen as cell zooming because the convergence umbrella is shrunk to zero. Currently, the combination of cell breathing and sleep mode emerges as cell zooming. That is why, cell zooming gets the advantages of load balancing from "cell breathing" concept and power saving from "sleep mode" concept. Figure 1-7 schematically demonstrates a brief concept of cell zooming.

Before Cell Zooming   After Cell Zooming

▲ Active cell
△ Switched-off cell
• Mobile stations
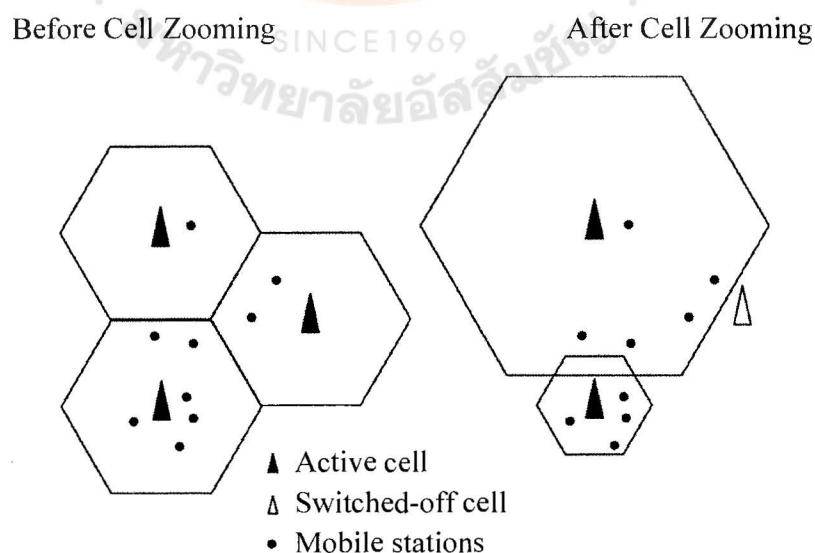
Figure 1-7 Conceptual scheme of cell zooming

Under the concept of cell zooming, the cell with light traffic load can zoom out to serve some of the users in two other cells. This reduces the traffic load in its neighbouring cells, and some cells can even go switch-off, resulting in energy saving.

On the other hand, a number of challenges still exist for deploying cell zooming strategy in practical applications. First, a trade-off between energy saving and the effects on QoS (Quality of Services) occurs due to uncertainties in the forecast of traffic information in the network. Second, if awareness of traffic and QoS is taken in cell zooming, a massive information exchange among mobile stations, base stations and central control server is required. This can lead to complexity and a high cost for signaling messages. Thus, in the literature, various feasible cell zooming algorithms are being proposed in forward-stepping attempts balancing between power saving and the challenges mentioned above. Therefore, cell zooming has emerged as an essential research area, and an increasing trend of researches about cell zooming has been built from initial point to the current position.

CHAPTER 2

Literature Review and Problem Statement

In this chapter, a survey of previous works that concerned with different cell zooming algorithms is performed. Finally, the problem that needs to be solved is addressed.

2.1 Previous Researches on Cell Zooming Algorithms

In the literature, a number of attempts have been done to combat the challenges in two main categories of cell zooming algorithms. These are:

1) Regular or static switch-off algorithm
2) Dynamic switch-off algorithm

2.1.1 Regular or static switch-off algorithm and related works

The regular switch-off algorithm is simpler compared to dynamic algorithm. In this algorithm, the cells are switched off in a predefined pattern by a network control server during a predefined period when low traffic arrival is expected or the traffic arrival is lower than a specified traffic threshold. The active cells are managed to zoom out by increasing transmitted power or antenna height to cover the convergence umbrella over the switched-off cells. Since the daily traffic distribution is mostly considered as regular and uniform throughout the network, the switched-off cell pattern will not vary time by time during the cell zooming period and also day by day. Thus, it is seen as static algorithm. A possible switched-off cell pattern and a sample of time frame for regular switch-off algorithm are shown in Figure 2-1 (a)-(b).

All the cells work in normal mode in non-zooming period. The main advantages of this type of algorithm are simplicity and noticeable power saving at night hours when traffic arrival is low.
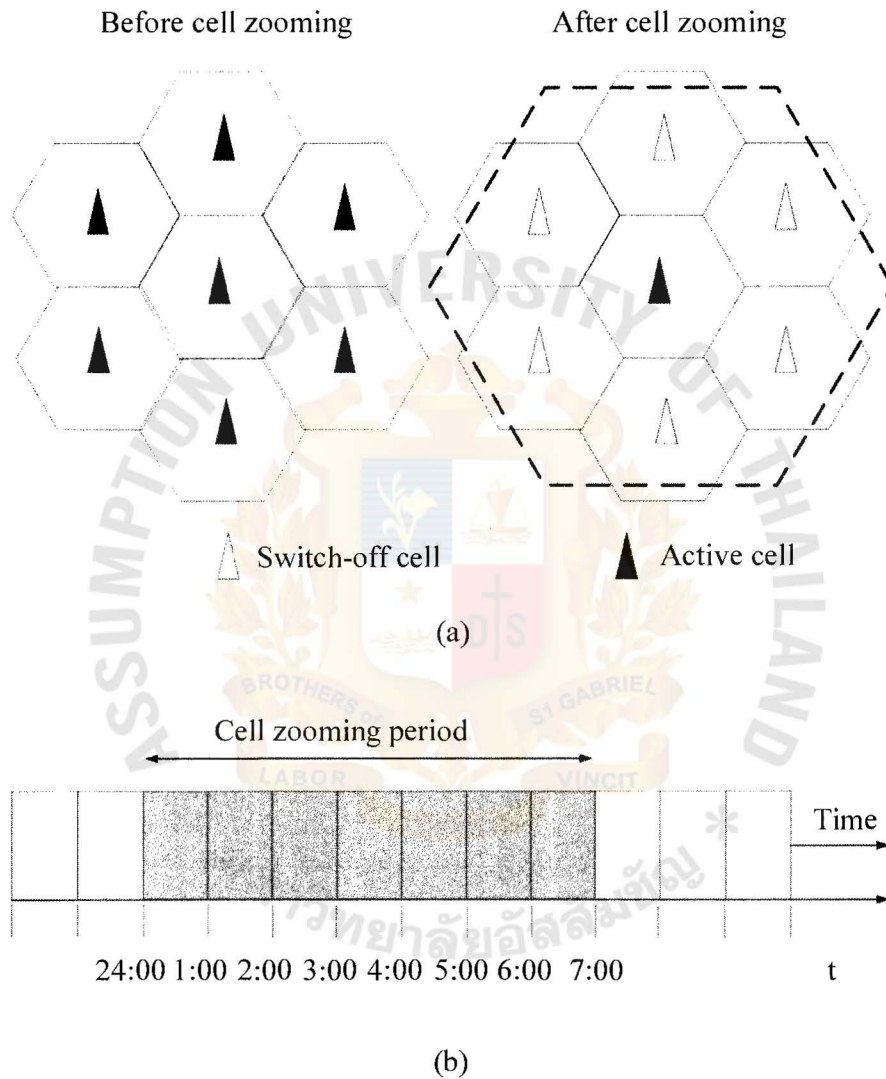
Figure 2-1 Basic regular switch-off algorithm (a) possible switched-off cell pattern

(b) a sample of time frame

On the other hand, the limitation of static algorithm is that it cannot be applied for full-day operation in which time-dependent traffic fluctuation and traffic spatial

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distribution is high. Also, it is not useful for a location where the traffic arrival pattern is not consistent day by day.

The earliest regular switch-off algorithm was proposed by Chiaraviglio et al. [7]. In this algorithm, three different site scenarios such as residential scenario, office scenario and hierarchical scenario were considered. Also, the authors considered that the peak traffic (active calls) in residential site happened during night while that in office site appeared during day hours. At this point, one can realize that when the site of interest is relatively specific, a survey of traffic profile should be taken rather than following general traffic profile. For instance, as the authors considered, today mobile subscribers in urban residential area prefer social calling or data accessing during relaxing time before midnight. Then, Marsan et al. [31] proposed different switch-off patterns for different network topologies such as Hexagonal, Crossroads, Manhattan configurations. From this work, it was noted that 4-out-of-5 switch-off pattern from Crossroads configuration gave the largest percentage of power saving. In later works [27, 29, 16], QoS constraints were applied to adaptively choose a switch-off pattern.

An inconvenient situation can exist to perform cell zooming with a particular pattern in a given network topology. Regarding this issue, the authors of [51] explained one possible problem and solution. The possible problem is that sometimes, "insufficient cell zooming" can occur due to deployment of large cells. Thus, the solution to this issue is deploying smaller cells to overcome the "insufficient cell zooming". Nahas et al. [51] also stated that sleep-mode with smaller cells saved more energy than using larger cells. Relating to smaller cell deployment, the authors of [11] highlighted the potentiality of "HetNets". HetNets are multi-tier radio access networks in which micro and/or pico/femto cells overlay the macros [11]. The authors

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discussed that the deployment of picocells would result in more energy efficient architecture.

Here, a notable point is that setting sleeping mode for a long period may not always be effective because the energy consumption of active cells increases due to far traffic from slept cells. It is called "network impact" [13]. It was proved by the authors of [38] by evaluating the performance of "Semi-Static-Sleep-Mode (SSSM)" concept in which the base stations were set in sleep-mode in an order of one hour. It was found that semi-static approach was less effective in power saving compared to sleep-mode in minute interval (dynamic concept), but it could reduce activation/deactivation times and signaling overhead. When a recap is taken, it can be noticed that the researches of static switch-off algorithms have given more attention to two main parameters that are switched-off cell pattern and switch-off time frame.

2.1.2 Dynamic switch-off algorithm and related works

The regular switch-off algorithms are no longer reliable in the networks with irregular traffic arrivals, and these are limited to only off-peak hours. The dynamic cell zooming algorithms are developed to overcome these drawbacks. Thus, it is relatively more complicated than static switch-off algorithm. In this algorithm, the traffic condition in each cell or a cluster of cells is dynamically inspected. This traffic load information is exchanged among collaborative base stations themselves (in distributed plan) or via a central server (in centralized plan). Then, the cell zooming decision is made depending on the traffic load condition in each cell. Thus, on/off cells are not statically defined. This dynamic algorithm can provide power saving and at the same time it can solve traffic congestion problem if it occurs. However, the challenge in dynamic switch-off algorithm is how to manage the requirement of

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massive information exchange among mobile users, base stations and control server. In addition, dynamic switch-off algorithm is not suitable for macro cells because reactivating time for switched-off macro cells is considerable and very fast on/off operation cannot be easily performed. Figure 2-2 (a)-(b) demonstrates the concept of dynamic switch-off algorithm and a sample of time frame.

Before cell zooming   After cell zooming

△   Switched-off cell   ○   Associated mobile users
▲   Active cell   ●   Mobile users
- - - Backhaul connection

(a)
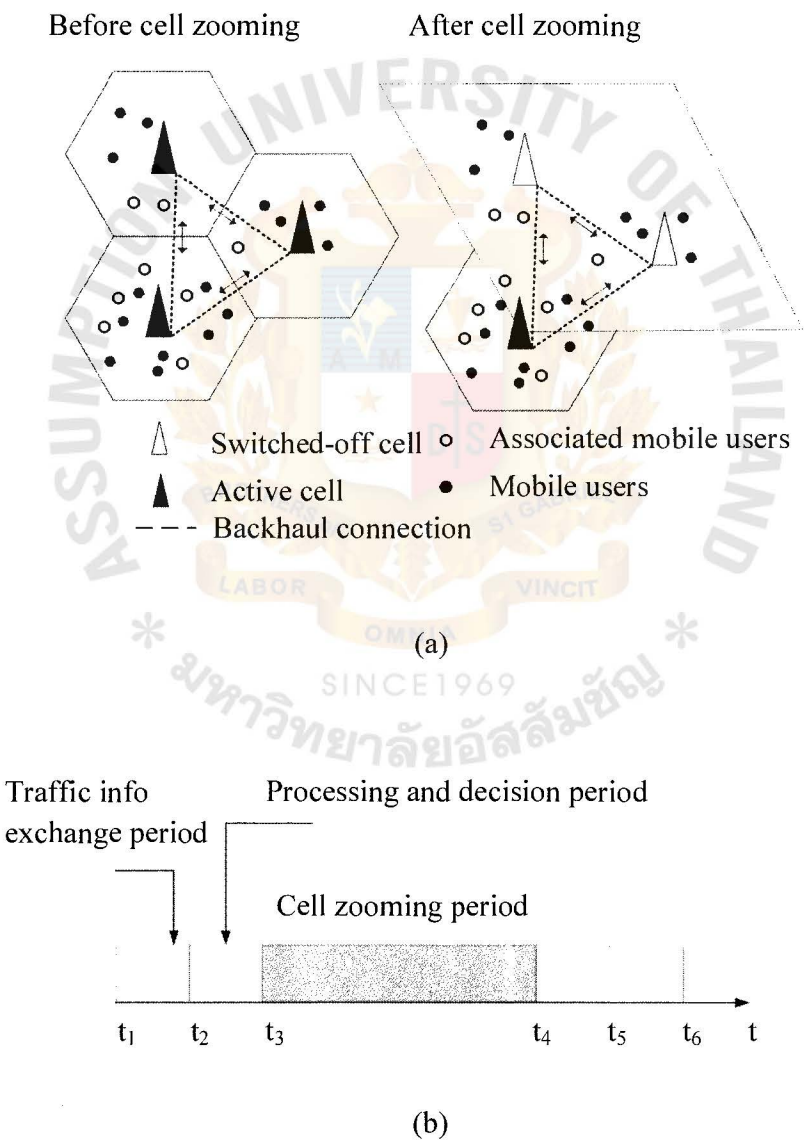
Figure 2-2 Basic dynamic switch-off algorithm (a) conceptual scheme

(b) a sample time frame

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It should be noted that the cell zooming period in the time frame of dynamic algorithm can vary according to traffic condition in each cell. For instance, if the traffic load is full in all cells, they will not perform cell zooming and there will be no cell zooming period. The information exchange period and processing period will alternatively go on.

Recently, regarding traffic spatial distribution, a group of researchers [4] started to propose location management-based cell zooming algorithms. The authors proposed three types of location-management cell zooming algorithms. They were "continuous zooming algorithm", "fuzzy zooming algorithm" and "discrete zooming algorithm". Since this work is related to continuous zooming algorithm, it is worth to briefly restate its concept here. The detailed concept of two other algorithms can be seen in [4].

In continuous zooming algorithm, the location of the farthest user in the cell is detected. Then, the cell is zoomed to the exact location where the farthest user exists. The concept is demonstrated in Figure 2-3.
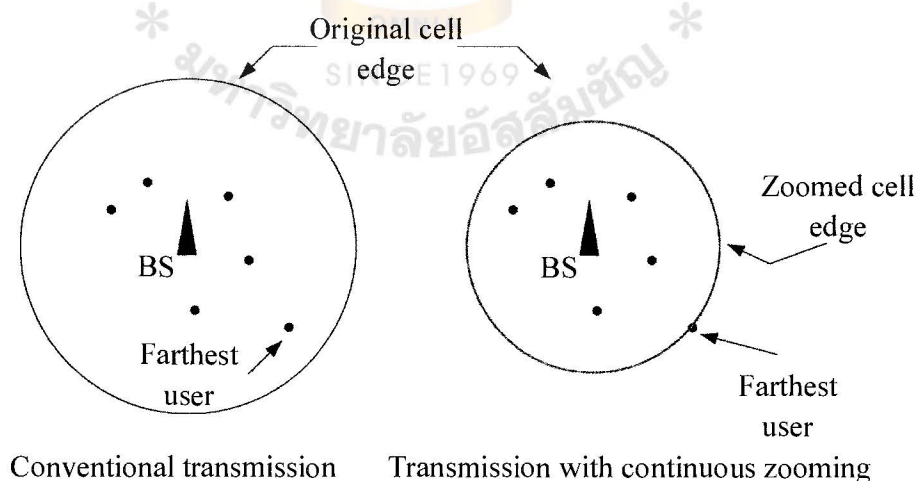
Figure 2-3 Concept of continuous cell zooming algorithm

The distinct features of this type of dynamic cell zooming algorithm are-

1) On/off switching delay is avoided because there is no switch-off scheme.

2) No-traffic exchange between base stations is needed because the cell zooming is performed individually in each cell.

3) Cell zooming can be performed with a certain information about traffic spatial distribution because the locations of users are detected by location management strategies.

4) The challenge is to find out a flexible location update strategy for detection of user location.

The earliest dynamic cell zooming algorithm in wireless base stations was introduced by Saker et al. [32]. The authors proposed the base station sleep-mode algorithm for 2G/3G coexisted network by taking management of traffic allocation between 2G and 3G base stations. The authors recommended that setting sleep-mode in 2G base stations would provide larger gains (energy saving and QoS) since the 3G system can support higher rate services that are not supported by 2G system. Since that time, the authors considered that the infrastructure needed for sleep-mode operation is an important issue to increase the possibility of the concept. The same authors [38] proposed sleep-mode concept for 2G and HSPA/HSPA+ networks with dynamic and semi-static resource management. In dynamic concept, the resources of base stations are activated or deactivated according to the traffic load at every minute interval, meanwhile at every one hour interval for semi-static concept.

Then, Zhisheng et al. [53] proposed centralized and distributed dynamic cell zooming algorithms by taking traffic spatial distribution into considerations. According to their simulated results, centralized algorithm performed better than distributed algorithm and static algorithm. Although dynamic cell zooming algorithms

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are showing better performance, one of the great challenges in practical implementation is dynamic shifting from active state to inactive state and vice-versa. The authors of [12] explained that it is not realistic to immediately activate the resources and it can cause capacity problems in practice. Also, if activation-deactivation is performed several times, it can lead to a large signaling overhead. Thus, the authors presented the optimal control for base station sleep-mode. Consequently, Xueying et al. [52] showed that setup time and shutting down time had the impact on the energy efficiency.

In another approach to have a fast response in active-inactive shifting, the authors of [9] considered management only on power amplifier rather than all the components of a base station. Following the traffic condition, the power amplifier was set into switching-on state, idle state, transmitting state and switch-off state. In accordance with traffic condition, the power amplifier was put into switch-off or idle mode to save the power consumption. The same approach was done by Ferling et al. [15].

Regarding the ON/OFF durations in dynamic sleep-mode algorithm, an important fact is that OFF duration can adversely affect the QoS in some applications. For example, if the cellular network is connected to a VoIP network, the maximum allowable delay is 20 ms. Besides, subframes that carry essential synchronization signals and automatic repeat request signals should not suddenly be switched off [49]. In this regard, Wang et al. [49] developed sleep-mode algorithms for LTE base stations based on the time-domain and spatial-domain of physical layer structure. Having the same idea, Zhisheng et al. [54] explained the trade-off between energy saving and delay to the customers. The mean delay had a linear relationship with the number of awaited users during start-up and sleep-mode.

So far, many works have concerned about power consumption of base stations in various cell zooming approaches. One distinct work [40] took power consumption of customer premises into account in proposing a cell zooming algorithm. The authors stated that reducing active cells can increase the power consumption in customer's premise, that cannot be neglected by the operator. The reason is that customers in slept cells are relatively far from active cells. The finding in [18] also showed that a number of active cells need to be increased to fulfill the compromised QoS when traffic spatial distribution is considered. In the works of Prithiviraj et al. [36] and Jie et al. [24] carefully considered the traffic spatial distribution in their cell zooming scenarios. To this extent that has been reviewed, it can be noticed that the traffic spatial distribution has become a crucial fact to be considered in developing a particular cell zooming algorithm. Then, as introduced above, a group of researchers [4] proposed location management strategies to know the user location exactly. The authors [4] proposed three dynamic cell zooming algorithms with movement-based location update strategy to detect the user's location. The authors evaluated the performance of these algorithms in a single cell network. The results showed that the continuous zooming algorithm gave the highest power saving. However, the authors stated that it is a challenge to apply movement-based location update method for continuous zooming algorithm. In this regard, periodic location update method for continuous cell zooming algorithm was proposed in previous attempt [44]. Then, the performances of these cell zooming algorithms for full day operation in seven cell networks were evaluated. According to simulated results, the lowest power consumption of the network was attained by using continuous zooming algorithm. On the other hand, the continuous zooming algorithm gave outage due to the user movement in the interval of periodic update.

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Finally, Figure 2-4 illustrates the leading direction of researches pertaining to cell zooming. Since the cell zooming was initially aimed for load balancing, the earlier works were related to the impact of load balancing by means of cell zooming. After introducing the power saving concept, many researchers worked on power saving capabilities of different cell zooming algorithms in both static and dynamic approaches. It is realized that the static cell zooming algorithms are less effective in power saving and they are not helpful for load balancing in high traffic hours. Thus, the researchers turned to dynamic cell zooming algorithms. However, great challenges emerged in dynamic cell zooming algorithms. For examples, on/off delay and non-uniform traffic intensity in spatial domain must be aware to satisfy best the trade-off between energy saving and QoS effect. Therefore, current attempts are being related to cell zooming algorithms by giving awareness on QoS. According to the two recent works [4, 45], it is likely that the researchers are turning into location management to integrate it as a mechanism in developing more reliable and effective cell zooming algorithms in the future.

Green communication by means of cell zooming

Dynamic switch-off (Traffic spatial distribution aware)

Dynamic switch-off (On/off delay aware)

Dynamic switch-off

Regular switch-off

Load balancing   Time ⟶
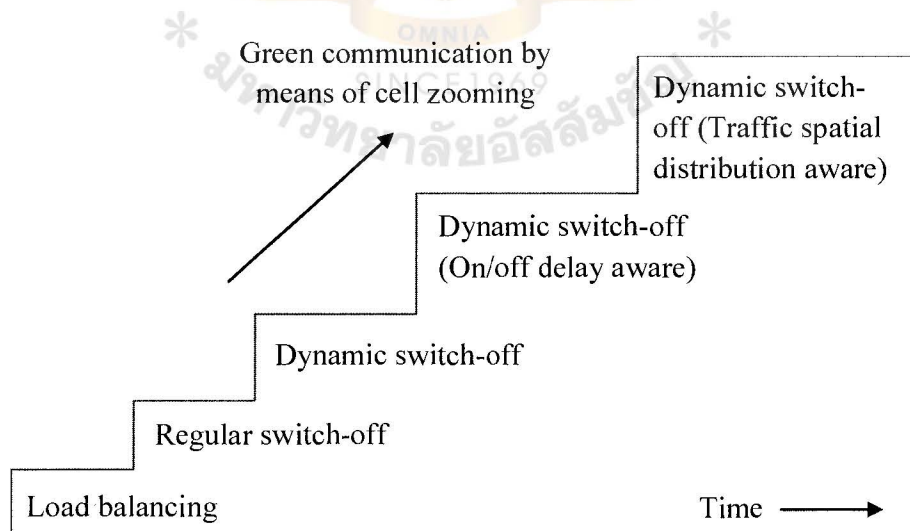
Figure 2-4 Trend of the researches on cell zooming algorithms

2.2 Problem Statement

As described in the trend of researches on cell zooming, location management-based cell zooming algorithms are currently getting into the research area due to their potentiality in the future. Here, the authors of [4] had laid the foundation of LM-based cell zooming algorithms (continuous zooming algorithm, discrete zooming algorithm and fuzzy zooming algorithm) and forward steps are currently in demand to increase their potentiality. More specifically, the fuzzy zooming algorithm and discrete zooming algorithm are ideally free of outage probability, but they are less effective in power saving and are less favourable. The continuous zooming algorithm can give better performance in power saving (see in Figure.2-5).
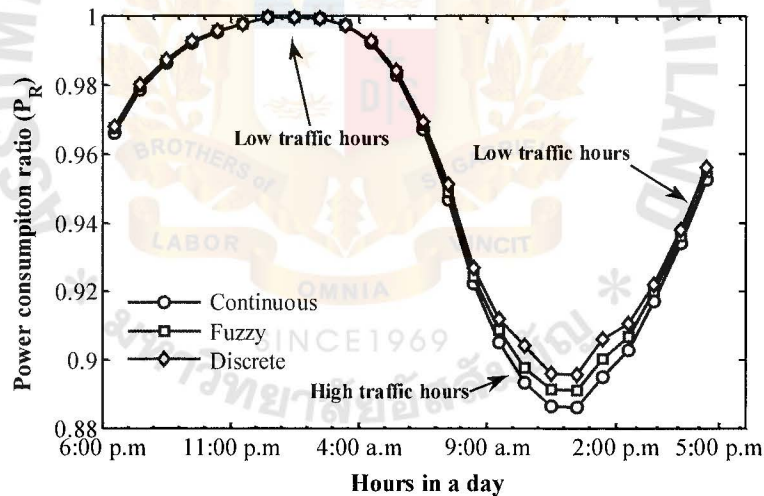
Figure 2-5 Comparison of power consumption by using three different

cell zooming algorithms [44]

However, continuous zooming algorithm is inconvenient with both of existing user location update strategies. First, movement-based location update is not reasonable for continuous zooming algorithm because the user will perform update

only when it changes its location from one predefined region to another predefined region, or only when it has moved more than predefined distance. Thus, it is not effective for continuous zooming algorithm.

Periodic update strategy is acceptable in continuous cell zooming algorithm since the location of the user is updated at every predefined time interval. However, when the periodic update is applied to continuous zooming algorithm, the outage occurs due to user mobility during the update interval [44]. This issue can be briefly described with a demonstration. For example, as demonstrated in Figure 2-6, at time t_1 the cell is zoomed according to updated information. At time t_2 before new update, the farthest user or other users may move out of convergence. In that condition, the user undergoes outage.

Condition at time, t_1 Condition at time, t_2
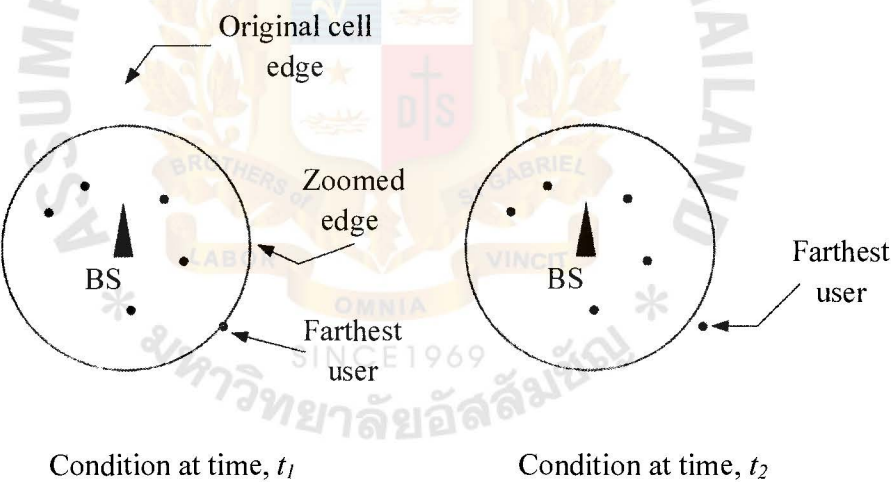
Figure 2-6 Probability of outage in continuous cell zooming algorithm

The outage can be reduced by using periodic update with a very small interval. But it will lead to signaling overhead because all users need to update very frequently. These all inconveniences are due to inflexibility of existing location update strategies as shown in Table 2-1.

Table 2-1 Advantages and disadvantages of exiting update strategies

Features	Periodic update strategy	Movement-based update strategy
Advantages	It is easy to implement because a simple timer to perform periodic update can be set in user premise.	It saves signaling cost when user mobility is low because the update is performed only when a user moves from one predefined region to another predefined region or only when a user has moved a certain distance.
Disadvantages	1) It becomes an unnecessary task when user mobility is low. 2) It will lead to high signaling cost when update interval is small.	1) It will lead to high signaling cost when the user mobility is high near the boundaries. 2) It is not compatible with continuous zooming algorithm.

2.3 Goal and Objectives

After proposing "cell zooming" as a potential strategy to reduce power consumption, intensive researches pertaining to "cell zooming" are crucially in demand. The main goal of this research is to partially fulfil in the development of effective update schemes that will be used in continuous cell zooming algorithm.

The objectives that to be implemented are as follows.

(1) To design adaptive location update schemes for reducing signaling messages (location update messages) in continuous cell zooming algorithm for energy-efficient operation of wireless-network

(2) To evaluate the performance of continuous cell zooming algorithm by using adaptive location update schemes in both omni-directional and sector-based cell networks

This research contributes new update schemes to the subject of location management and improving the performance of continuous cell zooming algorithm. Then, it provides information of the performances of proposed update strategy schemes.

2.4 Scope and Limitations

This research is particularly related to the matters of cellular network such as power consumption in base stations, radio transmission and location management.

A cluster of seven cells is considered as a sample network. The omni-directional and trisector-based cells are considered.

For adaptive location update schemes proposed in this work, a particular technique to measure the distance of the user from the base station is required. A possible technique is mentioned, but details about its accuracy are beyond the scope of this work.

The performances of proposed location update schemes are evaluated in terms of power saving, possible outage ratio and number of update messages in continuous cell zooming algorithm. This research is conducted by using MATLAB software as a simulation tool.

In simulation, there are some assumptions as follows.

(1) The network exists in a suburban area.

(2) The daily traffic arrival pattern to the network follows the Poisson distribution.

(3) The user mobility in the area of interest agrees with "Random Waypoint Model".

(4) Although there can be different types of traffic (e.g., instance messages, voice mails, internet access, voice calls), only voice calls are considered for simplification.

(5) Only macro base stations are deployed in the network.

CHAPTER 3

Proposed Location Update Schemes and Simulations

This chapter presents the concept of proposed adaptive location update schemes and continuous cell zooming algorithm. Also, the network parameters required in simulation such as cell type and network topology, radio transmission model, user mobility model and power consumption model are briefly discussed in this chapter.

3.1 Adaptive Location Update Schemes

As explained in problem statement, both traditional update strategies have imperfectness. The movement-based update is not compatible with continuous zooming algorithm because the user will never update if the movement is only in the same region or the moving distance is less than predefined distance. Thus, movement-based update strategy is suitable only for discrete (regional) cell zooming. The periodic update method is applicable in continuous cell zooming algorithm. However, a high outage ratio occurs when update interval is very long or it will lead to high signaling overhead when update interval is too short. Although different time intervals can be set for different users, it still needs a long term study of daily moving pattern of each user. Also, it is a risk to assume that the user does not change its moving pattern after some time. In this regard, adaptive location update schemes are proposed to deal with the issues mentioned above.

In time-adaptive periodic update (TAPU) scheme, the periodic update interval is varied according to the general user mobility level that changes with local time. For

example, the number of moving users at night hours is generally far smaller than that in day time. In day time, the numbers of moving users in office-starting hours (morning hours), lunch time (mid-day hours) and office-ending hours (evening hours) are larger than that in office-working hours. As a sample case in this work, three different user mobility levels (such as Level-1 < Level-2 < Level-3) are assumed for seven different local time intervals in a day. It is shown in Figure 3-1 (a). In practice, the pattern of mobility level in a network can be obtained by means of learning program of moving behaviour of mobile users. It should be noted that the pattern of user mobility level can be different from network to network and from office-day to holiday. Therefore, a longer update interval can be set for hours during which user mobility level is low and a shorter update interval can be set for hours of higher mobility level. The TAPU scheme is shown in Figure 3-1 (b). The network will select three different update intervals (such as $\Delta t_{up3} > \Delta t_{up2} > \Delta t_{up1}$). Then, it will often inspect the local time because user mobility level changes with local time. According to the local time, the network will set an appropriate update interval and broadcast to all users to perform update by using that update interval. Then, the work of MS is to often listen to the network to know the update interval. Then, it has to measure its distance (d_{MS}) from BS at each update interval according to pilot signal strength. Also, there are a number of potential user-positioning techniques although they are still under research [30]. When update time arrives, each MS has to report its location (d_{MS}) to the BS; so that network can analyze the farthest user distance in each cell. It should be noted that the location reported by mobile station is only the distance from BS but not global coordinates. Thus, it will not break the privacy of the user. It should be noted that the values of update intervals used in TAPU are configurable as required according to time-dependent mobility levels in the corresponding network.

(a)
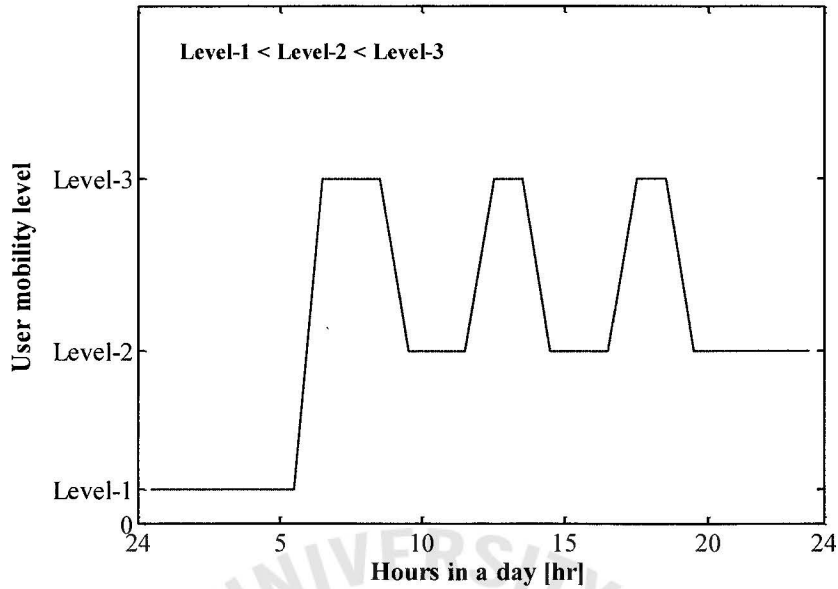
For BS (network)

– Set Δt_{up1}, Δt_{up2}, Δt_{up3} such as $\Delta t_{up3} > \Delta t_{up2} > \Delta t_{up1}$

– Inspect local time to estimate corresponding user mobility level

– Set appropriate update interval for that time (Δt_{up1} or Δt_{up2} or Δt_{up3})

– Broadcast to all users to do update with specified update interval

For MS

– Listen to network to obtain specified update interval

– Measure d_{MS} by means of pilot signal strength at every period

– Update location

(b)

Figure 3-1 Time-adaptive periodic update (TAPU)

(a) Sample user mobility level in a day (b) algorithm

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The second scheme is location-adaptive periodic update (LAPU) scheme in which the users perform location update according to their locations. For this scheme, the cell is logically divided into two regions. The outer region is defined as 'update region or update area'. At every update period, all users existed in update region are supposed to perform update and the other users outside update region are supposed to skip to update their locations. The concept of LAPU can be explained by using Figure 3-2 (a). In situation I, only users A and B will update in the coming period since they are in update region. But the user C will not update. In situation II, there is no user in update region and the network will receive no update message. In such situation, the network will inform all the users to update their locations. Then, the cell will be shrunk to the new farthest user in the coming period.

The update area should be set according to the estimated number of users in the cell. If update area and the total number of users in the network are large, the number of users who need to update will increase. If the update area is too small, situation II can often occur and the network has to often broadcast to all users, which is not effective. Please note that this update region is configurable as required and it is set as the region between two-third cell edge and the original cell edge in this work.

The LAPU scheme is shown in Figure 3-2 (b). In LAPU scheme, the task of the network is to set a periodic update interval (Δt_{up}) for all users uniformly. Then it has to regularly receive update messages from users in update region. If there is no update message, the network realizes that there is no MS in update region and all MSs are inside two-third cell edge or non-update region. For that situation, the network has to inform all users to perform update to know the farthest user location for that period even though they are not in update region. Then, the task of MS is to sense the update region. It requires two threshold values of pilot signal strength (λ_h and λ_i) that

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represent two-third cell edge (R_h) and original cell edge (R_i) respectively. These pilot signal thresholds will be predefined by network and the MS will keep these two pilot signal threshold values. Then, it has to measure the distance (d_{MS}) from BS according to pilot signal strength in each period. Moreover, it has to inspect its location, whether it is between R_h and R_i. If it is inside the update region, it has to perform update. Otherwise it can skip the update.

Here, one thing to be discussed is how a user senses the update region. In practice, the common pilot channel (CPICH) signal is used by MS to sense the cell boundary so that it can do cell reselection and handover [37, 46, 47]. This capability of user premise can be exploited to sense the update region in this scheme by setting two pilot signal thresholds (λ_h and λ_i) that are corresponding to two-third cell edge (R_h) and original cell edge (R_i) respectively in customer premises. In broadcasting process in TAPU and LAPU, the signal is transmitted until the original cell edge by using maximum power level in order to cover all the users in the cell. However, the power consumption is very low because it broadcasts information to all MSs in a cell for a short period of time.

Situation I   Situation II

(a)
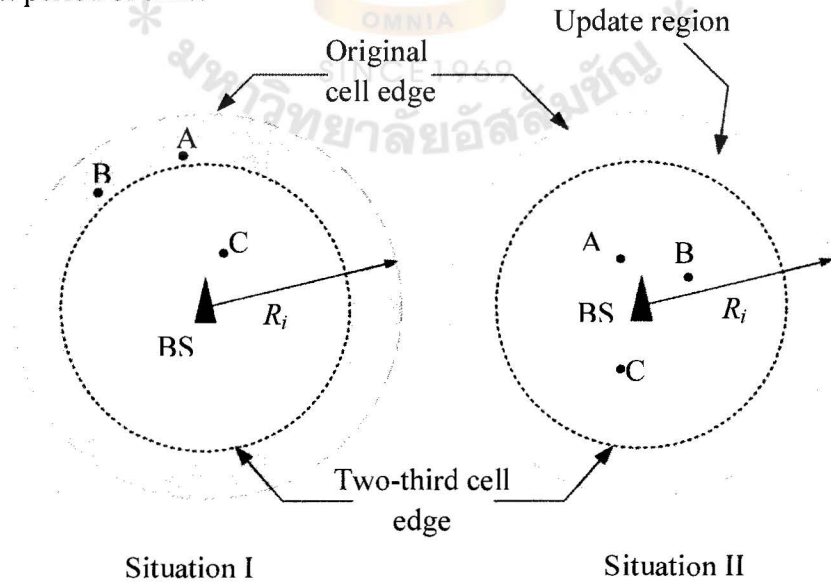
For BS (network)

– Set Δt_{up} $\forall$ MSs

– Receive update messages

    If no update message (because $\forall$ $d_{MS} < R_h$)

        Broadcast to $\forall$ MSs to perform update

    end

For MS

– Keep λ_h and λ_i to sense R_h and R_i

– Measure d_{MS} by means of pilot signal strength

– When update time arrives

    If $R_h \leq d_{MS} \leq R_i$

        Perform location update

    else

        Skip location update

    end

(b)

Figure 3-2 Location-adaptive periodic update (LAPU)

(a) example condition (b) algorithm

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3.2 Continuous Cell Zooming Algorithm and Required Infrastructure

The algorithm of continuous cell zooming is shown in Figure 3-3. The illustration has been shown in Figure 2-3 (on page 15).

– Reset	R_i
– Receive	d_{MS} from $\forall$ MSs in update region
– Find	max $[d_{MS}]$
– Set	$R_z = \text{max } [d_{MS}]$ for Δt_{up}
– end	

Figure 3-3 Continuous cell zooming algorithm

In Figure 3-3, R_i is initially designed cell radius, d_{MS} is the radial distance between the user and cell centre, R_z is the radius of zoomed cell and Δt_{up} is the periodic update interval. The infrastructure required for cell zooming algorithm is shown in Figure 3-4 (a). The base station can be controlled by a centralized control server or distributed server. A simple processing device is equipped at each sector of every base station (only one sector in omni-directional base station) to collect user location information in corresponding sector. The location feedback from every user to the base station server is the distance, magnitude from BS to the user, but not global coordinate point (*x*, *y*, *z*) information of each user. A number of location measuring techniques have been developed in wireless communication. In this way, the control server can know the farthest user in each cell at every periodic update time.

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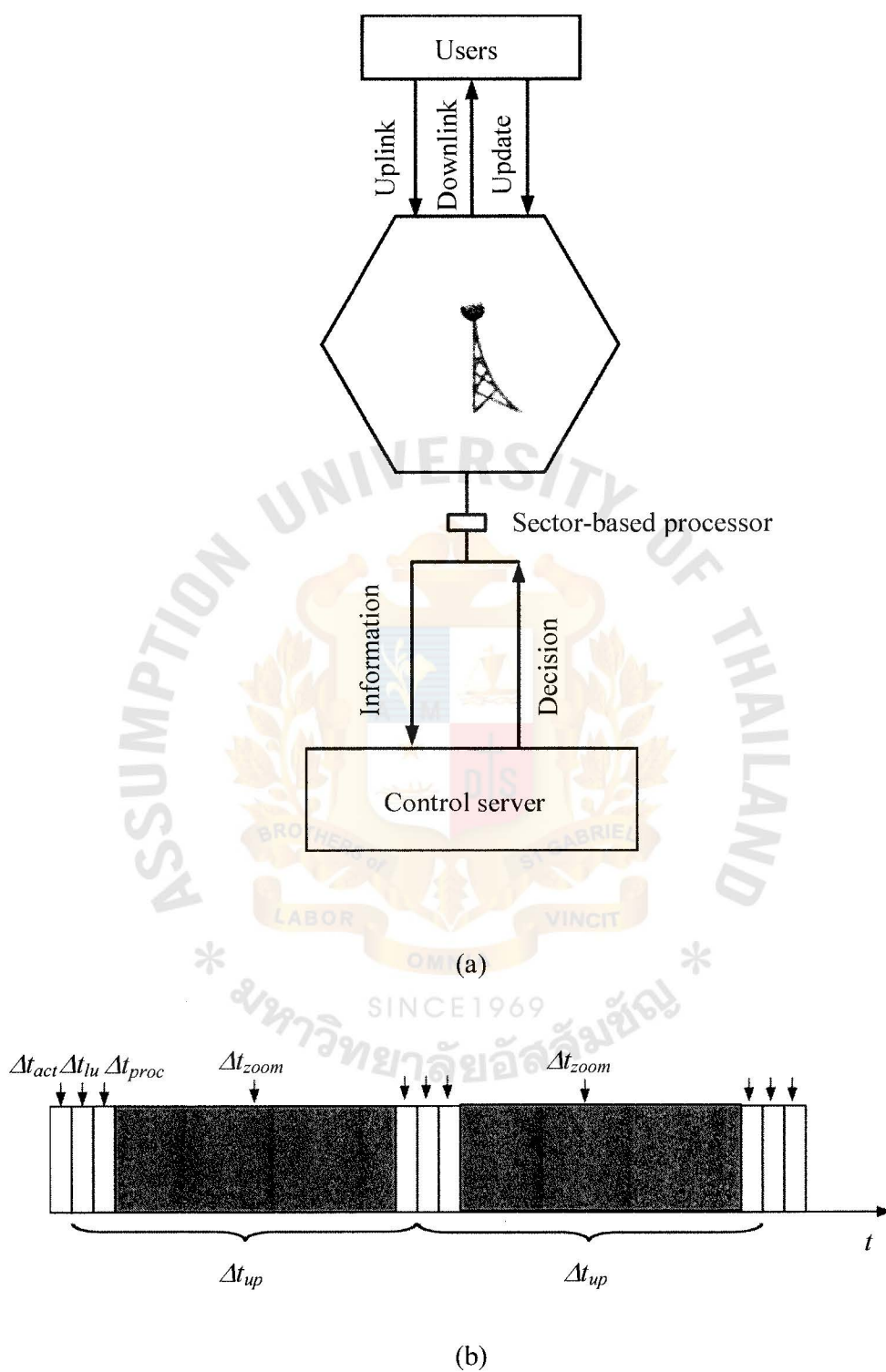
Figure 3-4 Framework of continuous cell zooming algorithm (a) infrastructure

(b) time frame sample

The time frame for each cycle of cell zooming operation with continuous algorithm is described in Figure 3-4 (b). First, all zoomed base stations in previous cycle are reset to the original cell size during Δt_{act}. Then Δt_{lu} is the time period for updating user location. The control server takes a time period of Δt_{proc} for making decision on cell zooming. Finally, Δt_{zoom} is effective cell zooming time. Thus, the effective cell zooming time is slightly less than periodic update interval (Δt_{up}).

3.3 Simulation Models and Parameters

3.3.1 Traffic arrival pattern

The traffic is generated by calling from subscribers in PSTN/1G/2G networks and/or data accessing in 3G/4G networks. For this reason, the pattern of call arrivals to a base station or in a network during equal time intervals in a full-day operation is alternatively termed as traffic arrival pattern.

The teletraffic varies according to the activity in the society [42]. The traffic arrived to a base station can be manually recorded as a sample. Then, a mathematical model can be applied to estimate traffic arrival to that base station for a long term. In the literature, the Poisson distribution model is mostly adopted to estimate the daily traffic pattern of a base station [4, 27, 53]. The normalized traffic for a day can be estimated by using Poisson probability distribution as follows.

$$\beta(t) = \frac{p(t,\mu)}{\max(p([T],\mu))} \qquad [T] = [1, 2, 3, \dots 24] \qquad (3.1)$$

$$p(t,\mu) = \frac{\mu^t}{t!}e^{-\mu} \qquad (3.2)$$

where, $\beta(t)$ is normalized traffic at time t, p is Poisson probability distribution function, t is a specific time in a day and μ is the mean time where the peak number of calls happened.

Figure 3-5 (a)-(b) show the comparison of measured traffic arrival pattern and approximate traffic arrival pattern by using Poisson distribution with a mean value of 15. Thus, the peak traffic rate during a day occurs at 15:00 O' clock (3:00 p.m.) and also it is changeable to match with the recorded sample from a base station. In short, the Poisson mathematical model is selected to simulate traffic arrival patterns of base station because it is acceptable for trade-off analysis.

(a)   (b)
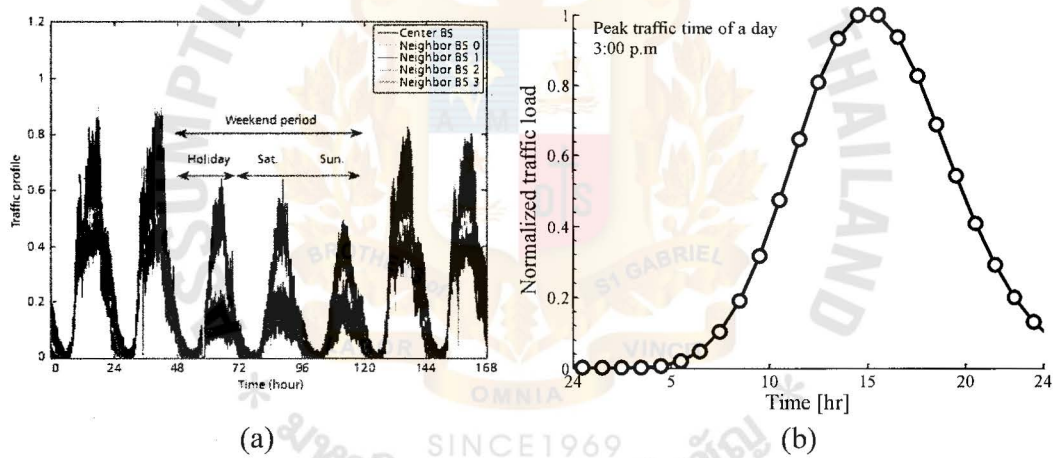
Figure 3-5 Traffic arrival pattern (a) real recorded pattern [39]

(b) simulated pattern with Poisson distribution

3.3.2 Radio propagation model

The radio propagation from transmitter to receiver is an essential topic that must be discussed in this work that concerns with wireless communication. In general, the transmitted power from a transmitter is not fully receivable at the receiver that exits

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at a distance. There are some losses mainly due to obstructions in the way that causes reflection, diffraction and scattering of radio waves. It also should be noted that the transmitted signal can be attenuated in the medium even if there are no obstructions in its path. In the literature, a number of models have been developed for different structures of the environment. However, the complexity of signal propagation makes it difficult to obtain a single model that characterizes path loss accurately across a range of different environments [17]. However, for general analysis of various system designs, it is sometimes best to use a simple model that captures the essence of signal propagation without resorting to complicated path loss models, which are only approximations to the real channel anyway [17]. Thus, the following simplified model for path loss as a function of distance is commonly used for system design [17].

$$P_r = P_{Tx} \ K \left(\frac{R_0}{R} \right)^{\gamma} \tag{3.3}$$

where, P_r is receivable power at the receiver, P_{Tx} is transmitted power from the transmitter, K is unitless constant, R_0 is a reference distance, R is transmission distance, γ is the path loss exponent. Here, the model (equation (3.3)) is generally only valid at transmission distances $R > R_0$, where R_0 is typically assumed to be 1-10 m indoors and 10-100 m outdoors [17]. From equation (3.1), the following relationship can be derived to find out the relationship of transmitted power with and without cell zooming.

$$P_{ri} = P_{Tx,i} \ K \left(\frac{R_0}{R_i} \right)^{\gamma} \tag{3.4}$$

$$P_{rz} = P_{Tx,z} \ K \left(\frac{R_0}{R_z} \right)^{\gamma} \tag{3.5}$$

In equation (3.4) and equation (3.5), $P_{Tx,i}$ denotes transmitted power for initially designed cell radius (R_i) and $P_{Tx,z}$ denotes transmitted power for zoomed cell radius

(R_z). Keeping minimum receivable power at any radius ($P_{ri}=P_{rz}$) the same, the following relationship is achieved.

$$\frac{P_{Tx,z}}{P_{Tx,i}} = \left(\frac{R_z}{R_i}\right)^{\gamma} \tag{3.6}$$

The value of γ depends on the propagation environment and Table 3-1 shows the typical path loss exponents for different environments. In this case, the value of 4 is selected for macro cells in a suburban area.

Table 3-1 Typical path loss exponent [17, 50]

Environment	γ range
Urban macrocells	3.7 – 6.5
Urban microcells	2.7 – 3.5
Office Building (same floor)	1.6 – 3.5
Office Building (multiple floors)	2 – 6
Store	1.8 – 2.2
Factory	1.6 – 3.3
Home	3

3.3.3 Random waypoint model

Since a general mobility model for cellular network does not yet exist, mobility models of ad hoc network are mostly adopted [30]. In this work, a sample network of suburban area is considered. For that area, it is reasonable to state that a random number of users move in random directions with random speeds at a time. In that situation, the random waypoint model is a well-matched model and it is adopted to model the user movement in the network considered. In this mobility model, a MS moves from its current location to a new location by randomly choosing a direction and speed in which to travel [5]. The new speed and direction are both randomly

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chosen from pre-defined ranges, $[V_{min} \quad V_{max}]$ and $[0 \quad 2\pi]$ respectively [5]. Figure 3-6 shows the movement pattern of a MS in a two dimensional area of 300 m × 600 m starting from a coordinate point of (133,138) with a speed range of [0 10 m/s].
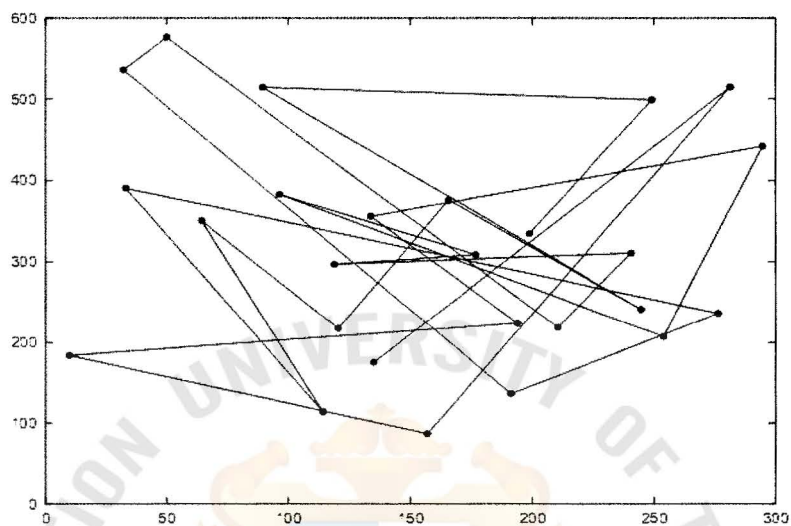
Figure 3-6 Movement pattern of a mobile station

by using random waypoint model [52]

In the random waypoint model, there is a pause time interval at a location before choosing a new direction and speed. The pause time is the time between two successive movements of a single user. In the literature, the pause time is set as a constant value [5] or randomly varied value [20]. If it is a constant and uniform value for all users, and initial moving time is the same, all users will move and pause at the same time together. However, in real field (e.g., cellular network), the pause time between successive movements of a user randomly varies from one second to several hours or several days. When the pause times of users are very small (e.g., 1 s), the network is very dynamic and the network is more stable when the pause time is longer [5].

For example, in areas such as city centre, bus stations and train stations, the users could be very busy (dynamic) and the pause time could be very small because there will be surely some users moving at a certain location in the network at any time. However, when the area of interest is small and not crowded, the mobility of the users could be more stable, which means that the pause times could be relatively long. Based on this fact, in this research, a sample network (seven cell network) of suburban area is considered and it is reasonable to assume that the smallest pause time is 1 minute, which means that there could be some moving users at every minute.

Moreover, the random waypoint model is slightly controlled to have a more realistic mobility model. In the model, time dependent user mobility levels in a day are defined. The graph is shown in Figure 3-1 (a). Thus, time dependent mobility levels and movement speed of users taken for this simulation are described in Table 3-2. The mobility level is the ratio of the maximum possible number of moving users to the total users in the network. It means that the total moving users at a time will not be greater than the maximum possible number of moving users at that time. The total number of users in the network is set in the range of 50–300.

Table 3-2 Mobility level and movement speed for different local time

Local time (hr)	Mobility level	Movement speed (m/s)
$24{:}00 < t \le 05{:}00$	0.1	[0-50]
$05{:}00 < t \le 08{:}00$	1	[0-50]
$08{:}00 < t \le 11{:}00$	0.5	[0-50]
$11{:}00 < t \le 14{:}00$	1	[0-50]
$14{:}00 < t \le 16{:}00$	0.5	[0-50]
$16{:}00 < t \le 18{:}00$	1	[0-50]
$18{:}00 < t \le 24{:}00$	0.5	[0-50]

3.3.4 Cell type and network topology

A mobile network is composed of multiple cells that cover a specific geographical area. Generally, a cell can be defined as the area covered by one sector, i.e. one antenna system [10]. Depending on the size of the area, type of base station and density of mobile users, the number of cells deployed in an area can vary. There are four types of base stations. They are macro, micro, pico and femtocell, which are different in components integrated in, size and capacity [34]. Sometimes, micro and pico cells are superimposed in macro cells in some modern networks [27, 11]. According to the number of antennas used, there are two different types of cell. The first one is omini-directional cell in which only one antenna is used and the transmitted signal radiates uniformly in all directions (360 degree). The second type is the sectorized cell in which a specific number of antennas are deployed in the equally divided angular area from 360 degree. For example, trisectorized base stations, one antenna serves for one angular area of 120 degree.

(a)   (b)
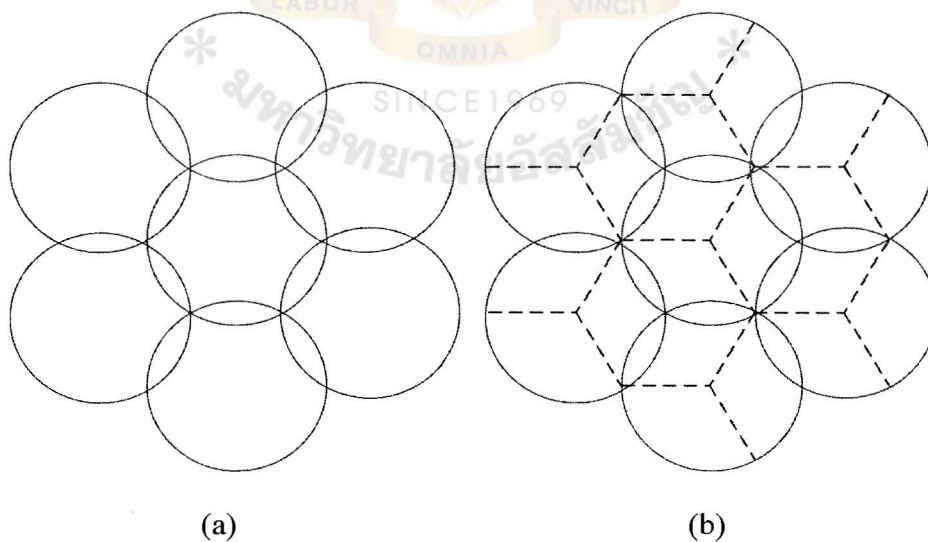
Figure 3-7 Cell type and network topology (a) Omni-direcitonal cell network

(b) Sector-based cell network

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The network topology depends on the shape of the area and the number of cells deployed. The network topology can fall in one of three main categories, such as Hexagonal, Manhattan and Crossroads configuration as described in [31].

In this work, both omni-directional and sector-based cell type are considered setting in Hexagonal configuration. As a sample network, only a cluster of seven cells are deployed. Figure 3-7 (a)-(b) show the network topology with two different cell types considered in this work. The detailed parameters of the network are listed in Table 3-3.

Table 3-3 Detailed parameters of the network [34, 27]

Part	Parameters	Omni-directional	Sector-based
Base station	Number of sectors (N_{sec})	1	3
	Number of transceiver	SISO	SISO
	Initial radius (R_i)	0.35 km	0.35 km
	Two-thrird cell radius (R_h)	0.233 km	0.233 km
	Maximum capacity	0.4 Mb/s	1.2 Mb/s
	Maximum transmitted power per sector (P_{Tx})	20 kW	20 kW
Network traffic	Area type	Suburban	
	Maximum number of traffic in each cell at noon period (11:00-12:00)	250 voice calls	750 voice calls
	Data rate for single user (voice communication)	12 kb/s	
	Average sojourn time	60 s	

3.4 Performance Metrics

Three metrics are used to evaluate the performances of adaptive location update schemes. These are transmitted power ratio, outage ratio and the number of update messages.

3.4.1 Transmitted power ratio

First, the power consumption continuous cell zooming algorithm is evaluated in terms of transmitted power ratio. In this work, there is no switch-off scheme on any BS. Therefore, the transmitted power ratio is evaluated as the ratio of peak conventional transmitted power to transmitted power with cell zooming in day as follows.

$$Power\ consumption\ ratio = \frac{Transmitted\ power\ with\ cell\ \ zooming}{Peak\ conventional\ transmitted\ power} \qquad (3.7)$$

3.4.2 Outage ratio

In the literature, the outage is traditionally defined as a situation when a user experiences lower strength than receivable one [27]. In this work, only the users out of convergence region are counted as outages. The outage occurs in continuous cell zooming algorithm due to user movement during cell zooming operation. The outage ratio in a cell zooming period is the ratio of users who undergo outage during a cell zooming period to the total number of users that exist in the network. It is automatically evaluated by simulation tool.

3.4.3 Number of update messages

This metric represents signaling overhead. If the massive information exchange is required, it will lead to not only signaling cost, but also high power consumption in customer premise. It is expected to reduce the number of update messages by using proposed update schemes. The total number of update messages exchanged between the BS and user is evaluated for every cell zooming period. It is automatically evaluated by simulation tool.

3.5 Simulation Tool

In this work, MATLAB software is used as a simulation tool. A MATLAB program is created to let a certain number of mobile stations move into the area of seven cells network by using the random waypoint mobility model. At every periodic update interval, the number of update messages to each base station is evaluated. Then, the farthest user location in each cell is found out. Then, cell zooming is performed and power consumption is evaluated.

CHAPTER 4

Results and Discussion

In this chapter, the performances of three different location update schemes (CPU, TAPU and LAPU) applied in continuous cell zooming algorithm are analyzed in three different scenarios. The scenarios are constructed as follows.

Scenario 1 (Full day operation)

In this scenario, the performances of three location update schemes are analyzed with the variation of the time in a day. The number of call per hour is varied with the time of the day. The total number of users in the network is 100 and the moving speed range is [0-50] m/s.

Scenario 2 (Variation of the total number of users in the network)

In this scenario, the performances of three location update schemes are analyzed in a network with the variation of number of users. Thus, the moving speed range is [0-50] m/s and the number of users in the network is changed from 50 to 300.

Scenario 3 (Variation of average moving speed of users)

In the last scenario, the performances of three location update schemes are evaluated in a network with the variation of average moving speeds of users. Thus, the average moving speeds of users in the network is varied from 1 m/s to 30 m/s. The number of users in the network constant as 100.

Table 4-1 shows the related information in the simulation scenarios mentioned above.

Table 4-1 Essential information in the simulation scenarios

Parameters	Scenario 1	Scenario 2	Scenario 3
Cell type	Macro cell	Macro cell	Macro cell
Networks	Omni/ Sector-based (7 cells)	Omni/ Sector-based (7 cells)	Omni/ Sector-based (7 cells)
Network area	Suburban area	Suburban area	Suburban area
Simulation time	Full day (24 hrs)	Full day (24 hrs)	Full day (24 hrs)
Traffic type	Voice call only	Voice call only	Voice call only

4.1 Cell Zooming in Omni-directional and Sector-based Cell Networks

The simulations are performed in MATLAB software. The results are average values of 3-day operation. In conventional periodic update (CPU) scheme and location-adaptive periodic update (LAPU) scheme, the constant update interval of 1 minute, which is the same as smallest pause time, is set for the whole day. In time-adaptive periodic update (TAPU), Δt_{up1}, Δt_{up2} and Δt_{up3} are set to 5 minutes, 3 minutes and 1 minute respectively. Figure.4-1 (a)-(b) show the sample distributions of MSs in networks and configurations of omni-directional and sector-based cells under zoomed condition according to the location of the farthest MS in each cell. It can be seen that cell zooming is performed cell by cell in omni-directional cell network because it has only one sector. Meanwhile, in sector-based cell network, cell zooming is performed

sector by sector based on the farthest user in each sector. It is understandable that cell zooming can be performed more significantly in the sector-based cell network compared to omni-directional cell network. In other words, cell zooming in sector-based cell is more effective than that in omni-directional cell.
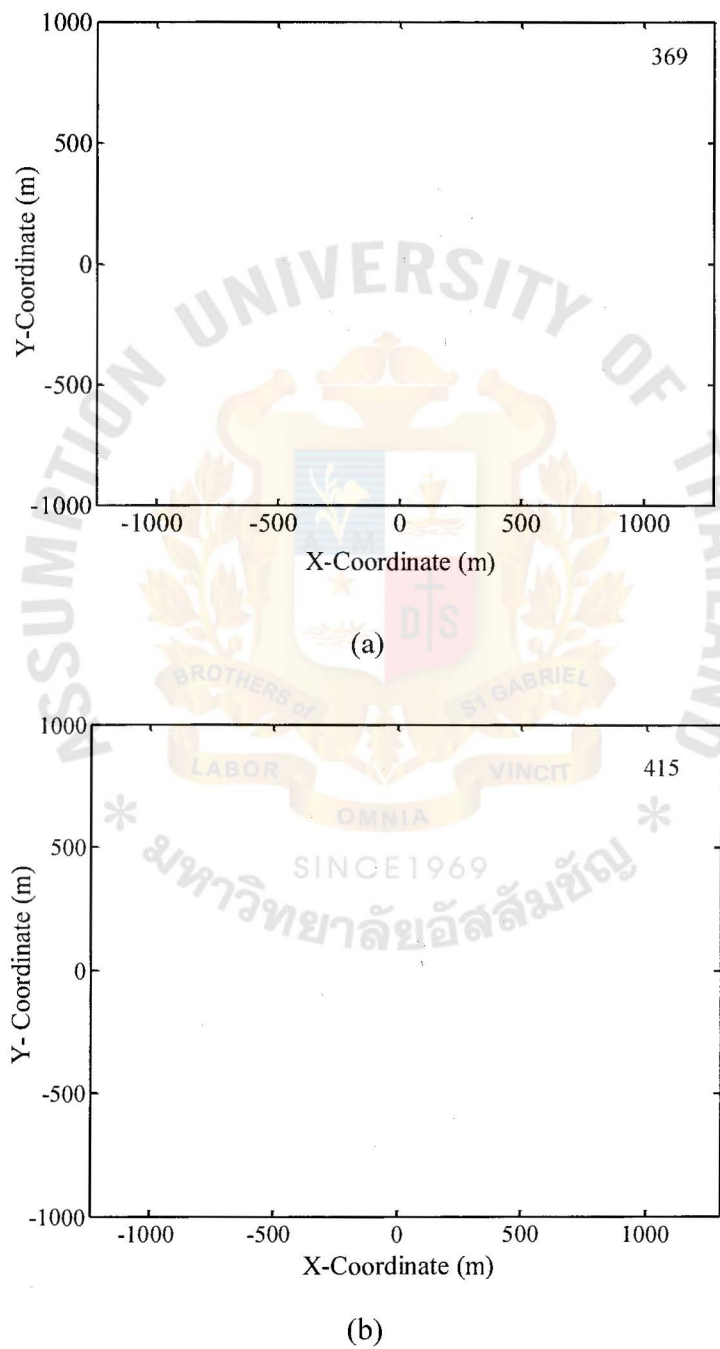

(a)

(b)

Figure 4-1 Distribution of MSs and configuration of zoomed cells (a) Omni-directional cell network (b) Sector-based cell network

4.2 Performance of Proposed Update Schemes in Daily Operation of a Network

4.2.1 Transmitted power ratio in daily operation of a network

Figure 4-2 (a)-(b) show the comparison of ratios of transmitted power without cell zooming and with continuous cell zooming in which three different periodic update schemes (CPU, TAPU and LAPU) are applied. Firstly, it can be seen that deploying continuous cell zooming in the network can save considerable transmitted power because the required transmission range is dynamically adjusted according to the farthest user in the cell rather than it is statically transmitted to originally designed cell edge regardless of user location. Also, it is noticeable that the relative power saving is larger in sector-based cell network because sector-based cell zooming is more effective as explained above. Transmitted power can be saved by maximum of 20% in omni-directional cell network and by maximum of 40% in sector-based cell network. However, it should be noted that the amount of power saving also depends on the number of users in the network.
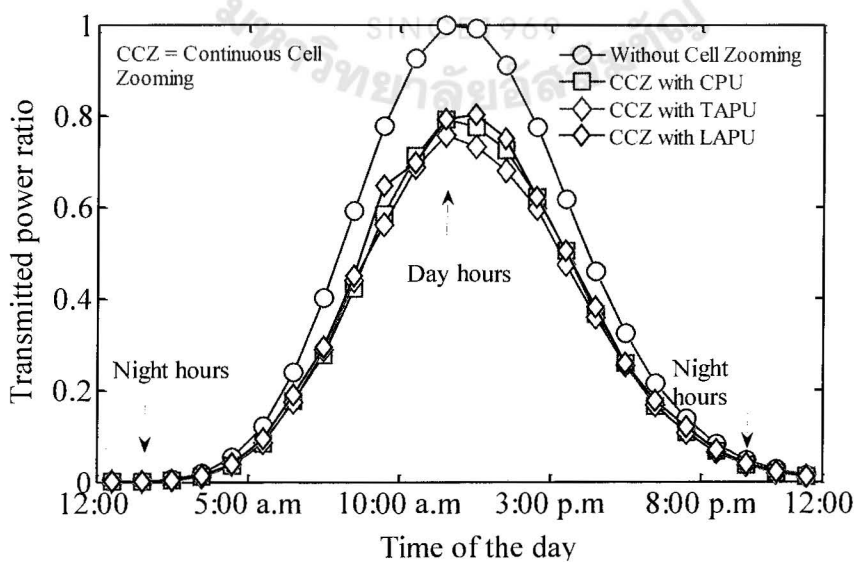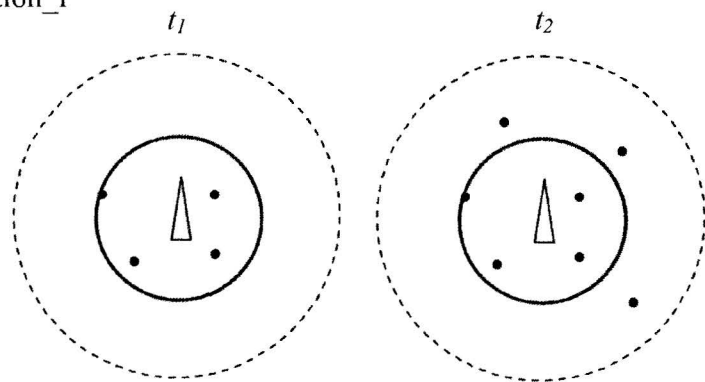

(a)
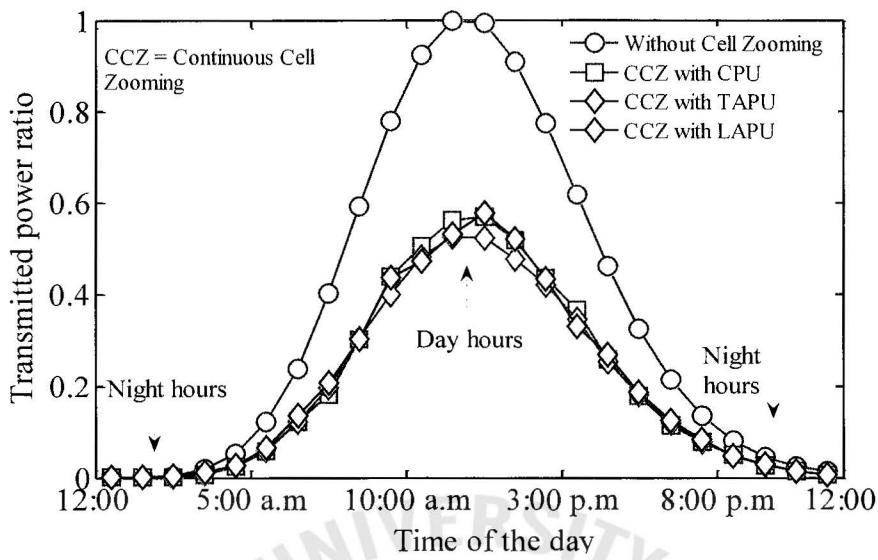
(b)

Figure 4-2 Transmitted power ratio in continuous cell zooming algorithm with

different location update schemes (a) omni-directional cell network

(b) sector-based cell network

The reason is that when the number of users in the network is larger, there is a higher probability of existence of users near the cell edge. Thus, there is less chance to zoom the cell frequently, and there will be less power saving. Here, it is noticeable that the LAPU scheme is comparable to CPU scheme. The reason is that the update intervals used in CPU and LAPU are the same. A slightly different power saving is attained at high traffic hours when TAPU is applied. It is due to the application of longer update periods (3 minutes and 5 minutes) in TAPU, which results in longer durations of cell zooming regardless of user movement to further distance or near distance during zooming period. This can result in slightly more or less power saving when compared to CPU and LAPU.

For further understanding, one can compare possible example conditions, condition_I and condition_II, in TAPU demonstrated in Figure 4-3.

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Possible condition_I

Possible condition_II

— — — Original cell edge   △ BS

———— Zoomed cell edge   • MS
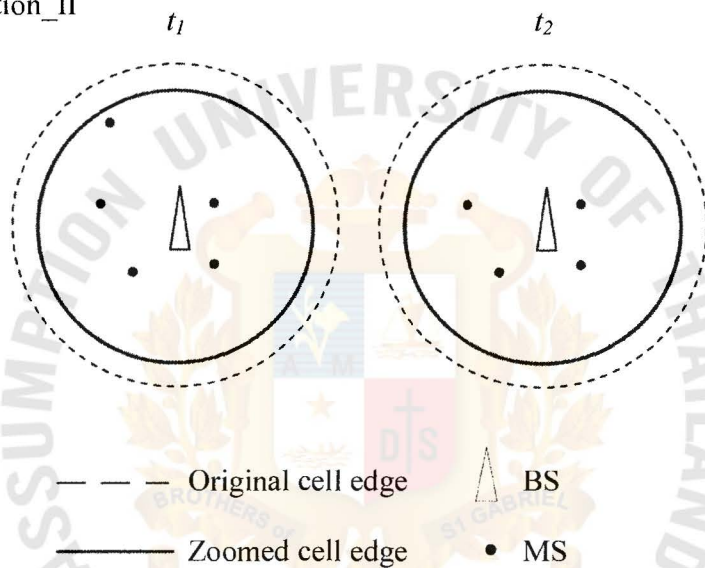
Figure 4-3 Possible conditions in TAPU

In condition_I, let's say, the cell is zoomed at time, t_1. Then, t_2 is a time during cell zooming period. Let's say cell zooming period is long. At t_2 during cell zooming, the users have moved to further places and some users even undergo outage. However, the cell zooming will be maintained in previous condition until next update process. In that condition, the TAPU has lower transmitted power than CPU and LAPU because CPU and LAPU change the zoomed cell edge more frequently. Also, there will be outage in TAPU.

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In condition_II, let's say, the cell is zoomed at t_1. At the beginning the farthest user is very far from BS. At t_2 during cell zooming period, the users move near to BS. However, the zoomed cell edge is still at a far distance since zooming period is very long. In that condition, TAPU can result in a higher transmitted power due to longer update intervals. In CPU and LAPU, the new user location is updated in a shorter period. Therefore, TAPU can result in slightly more or less power saving compared to CPU and LAPU.

It should be note that TAPU can result in unstable (inconsistent) power saving due to long interval periods in high mobility environment at high traffic hours. However, it could be more effective compared to CPU and LAPU in static or low mobility environments because it will significantly reduce the number of update messages since it uses longer update intervals.

4.2.2 Outage ratio in daily operation of a network

Figure 4-4 (a)-(b) show the comparison of outage ratios in continuous cell zooming with three different location update schemes. Here, the result at each local time is average outage ratio per minute (each movement) at that local time. Firstly, it is worth to discuss about outage ratio in TAPU.

For TAPU, outage occurs proportionally to the mobility levels presented (see Figure.3-1(a) on page-27). It should be noted that different networks could have different mobility levels in a day. Here, it can be seen that there is outage when update interval is longer than the pause time of user movement. For example, at night hours, the update interval is 5 minutes and the smallest pause time of moving users is 1 minute. Thus, during cell zooming period of 5 minutes, the users may move to outside convergence region and experience outage.

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However, the outage ratio in night hours is lower than that in day time because the mobility level is lower during night hours. Also, it can be seen that when update interval is set the same as the smallest pause time of moving users (e.g., during 4:00 p.m to 6:00 p.m), outage can be avoided.
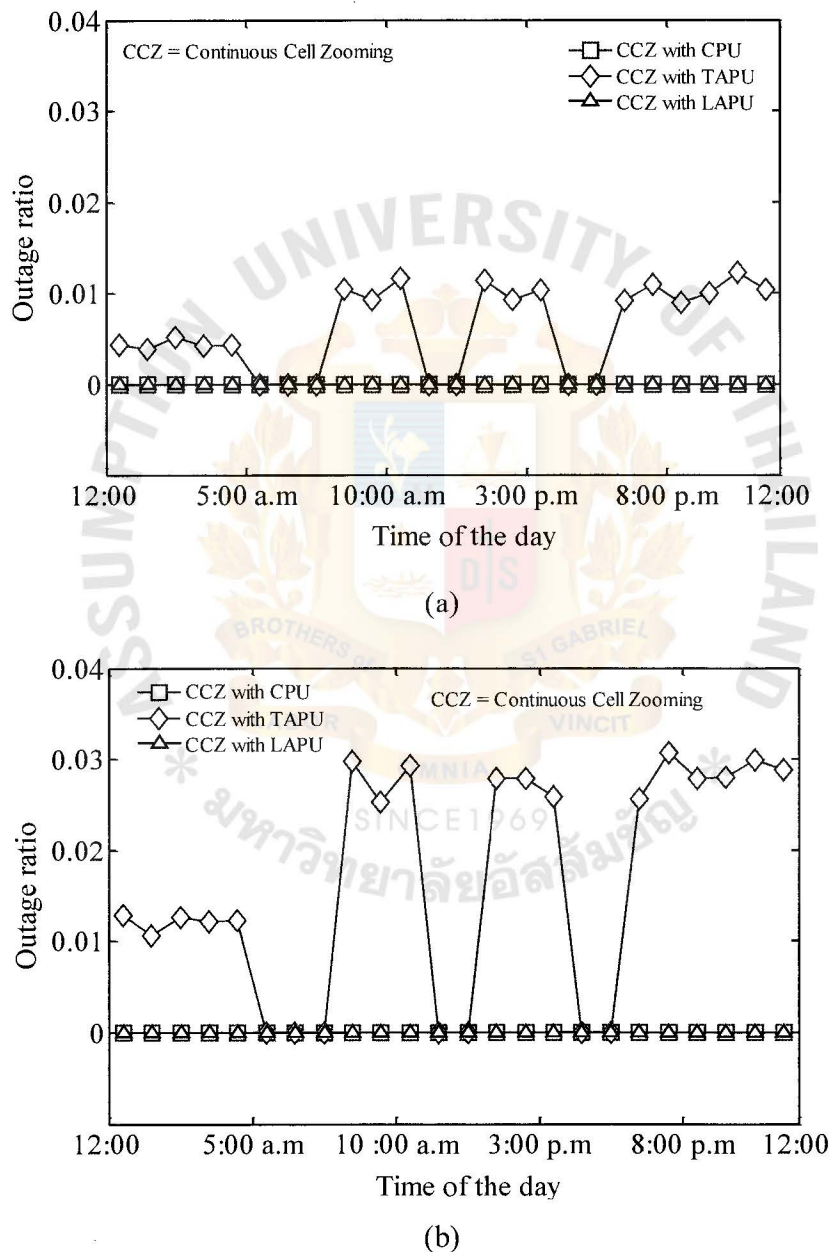

(a)

(b)

Figure 4-4 Outage ratio in continuous cell zooming algorithm with different location update schemes (a) omni-directional cell network (b) sector-based cell network

At night from 7:00 p.m to 12:00 p.m, the outage is still high because mobility level is moderate and update interval is longe. Therefore, it is possible to state that the outage in continuous cell zooming depends on user mobility level, update interval and the minimum pause time of moving users. Therefore, to develop a reliable scheme, these three parameters should be carefully justified. One more point to note is that the outage ratio in the sector-based cell network is greater than that in omni-directional cell network due to zooming more significantly in sector-based cell network. When zooming area is more effective on one hand, outage area is wider on other hand. This result in both larger power saving and higher outage.

Then, one can see that there is no outage in continuous cell zooming with CPU and LAPU because in these schemes, the location update interval and cell zooming duration are set the same as the smallest pause time of moving users. In other words, cell zooming is performed only in the smallest pause time of the moving users. However, in real field, there can be some conditions in which outage occurs although CPU or LAPU is applied. For example, in real field, some users are continuously moving for some time with zero pause time. In this situation, the user may undergo outage if he/she is the farthest user because the zoomed cell edge cannot continuously follow the moving user. Also, some users moving with a very high speed may miss to update their location.

An example demonstration is shown in Figure 4-5. Let's say the user A is moving with a very high speed. It may be or may not be able to update. It is uncertain (May-Be-Yes / May-Be-No) condition. Let's assume, it misses to update due to its very high speed. The user B and other users can update. Then, the network knows user B as the farthest user and the cell is zoomed to user B. Thus, user A undergoes outage. In current simulations, all users are able to update even if they are moving

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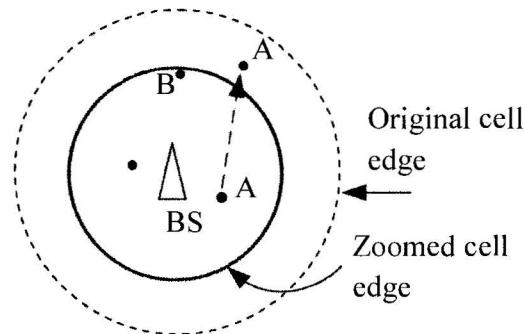with a high speed. Thus, in current simulated results of CPU and LAPU, even no accidental outage occurs.

Figure. 4-5 Possible accidental condition in real field

4.2.3 Number of update messages in daily operation of a network

The comparison of the numbers of update messages per hour achieved by different update scheme is shown in Figure 4-6 (a)-(b). It is obvious that CPU scheme has constant number of update messages over the period because every user performs update at every interval. For example, CPU with 100 users and 1 minute interval, there are 6,000 messages at every one hour. This leads to unnecessary tasks and unfavourable signaling cost. It will linearly increase with the increment of the number of the users in the network. By using TAPU, the number of update messages is reduced when longer update intervals are used. One can see that the number of update messages is reduced when 3 minutes and 5 minute update intervals are applied. During hours when 1 minute interval is used, TAPU also has the same number of update messages as CPU. However, TAPU reduces the number of messages in overall comparison. On the other hand, outage occurs in cell zooming with TAPU due to using longer update intervals. The number of update messages in TAPU will also

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linearly increase when the number of users in the network increases. By using LAPU, the number of update messages is significantly reduced compared to CPU scheme and it is still comparable to TAPU. It can be explained as follows.
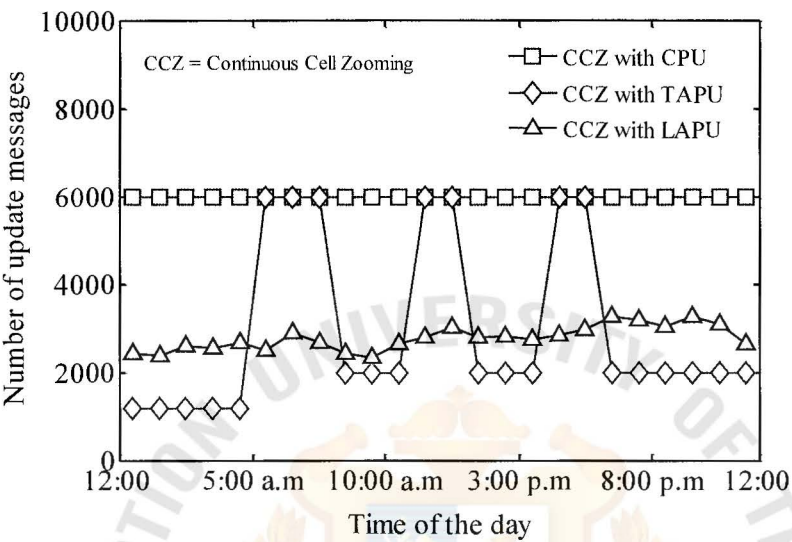
(a)
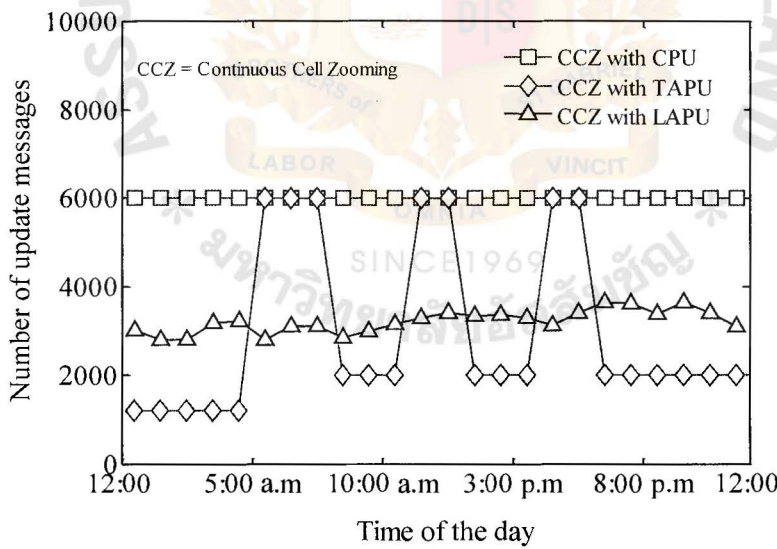
(b)

Figure 4-6 Number of update messages in continuous cell zooming algorithm with different location update schemes (a) omni-directional cell network (b) sector-based cell network

According to LAPU scheme, only users who are in the update region need to perform location update although all users own update timer. When users are distributed in the network, only a certain portion of users falls in the update region of each cell. In other words, it is rare to find that update region (cell edge region) is crowded with users. It is also true in real field. This reduces unnecessary messages and consequently signaling cost. When overall comparison is taken, the total numbers of update messages in TAPU and LAPU are about half of that in CPU. The total number of update messages by LAPU in sector-based cell network is somewhat larger than that in omni-directional cell network. It should be noted that the number of update messages in LAPU also depends on the size of update region.

4.3 Performance of Proposed Update Schemes in a Network with Different Numbers of Users

The performances of TAPU and LAPU are analyzed in the network with the variation of number of users. The total number of users in the network is changed from 50 to 300. The speed range of [0-50] m/s is kept the same for every number of users. The result at each point is the average value of the whole day operation which is averaged from 3-day operation.

4.3.1 Transmitted power ratio with different numbers of users

Figure 4-7 (a)-(b) show the comparison of transmitted power ratio by continuous cell zooming algorithm at different numbers of users. The transmitted power ratio increases with the increment of the number of users in the network. In other words, power saving decreases with the increment of the number of users. In

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omni-directional cell network, compared to the operation without cell zooming, the power saving of every scheme is about 35% when the number of users is 50 and 10% when the number of users is increased to 300. It is about 61% when the number of users is 50 and 24 % when the number of user is 300 in sector-based cell network.
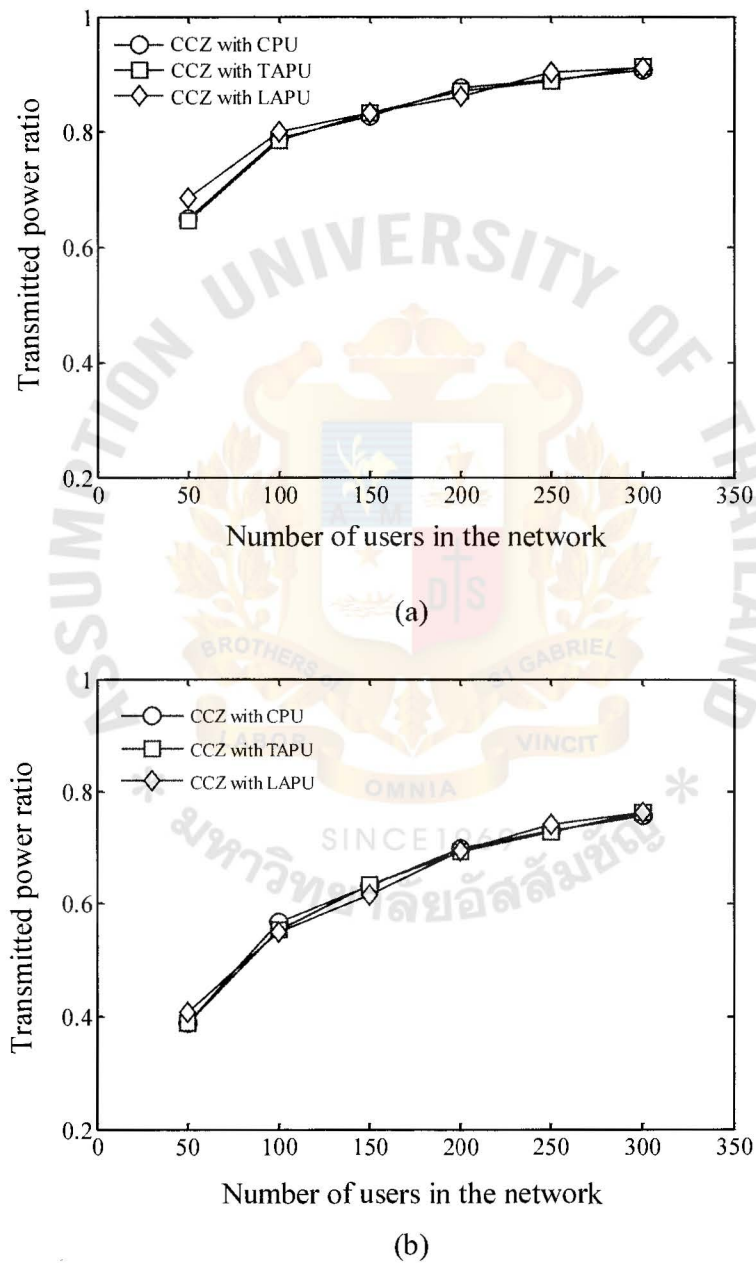

(a)

(b)

Figure 4-7 Transmitted power ratio at different numbers of users (a) omni-directional cell network (b) sector-based cell network

It is clear that power saving is dependent of total number of users existed in the network. It can be explained by using demonstration as follows.
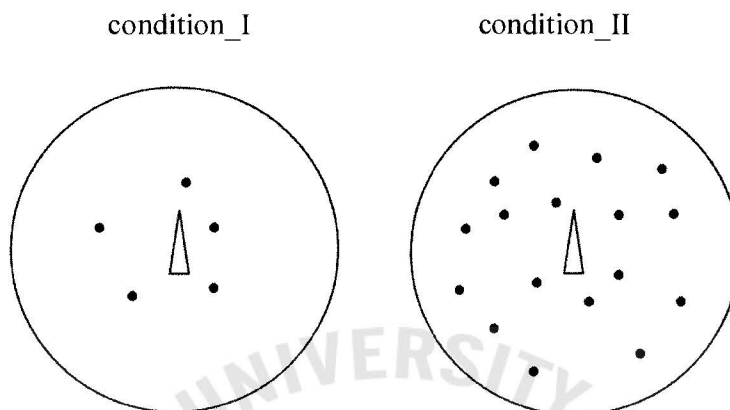
condition_I   condition_II
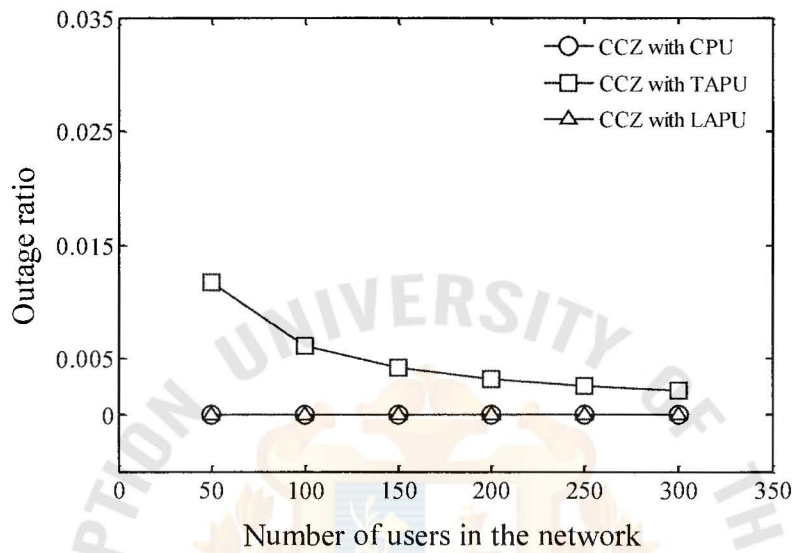

Figure 4-8 A cell with different number of users

As shown in condition_I and condition_II in Figure 4-8, when there is a large number of users, there is a larger probability of existence of user near the cell edge. Thus, cell zooming cannot be performed very significantly when there is a large number of users compared to condition with a small number of users.

4.3.2 Outage ratio with different numbers of users

The comparison of outage ratios occurred in CPU, TAPU and LAPU schemes in omni-directional cell network and sector-based network is shown in Figure 4-9 (a)-(b). It can be seen that the outage ratios in CPU and LAPU are kept at zero. The reason is that in these schemes, the smallest pause time of moving users and update interval is the same although the number of users is changed. Also, it is because of that possible accidental cognitions are not considered in the simulation. These facts have been explained in previous section.

In TAPU, outage occurs in both omni-directional cell network and sector-based cell network and the outage ratio decreases with the increment of the number of users in the network. The reasons can be explained by using demonstration as follows.

(a)
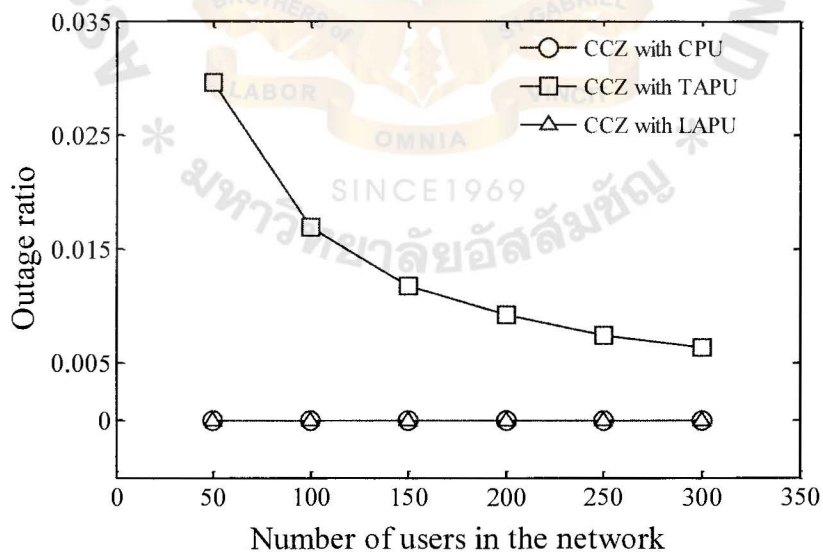
(b)

Figure 4-9 Outage ratio at different numbers of users (a) omni-directional cell

network (b) sector-based cell network

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One can compare condition_I and condition_II shown in Figure 4-10. The larger the number of users, the higher the probability of existence of users near the cell edge. It gives less chance to zoom the cell or the cell can be zoomed only a few percent. Therefore, outage area during cell zooming is smaller as shown in condition_II. In contrast, when there is less number of users in the cell as shown in condition_I, there is less possibility of existence of user near cell edge. Therefore, the cell can be zoomed considerably and the outage area is also large. In that condition outage easily occurs.
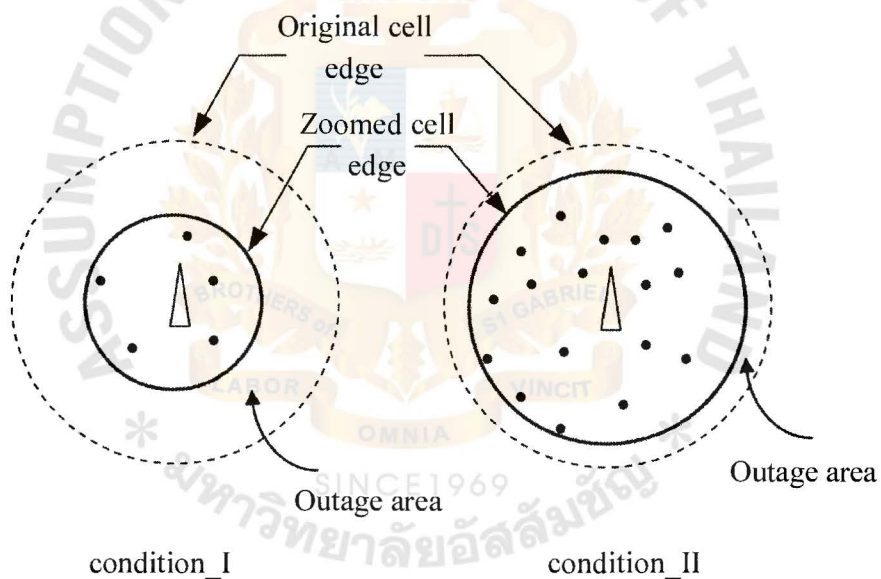
Figure 4-10 Possible conditions in a cell (a) with a less number of user

(b) with a larger number of users

There is another reason of decreasing outage ratio. One should remember that the outage ratio is the ratio of total outage users to the total users existed in the network (as defined in section 3.4.2 on page- 41). According to this definition, outage ratio will decrease when total number of users, which is denominator, increases. The

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outage ratio is larger in sector-based cell network. As explained in previous section, the cell is zoomed more significantly in sector-based cell network. It makes larger outage area in sector-based cell network, which results in a larger number of outages.

4.3.3 Number of update messages with different numbers of users

Figure 4-11 (a)-(b) depict the average number of update messages per hour given by three update schemes in omni-directional cell network and sector-based cell network. Firstly, one can understand that the average number of update messages in CPU, TAPU and LAPU linearly increases with the increment of the number of users in the network. It is clear that the number of update messages is obviously dependent of the number of users and update interval. On noticeable point is that LAPU with a large update area (R_h=2/3 R_i), gives approximately the same performance in both omni-directional and sector-based cells. However, if update area is smaller, LAPU will perform better in omni-directional cell. It has the following reason.

(a)
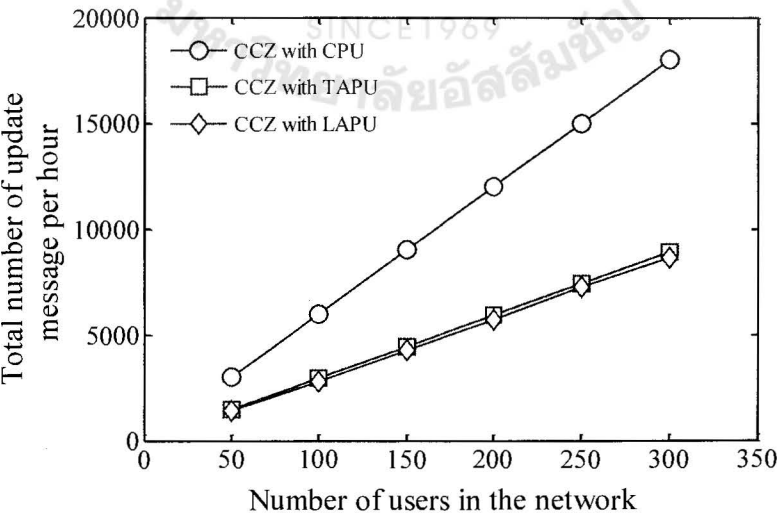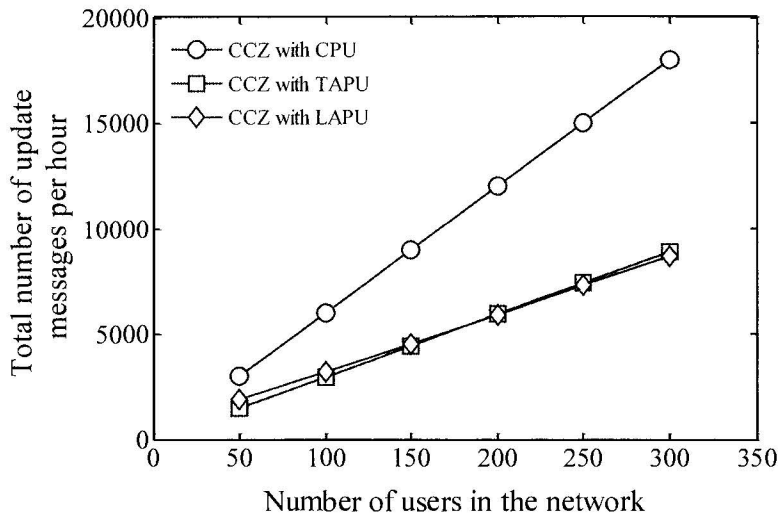
Figure 4-11 Number of update messages at different numbers of users (a) omni-directional cell network (b) sector-based cell network

Figure 4-12 demonstrates a possible condition in omni-directional cell and sector-based cell with small update areas. In this condition, for omni cell, there is a user in update region. Thus, BS does not need to inform all users to perform update. Only one user will update.

For the same user distribution in sector-based cell, there is a user in the update area of sector-1. However, sector-2 and sector-3 have no update user because no user falls in their update areas. In that condition, sector-2 and sector-3 will inform all users in their sectors to update. Thus, there will be a larger number of update messages in sector-based cell compared to omni-direction cell. This condition will often happen in sector-based cell when update area is very small. Therefore, when the number of users is small, a lager area should be set to avoid this condition. Also, it should be noted that, if the number of users in the network is larger, a small update area is required to reduce the number of update messages.
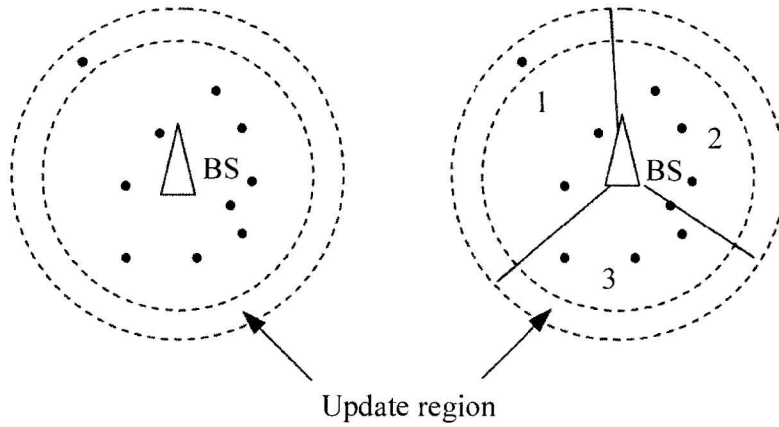
Update region

Figure 4-12 Possible conditions in omni and sector-based cell with small
update area

4.4 Performance of Proposed Update Schemes in a Network with Different Average Moving Speeds

The performances of proposed update schemes depend on the number of users and user distribution in the network. In turn, the user distribution can be influenced by moving speed of users at a constant number of users in the network. Therefore, in this section, the relationship between the performances of proposed update schemes and average moving speed of users is analyzed. The number of users in the network is kept constant as 100. Then average moving speed is changed from 1 m/s to 30 m/s.

4.4.1 Transmitted power ratio with different average moving speeds

Figure 4-13 describes the transmitted power ratios in continuous cell zooming algorithm with three different update schemes. The average moving speed of users is changed from 1 m/s to 30 m/s. Here, it can be observed that the transmitted power

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ratios in both omni and sector-based cells have no consistent increasing or decreasing trend with the increment of average moving speed of users. The transmitted power decreases back at 5 m/s and 20 m/s and it show increasing trend at other speeds.
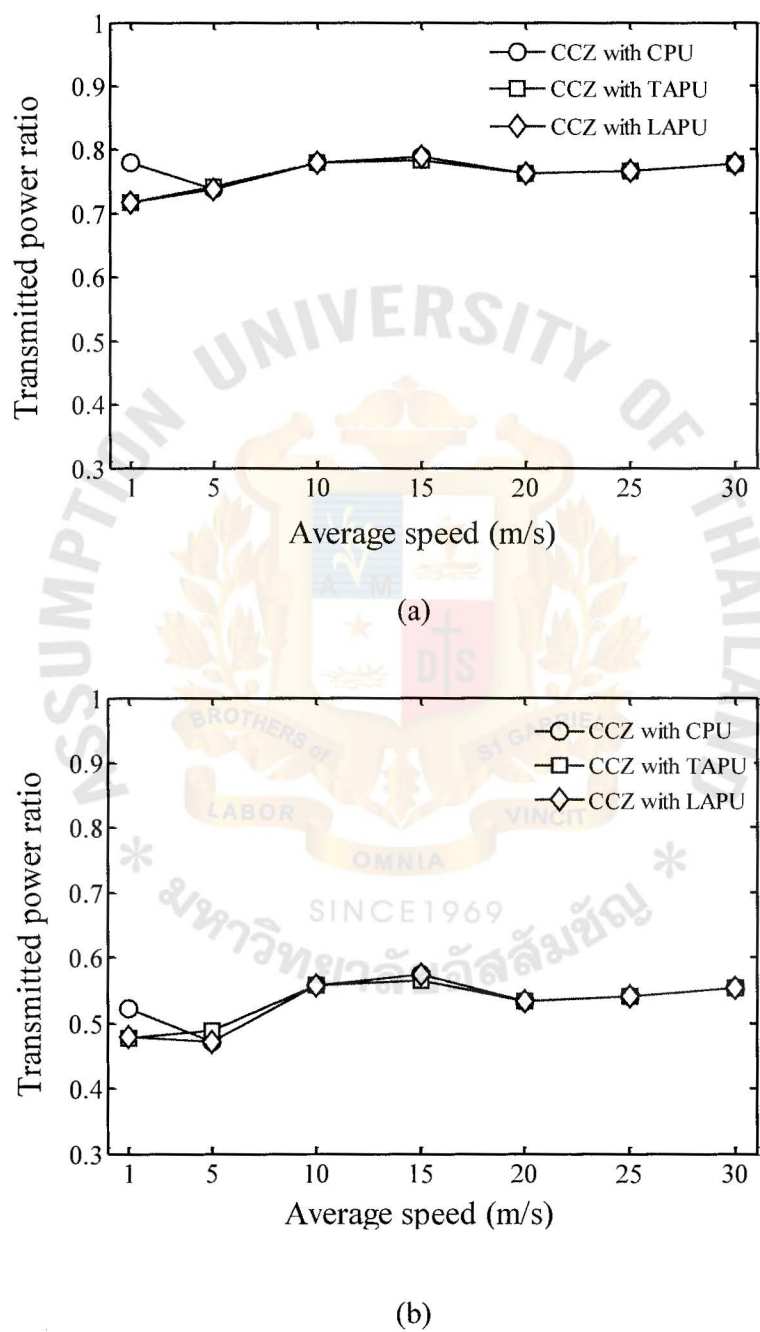

(a)

(b)

Figure 4-13 Transmitted power ratio at different average speeds (a) omni-directional cell network (b) sector-based cell network

Also, it is noticeable that the change of transmitted power ratio is not significant. It can be said that the trend is dynamic since there are increasing trend and decreasing trend. It changes in the range of 0.7–0.8 in omni-directional cell network and 0.4-0.6 in sector-based cell network. The reasons can be explained by using the following demonstrations.

Figure 4-14 (a)-(d) show the possible user positions and moving directions with a high speed. Figure 4-14 (a) shows that the users at the cell center can reach to the cell edge very easily due to moving with a high speed. In the same way, Figure 4-14 (b) demonstrates that the users at the cell edge can reach to cell center very easily due to moving with a high speed. Figure 4-14 (c) displays that users can move in and move out very dynamically in the cell area. Therefore, it is not certain to state that the transmitted power will be higher or lower due to moving with a higher speed. It depends on where the users start to move and which direction the users move to.
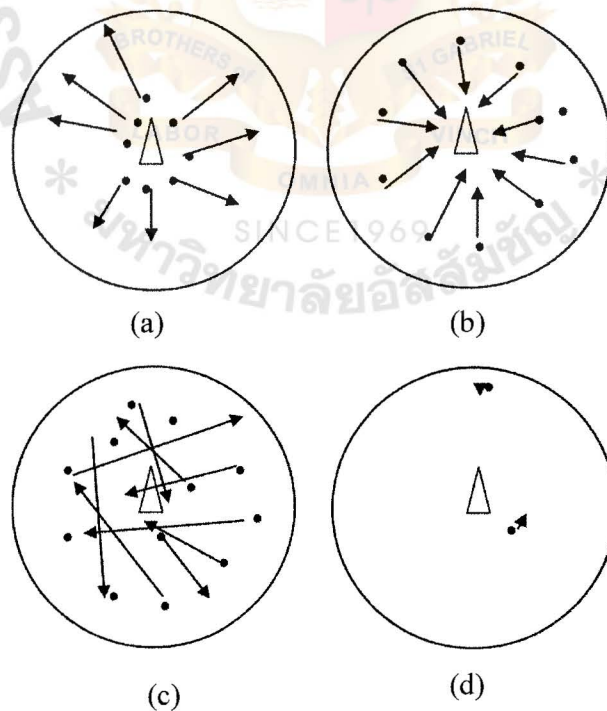

Figure 4-14 (a)-(d) Possible user moving conditions in a cell

Then, one may wonder if transmitted power will be low if the moving speed is low. It is also not certain. As shown in Figure 4-14(d), when users are moving very slowly, the user at the cell edge cannot reach very quickly to the cell center. It will maintain its far distance for long. In the same way, the user at cell center will not go far very easily. It can maintain its close distance for a long time. According to these two conditions, the transmitted power can be higher or can be lower.

4.4.2 Outage ratio with different average moving speeds

Figure 4-15 (a)-(b) show the comparison of outage ratios in cell zooming with three different update schemes. The outage ratios in CPU and LAPU are still zero. However, as explained before, in practice, there could be outage in CPU and LAPU because some users may miss to update due to moving with a very high speed. Also, when update interval and the smallest pause time of moving users not the same, there will be outage in CPU and LAPU.
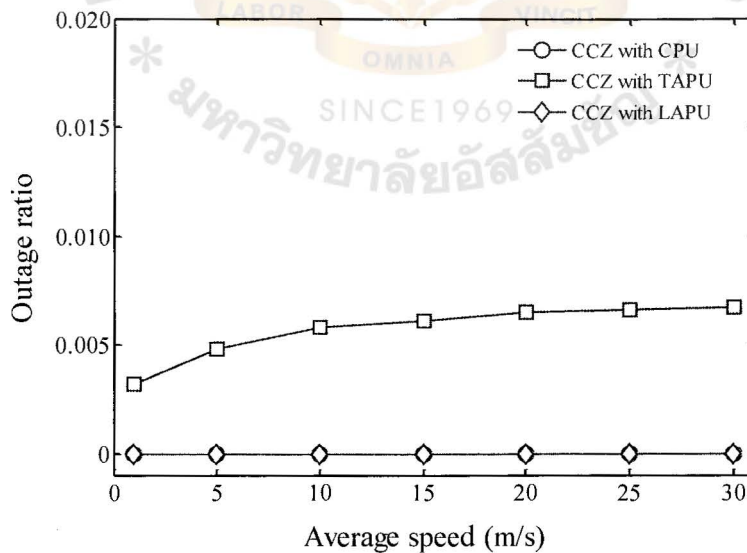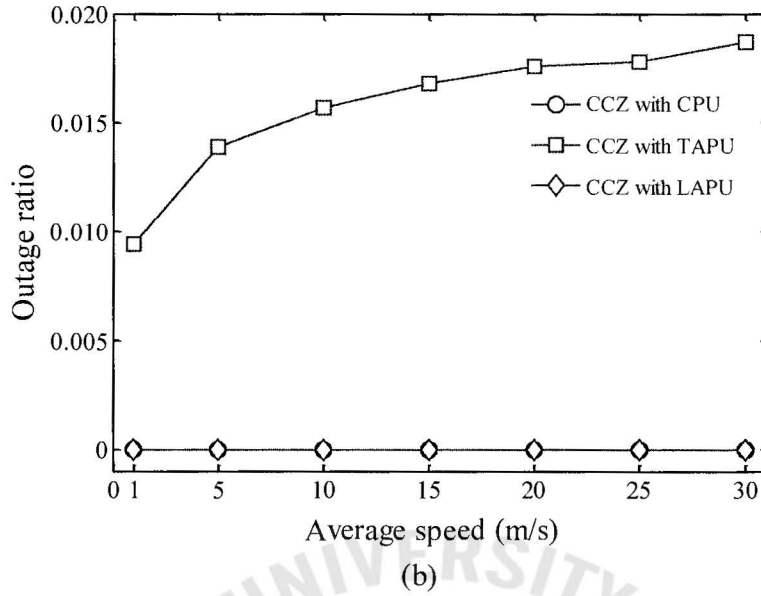

(a)

Figure 4-15 Outage ratio at different average speeds (a) omni-directional cell

network (b) sector-based cell network

For TAPU, the effect of speed on outage ratio is obvious. It is clear that the outage can easily occurs when users are moving with a very high speed. Thus, the outage ratio increases with the increment of average speed. The outage ratio is higher in sector-based cell network.

4.4.3 Number of update messages different average moving speeds

The number of update messages in LAPU depends on how many users exist in the update region. In other words, it also depends on how the users move, from cell center to cell edge or from cell edge to cell center. According to the results shown in Figure 4-16 (a)-(b), the number of update messages in LAPU has the same trend with the transmitted power ratio in LAPU.

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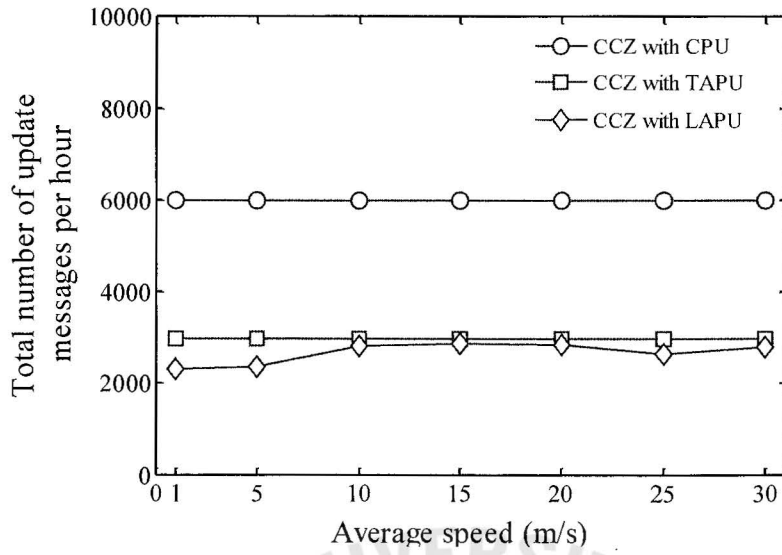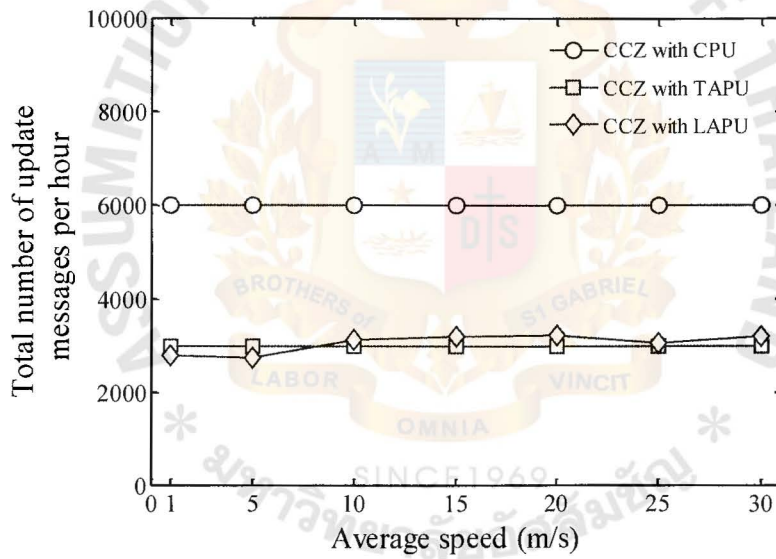
Figure 4-16 Number of update messages at different average speeds (a) omni-

directional cell network (b) sector-based cell network

When transmitted power is low, it means that the users move to cell center.

Thus, there will be less number of users in update region, which results in lower

number of update messages. When transmitted power is high, it means that the users

move to cell edge. Thus, there will be a larger number of users in update region, which results in a larger number of update messages.

Here, one noticeable point is that LAPU does not give the same performance in omni-directional cell and sector-based cell with the variation of speed. It seems that when user distribution is very dynamic in the sector-based network, the condition, in which the BS has to inform to all users to inform update since there is no user in update region, often happens. Thus, the number of update messages achieved by LAPU is larger in sector-based cell than in omni-directional cell.

4.5 Effects of Cell Zooming on other QoS Parameters

4.5.1 Effect on throughput

An essential parameter that characterizes the QoS of a communication system is throughput. The throughput is traditionally defined as the rate of successful message delivery over a communication channel. The throughput can be affected by limitations of physical medium, transmission medium, available processing power of the system components and end-user behavior. In this section, the effect of cell zooming on throughput is theoretically analyzed. Thus, a well known theorem, called Shannon's Upper Bound, should be recalled as follows.

$$C = B \, log_2 \left(1 + \frac{P_{rev.signal}}{P_{noise}}\right) \tag{4.1}$$

where ,

$$C \qquad = \text{Maximum throughput (bit/s)}$$

$$B \qquad = \text{Bandwidth (Hz)}$$

$$P_{rev.signal} \quad = \text{Total received power (W)}$$

$$P_{noise} \qquad = \text{Noise power (W)}$$

In term of Singal-to-Noise Ratio, Eq.(4.1) can be expressed as,

$$C = B\log_2 \left(1 + SNR\right) \tag{4.2}$$

where,

SNR = Signal-to-Noise Ratio ($P_{rev,signal}/P_{noise}$)

From Eq.(4.2), it can be seen that the maximum possible throughput (C) is influenced by bandwidth (B) and Signal-to-Noise Ratio (SNR). Then, the bandwidth depends on the equipment in physical layers and protocols applied. The noise power is dependent of environmental condition and the distance between the user and BS.

In practice, maximum throughput is designed based on SNR at the designed cell edge. However, SNR can vary from one user to another user depending on received signal power and the noise power. Thus, the maximum throughput to one user can be different from that to another user. Thus, the variation of maximum throughput occurs even in original operation without cell zooming. It can be explained by using demonstration in Figure 4-17.
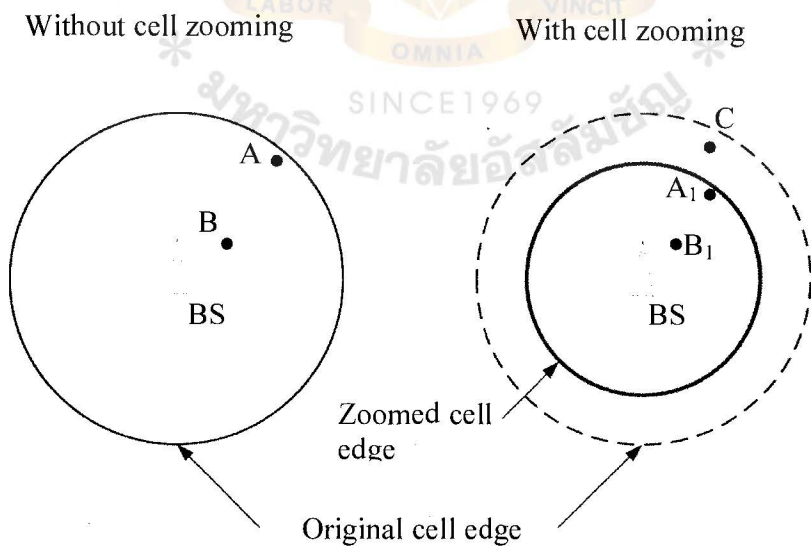

Figure 4-17 Effect of cell zooming on throughput

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For example, as shown in Figure 4-17, in operation without cell zooming, the throughputs to user A and user B can be different because the users have different received signal power according to their distances from BS.

It should be noted that in the operation with continuous cell zooming, the cell is zoomed (transmitted power is adjusted) by keeping originally designed receivable signal power to the farthest receiver at the zoomed cell edge (see from Eq. (3.3) to (3.6) on pages 35-36).

Let's consider the case of user B and user B_1. The user B and user B_1 exist at the same distance from their corresponding base stations. However, compared to user B, user B_1 will have lower received signal power because transmitted power is proportionally reduced in cell zooming. Thus, compared to user B in operation without cell zooming, the user B_1 in the operation with cell zooming will receive lower throughput. In this condition, the effect of cell zooming on throughput occurs.

Then, for a user who goes out from convergence region during cell zooming period, it will receive low or zero signal power. For example, user C will receive zero throughput since it goes out of convergence region. In this condition, the effect of cell zooming on throughput occurs. In this analysis, it is counted as outage.

4.5.2 Effect on latency

Latency is one of the parameters that characterize the QoS of a communication system. The latency is defined as the time duration taken for a certain amount of data to travel from source to destination. Thus, there are two main parameters that govern the latency. These are transmission delay and propagation delay. Then propagation delay depends on transmission medium and the distance between source and destination.

Then, transmission delay depends on throughput, the performance equipments in physical layer and the protocols applied in transmission. The latency will increase when transmission delay increases. Then, as explained in previous section by using Figure 4-17, when throughput is lower due to cell zooming, transmission delay will increase. Thus, the users could experience a higher latency.

CHAPTER 5

Conclusion and Recommendation

This research proposes and evaluates two location update schemes namely time-adaptive periodic update (TAPU) and location-adaptive periodic update (LAPU) for continuous cell zooming algorithm in mobile wireless networks. The performances of these two schemes are compared with that of conventional periodic update (CPU) scheme.

The CPU scheme is unfavourable because it results in a large number of update messages that leads to a high signaling cost. In TAPU scheme, the update interval of all users is changed according to time-dependent user mobility level. In LAPU scheme, an update region is pre-defined in each cell for all users and the users who exist in the pre-defined update region have to update their locations. After analyzing the performances of proposed update schemes by applying in continuous cell zooming algorithm in both omni-directional and sector-based cell networks, the following conclusion can be drawn.

(1) As long as the update interval applied in TAPU and LAPU is the same as that in CPU, there will be no effect on power saving capability of continuous cell zooming algorithm. In this study, a slight different between power saving by CPU and that by TAPU is due to applying relatively longer update intervals in TAPU. Thus, the power saving capability of a proposed update method depends on update interval applied in it.

(2) Then, update interval applied in a proposed update schemes (TAPU and LAPU) and the user mobility level will affect the outage. The scheme with a longer update interval will give a larger number of outages and the scheme with a shorter update interval will give a smaller number of outages. It is better to choose an update interval that is approximately the same as the smallest pause time of moving users in the network to avoid outage. Although no outage occurs in CPU and LAPU in this study, there will be outage if the intervals in these schemes are longer than smallest pause time of moving users. Also, there could be accidental outage in any scheme if the user misses to update in real field.

(3) The shorter the update interval in CPU and TAPU, the larger the number of update messages in cell zooming operation which is unfavourable. In this sense, LAPU is favourable because it can reduce the number of update messages depending on the size of update area specified. However, if the update area of LAPU is large, it will also give a larger number of update messages.

(4) The total number of users existed in the network affect on the performance of each scheme. In any scheme, the transmitted power ratio increases, the outage ratio decreases and the number of update messages increases with the increment of number of users.

(5) The average moving speed of users in the network can also affect the performance of each scheme. However it does not show a consistent effect. Due to higher moving speed, the transmitted power can be higher or lower. However, the outage becomes higher when the average moving speed is higher. There is no effect of moving speed on the number of

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update messages in TAPU and CPU. Also, it does not show a consistent effect on the number of update messages in LAPU. It depends on which direction the user move and where they start to move.

In this research, the traffic arrival pattern to base stations and the mobility level pattern in the network are assumed to be the same for every day. Also, only voice call is considered as traffic. In LAPU scheme, static update area is considered. In practice, the traffic arrival pattern to base stations and the mobility level in the network can vary day by day. Also, there can be different types of traffic (such as data access, messages, voice call and video streaming) from mobile phones in modern wireless networks. Thus, the following further investigations can be recommended as further works. For example, a learning program of traffic arrival pattern to base stations and the user mobility level pattern in the corresponding network can be implemented rather than assuming it the same for every day. Then, a dynamic update area can be applied in LAPU to increase the effectiveness of LAPU. Moreover, a new hybrid method can be developed by combining the proposed update schemes (TAPU and LAPU) to achieve better performance.

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APPENDIX A

Source Code Verification

The concept of continuous cell zooming algorithm applied in this work is the same as that proposed in [4]. The source code for simulation of continuous cell zooming algorithm is implemented by using MATLAB software. To verify the concept of continuous cell zooming algorithm and the source code implemented in this work, the primary simulated results of transmitted power ratio at different number of calls (traffic) are compared with the results of previous work [4].

Since some information in previous work are not available, exactly the same scenarios cannot be made in comparison. However, a fair comparison can be made based on the same number of calls (traffic) per hours because the ratio of total transmitted power in the whole network is normalized value. Therefore, the transmitted power ratios of two scenarios from current work and previous work are compared.

$$Power\ consumption\ ratio = \frac{P_{transmit,\ network\ with\ cell\ zooming}}{P_{peak\ transmit,\ network\ without\ cell\ zooming}} \tag{A-1}$$

According to this equation, power consumption ratio is a relative value between transmission with cell zooming and that without cell zooming in each network. Thus, it is normalized values from each network and a fair comparison can be made.

Figure. 4-1 shows the comparison of transmitted power ratios form current work and previous work. The results (normalized values) from current simulation show a good agreement with the results of previous work. The power ratios from both current and previous works show similar increasing trends with the increase of

number of calls per hour. A slight difference between two groups of results is due to different network parameters such as power consumption of base station, path loss exponent. Also, moving speed, the farthest user location and the update interval can affect the results. The information of these essential parameters is not available in previous work. However, the normalized results show the same trend since the concepts of algorithms are the same. Thus, the concept and the source code implemented in this work are well verified.

Table A-1 Scenarios for source code verification

Parameters	Current work	Previous work [4]
Cell type	Omni-directional cell	Omni-directional cell
Number of cells	1	1
Maximum cell radius	500 m	500 m
Maximum transmitted power	20 kW	Not mentioned
Number of calls per hour in each cell	50-400	50-400
Inter arrival time	360 s (6 min)	360 s (6 min)
Location update method	Conventional periodic update method	Not mentioned
Farthest user location	Randomly distributed	Not mentioned
Range of moving speed	[0-50] m/s	Not mentioned
Value of path loss exponent	4	2–4
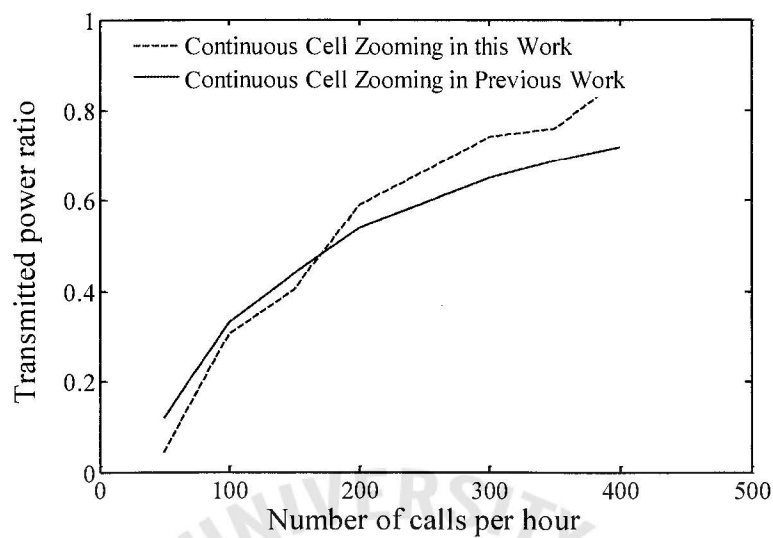
Figure A-1 Comparison of transmitted power ratio

APPENDIX B

Results for Different Operation Days

The values of transmitted power ratio, outage ratio and the number of update messages presented in Chapter 4 are the average values obtained from 3-day operation. This section presents the transmitted power ratio, outage ratio and the number of update messages achieved by CPU, TAPU and LAPU in each day from 3-day operation.

Then, simulations for two additional days are performed. After that, the comparisons of average values of performance parameters obtained from 3-day operation and 5-day operation are illustrated.

Figures B-1 to B-6 show the transmitted power ratio, outage ratio and the number of update messages achieved by CPU, TAPU and LAPU in each single day and the average values of each parameters from 3-day operation. It can be seen that transmitted power ratio, outage ratio and the number of update messages achieved by each scheme in each day show the same trend with the average values of 3-day operation. Also, the values of every performance parameter in each day are close to the average values.

Figures B-7 to B-12 show the comparisons of average values of 3-day operation and 5-day operation. In Figure B-9 and Figure B-10, the comparison of outage ratio is made only for TAPU because there is no outage in other two schemes, CPU and LAPU. Likewise, in Figure B-11 and Figure B-12, the comparison of the number of update messages is performed only for LAPU because the number of update messages in CPU and TAPU are constant in every day.

It can be seen that for every performance parameter, the average values obtained from 3-day operation are approximately the same and have the same direction with the average values obtained from 5-day operation. Thus, it can be concluded that the average values of 3-day operation presented in Chapter 4 are acceptable.

Also, the results in scenario 2 and scenario 3 presented in Chapter 4 are average values obtained from 3-day operation. Therefore, they will also not have significant deviation from the average values of 5-day operation.
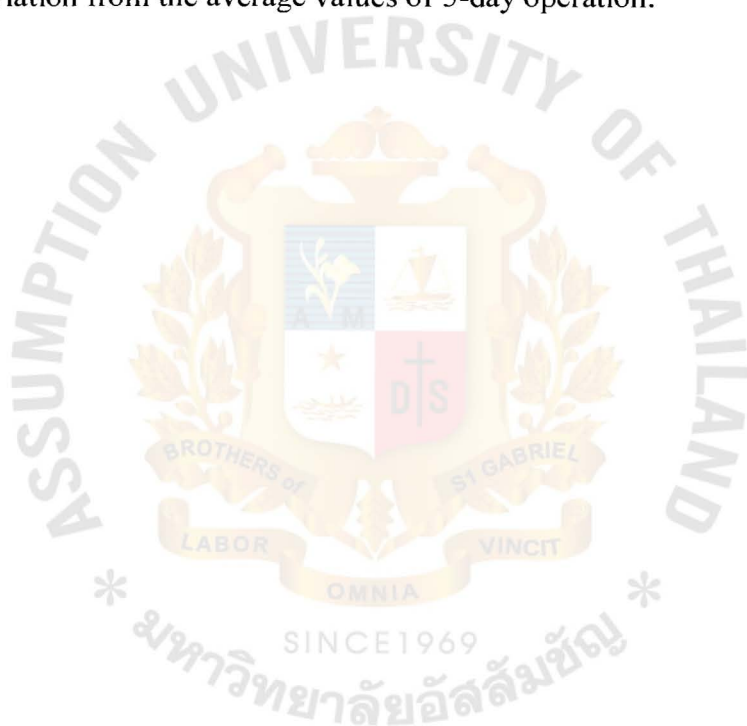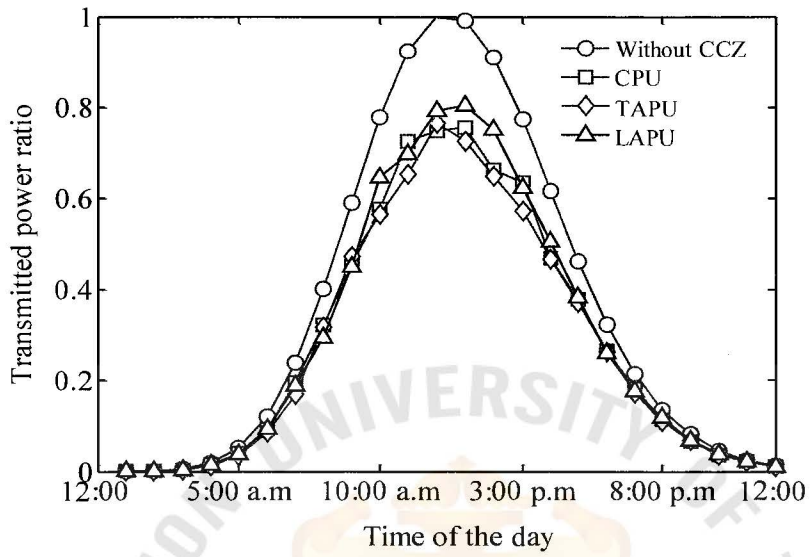
(a)
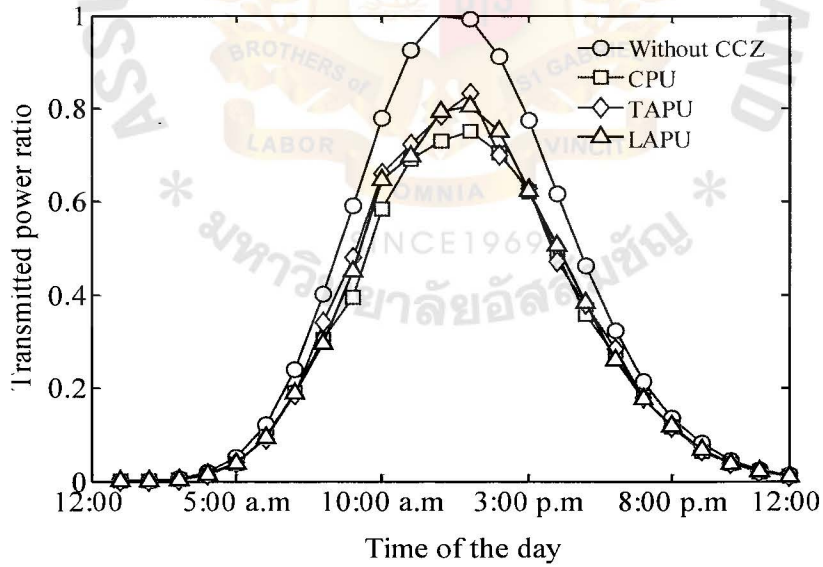
(b)
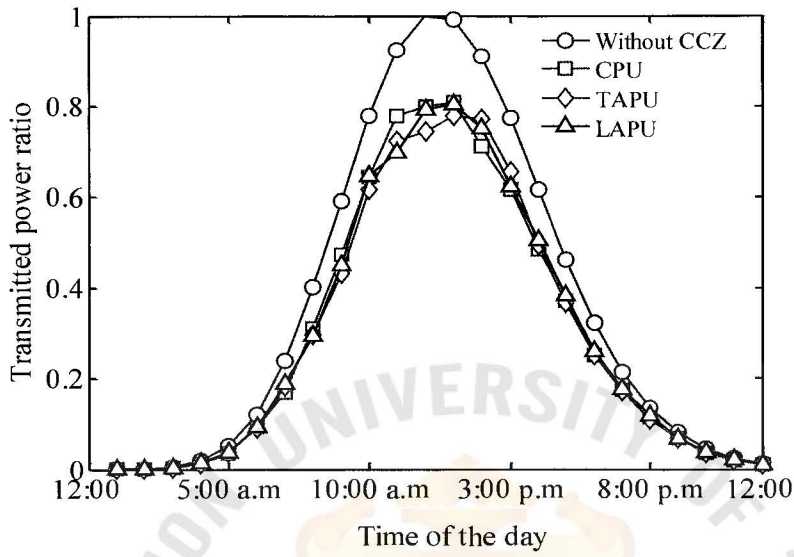
(c)
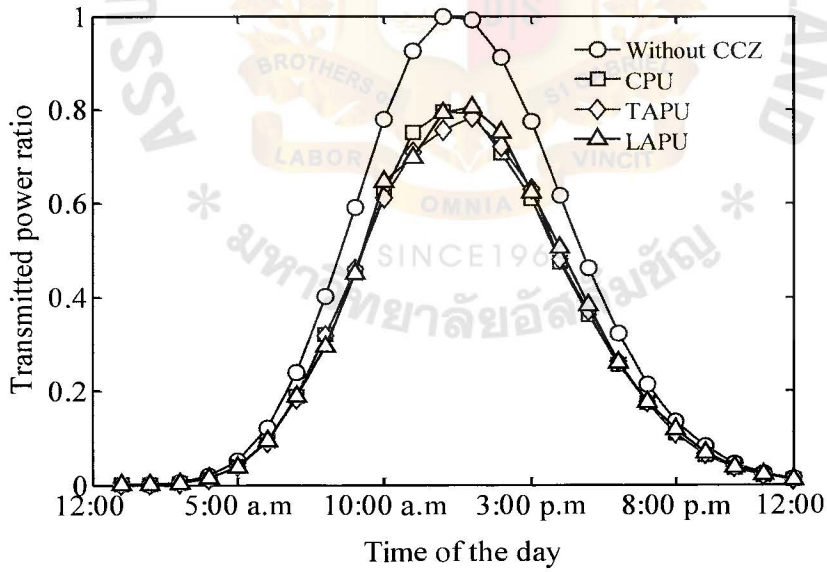
(d)

Figure B-1 Comparison of power saving capability of continuous cell zooming algorithm with different location update schemes in omni-directional cell network (a) Day 1 (b) Day 2 (c) Day 3 (d) Average of 3-day operation
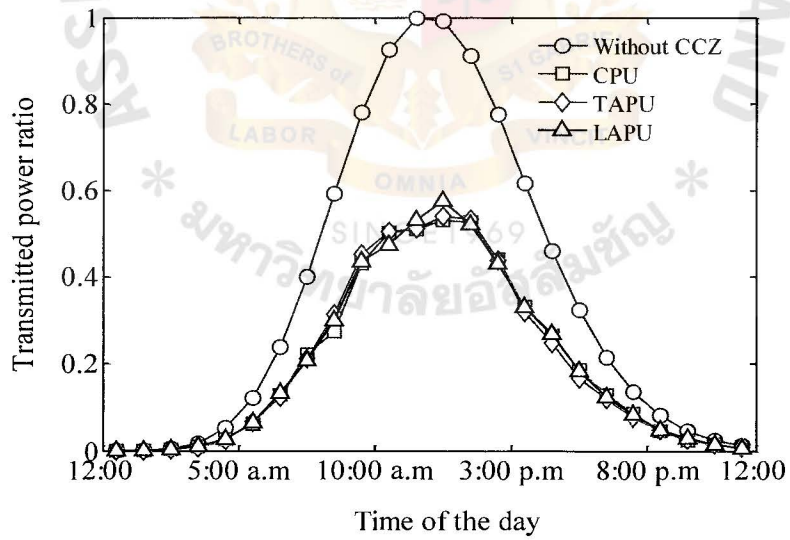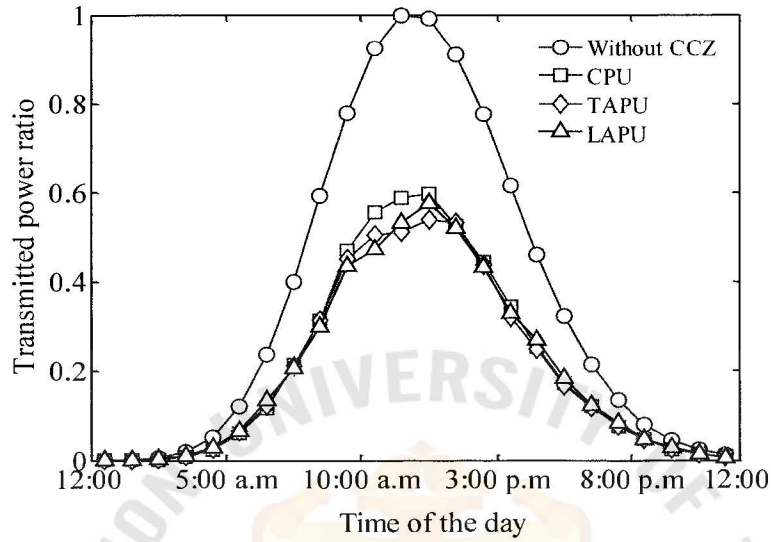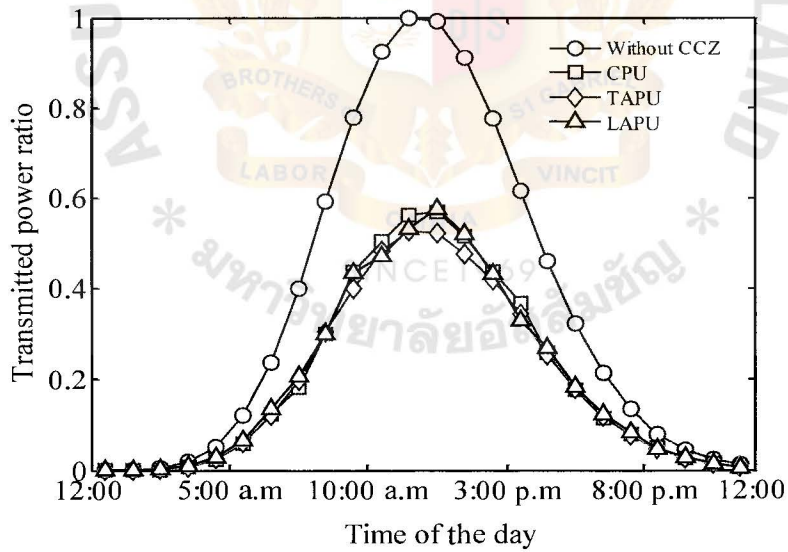
(a)

(b)

88
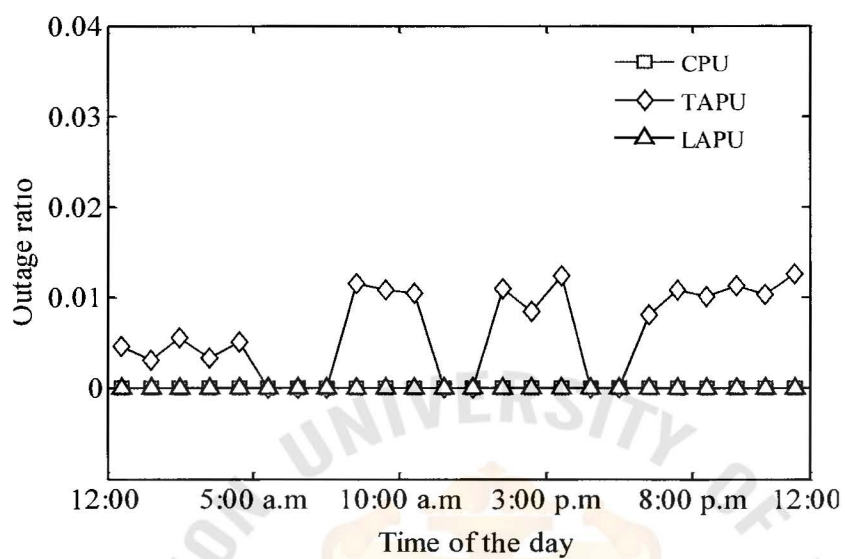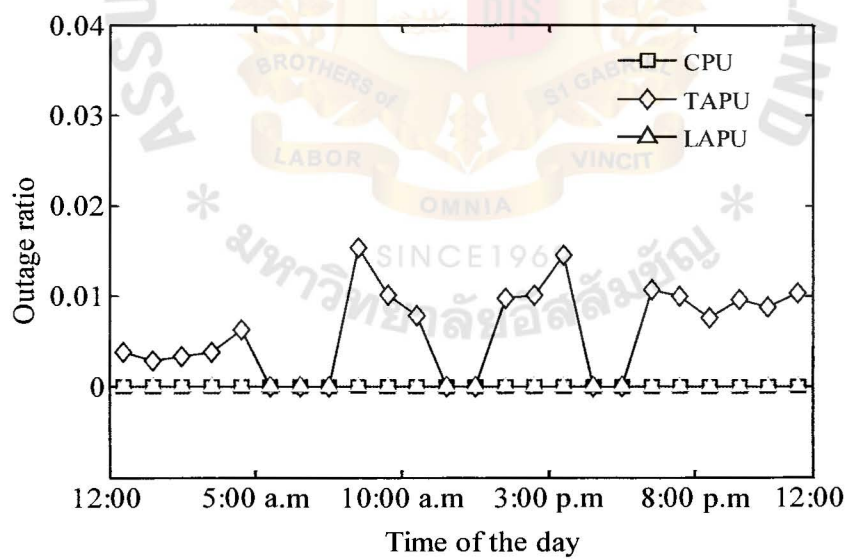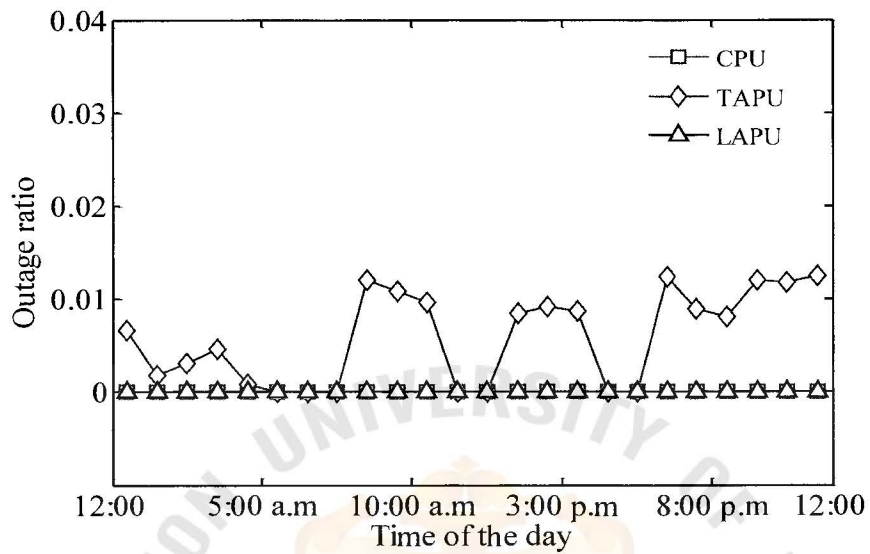
(c)
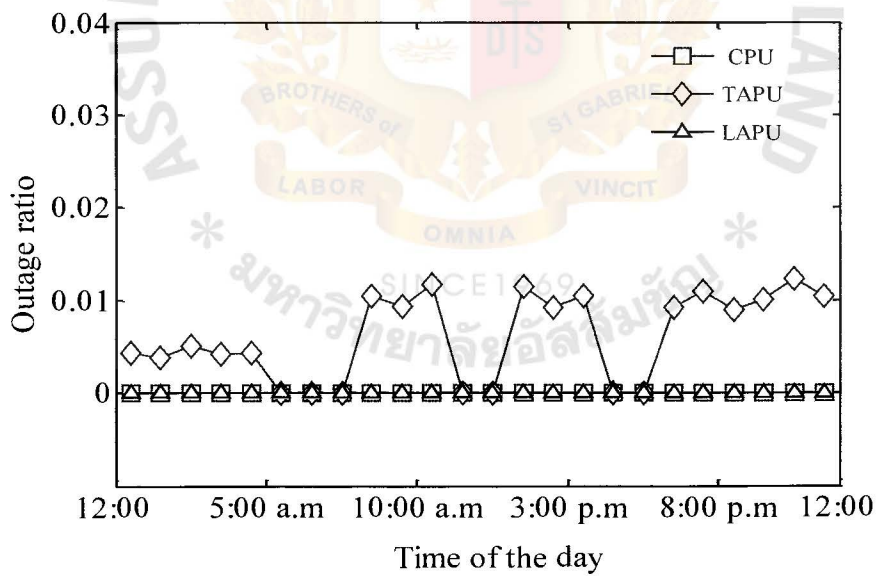
(d)

Figure B-2 Comparison of outage ratio in continuous cell zooming algorithm with
different location update schemes in omni-directional cell network
(a) Day 1 (b) Day 2 (c) Day 3 (d) Average of 3-day operation
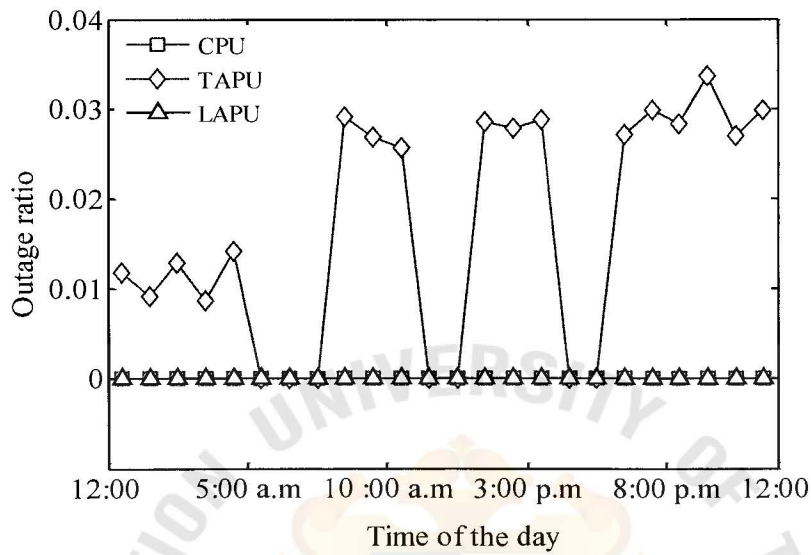
(a)

(b)

90
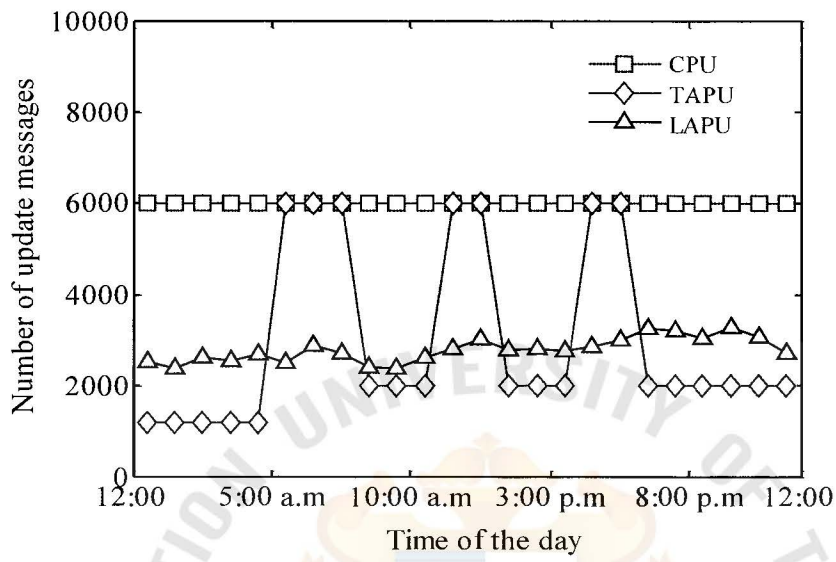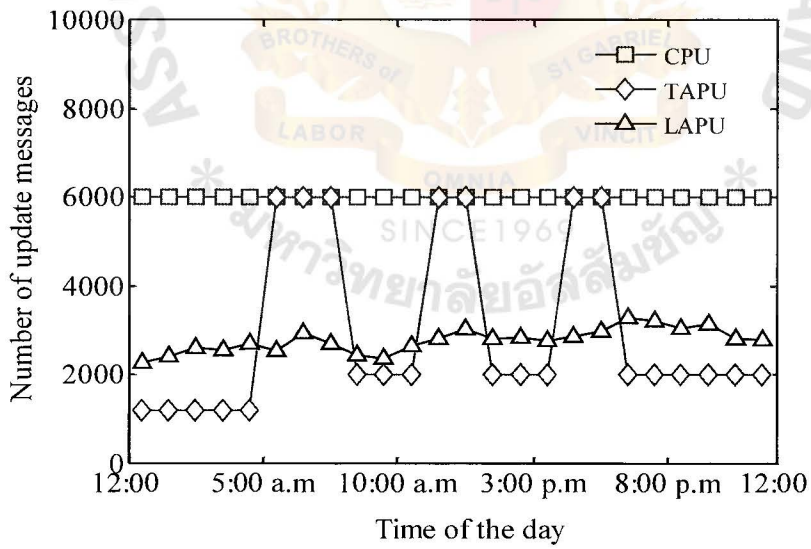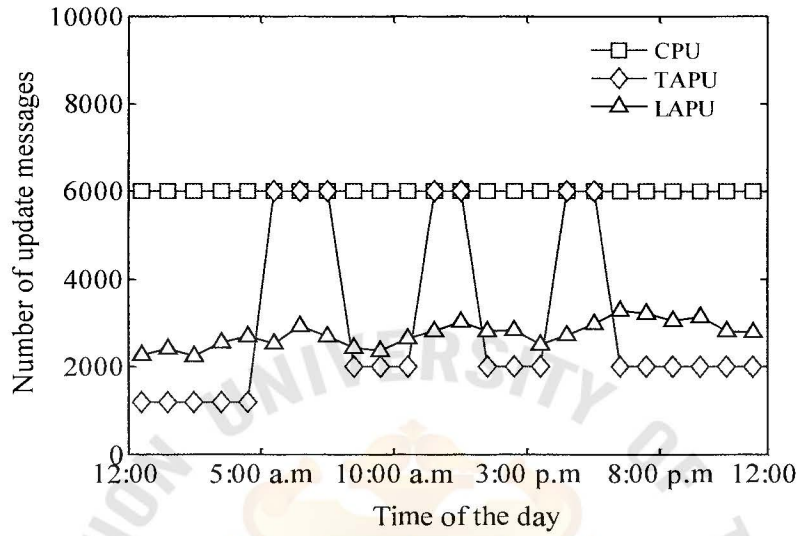
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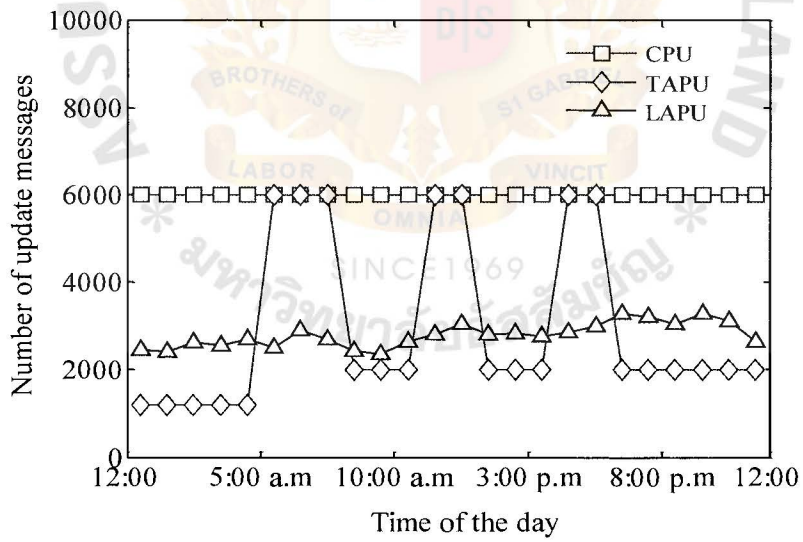
(d)

Figure B-3 Comparison of the number of update messages in continuous cell zooming algorithm with different location update schemes in omni-directional cell network (a) Day 1 (b) Day 2 (c) Day 3 (d) Average of 3-day operation
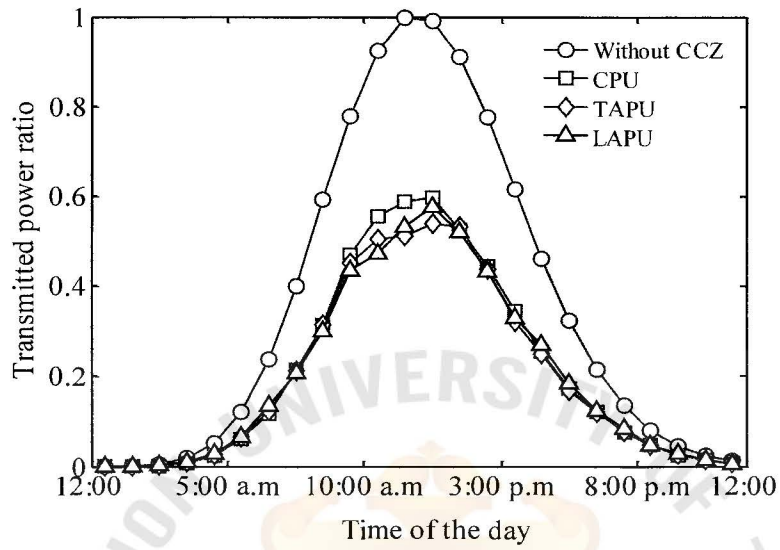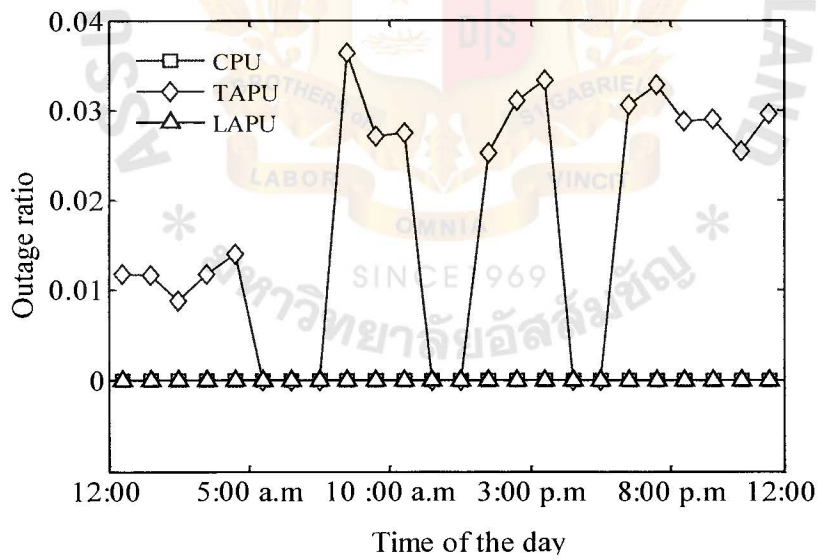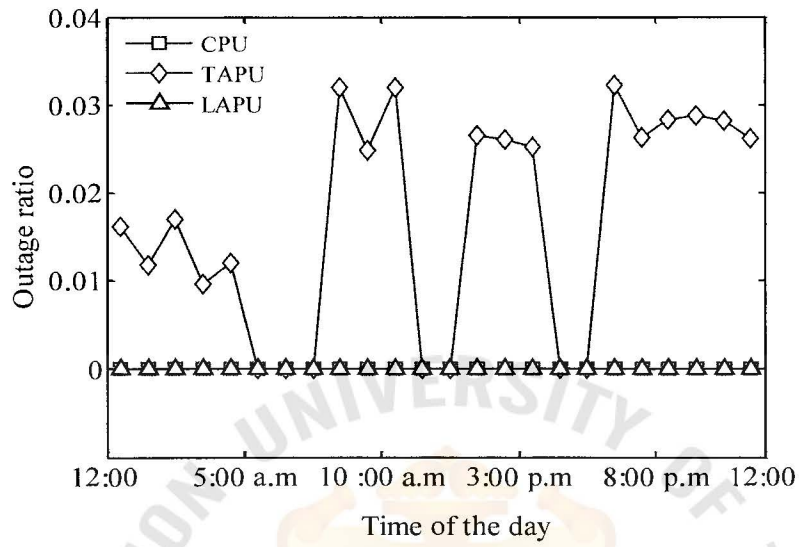
(a)

(b)

(c)

(d)

Figure B-4 Comparison of power saving capability of continuous cell zooming algorithm with different location update schemes in sector-based cell network (a) Day 1 (b) Day 2 (c) Day 3 (d) Average of 3-day operation
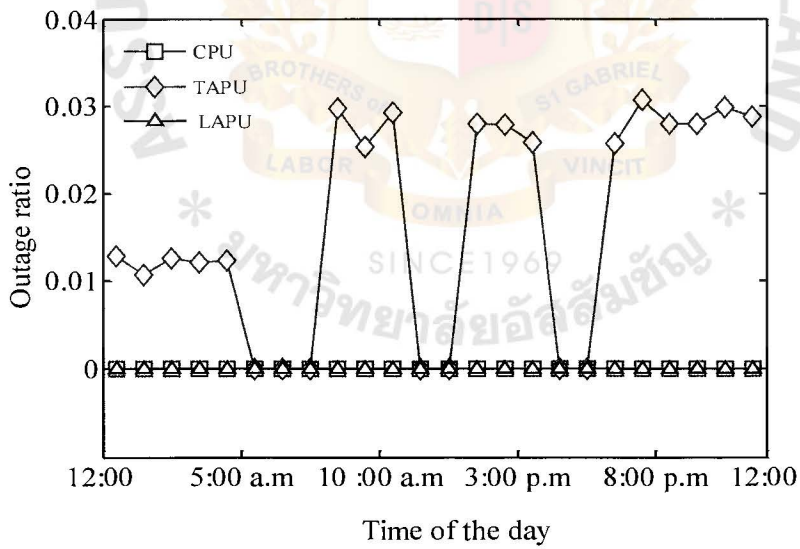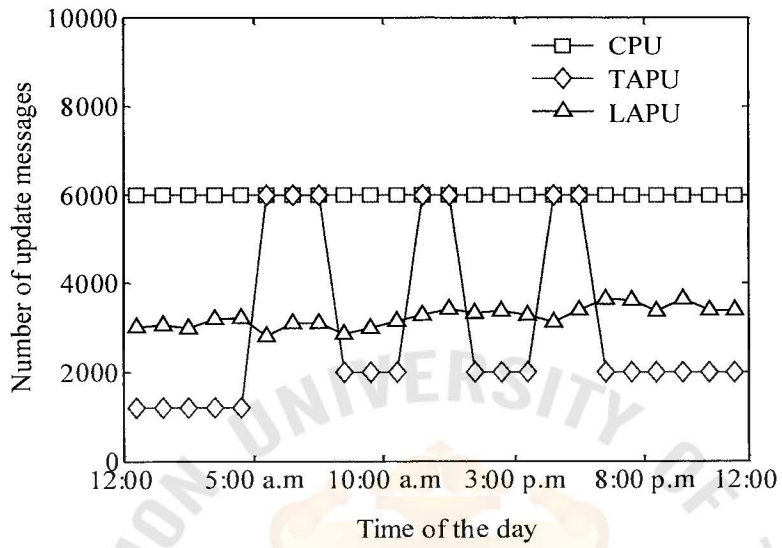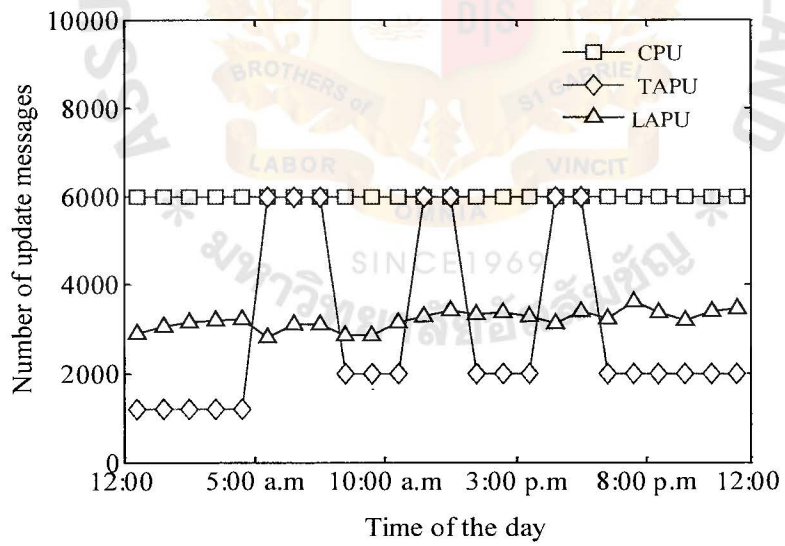
(a)

(b)

94

(c)

(d)

Figure B-5 Comparison of outage ratio in continuous cell zooming algorithm with
different location update schemes in sector-based cell network
(a) Day 1 (b) Day 2 (c) Day 3 (d) Average of 3-day operation

(a)

(b)

(c)

(d)

Figure B-6 Comparison of the number of update messages in continuous cell zooming algorithm with different location update schemes in sector-based cell network (a) Day 1 (b) Day 2 (c) Day 3 (d) Average of 3-day operation
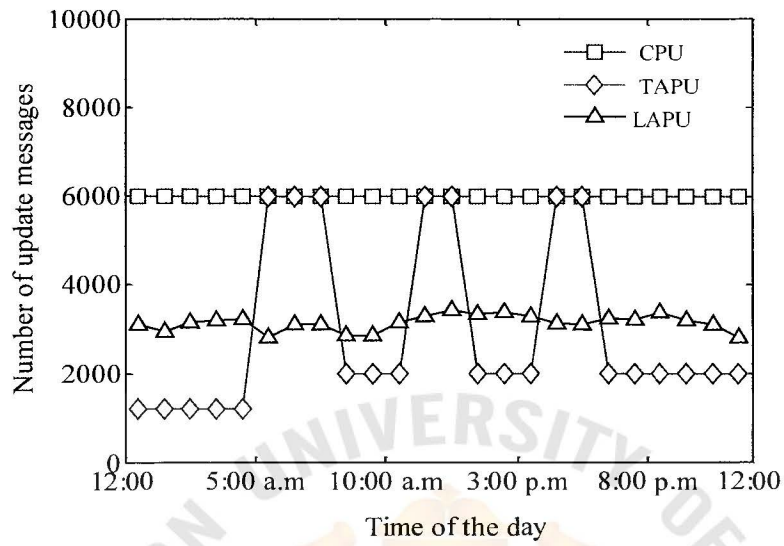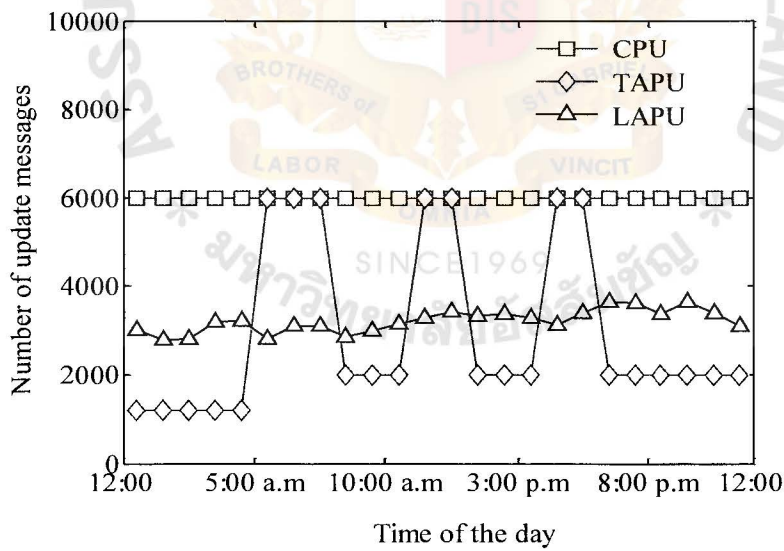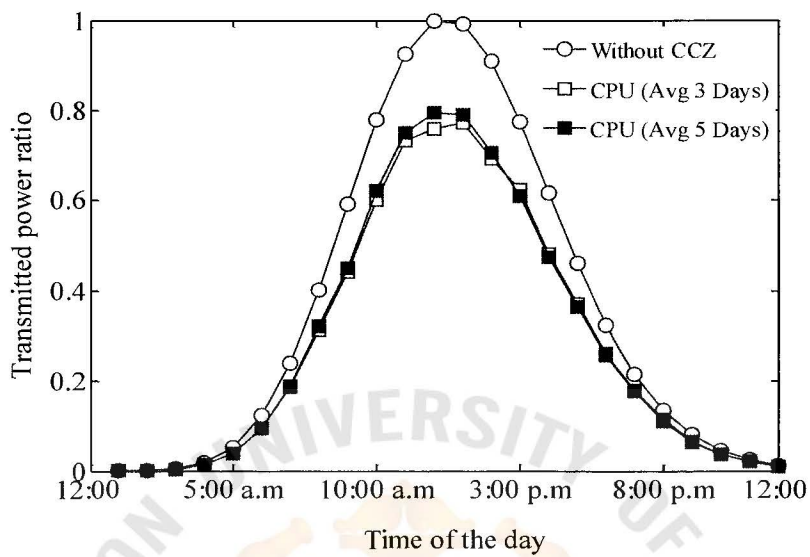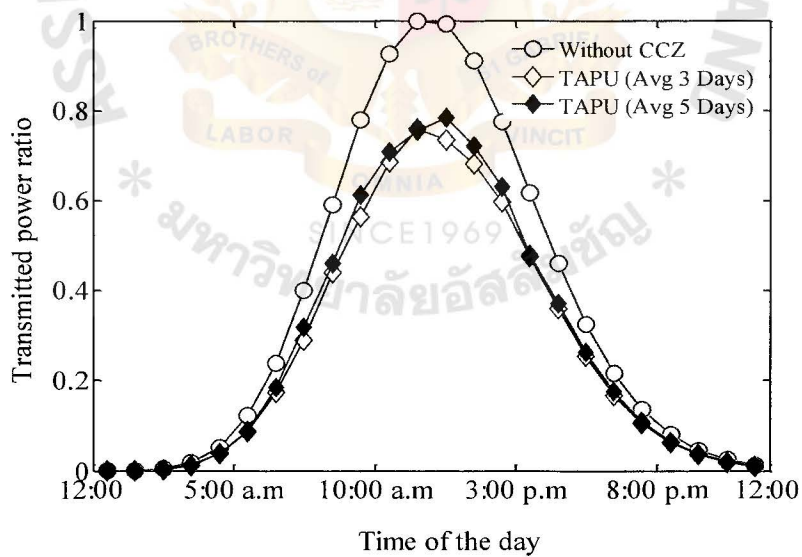
97

(a)

(b)

98
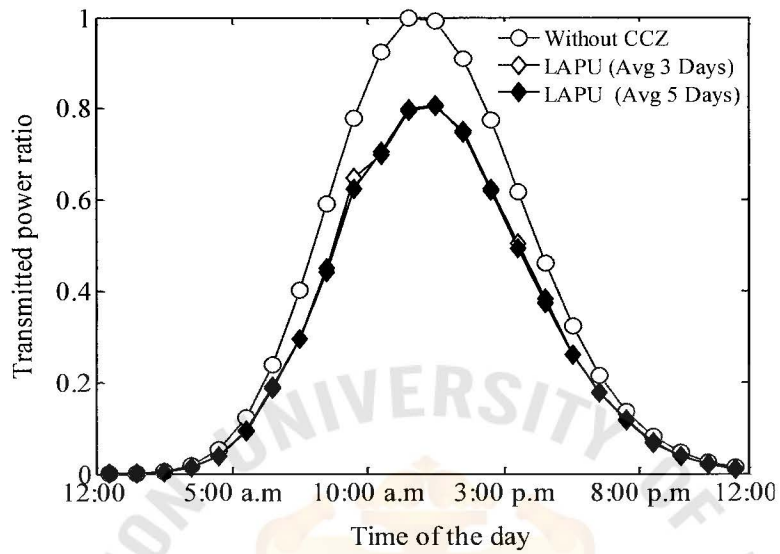
(c)

Figure B-7 Comparison of power saving capability in continuous cell

zooming algorithm in omni-directional cell network

(a) with CPU in 3-day and 5-day operations

(b) with TAPU in 3-day and 5-day operations

(c) with LAPU in 3-day and 5-day operations

(a)

(b)

100
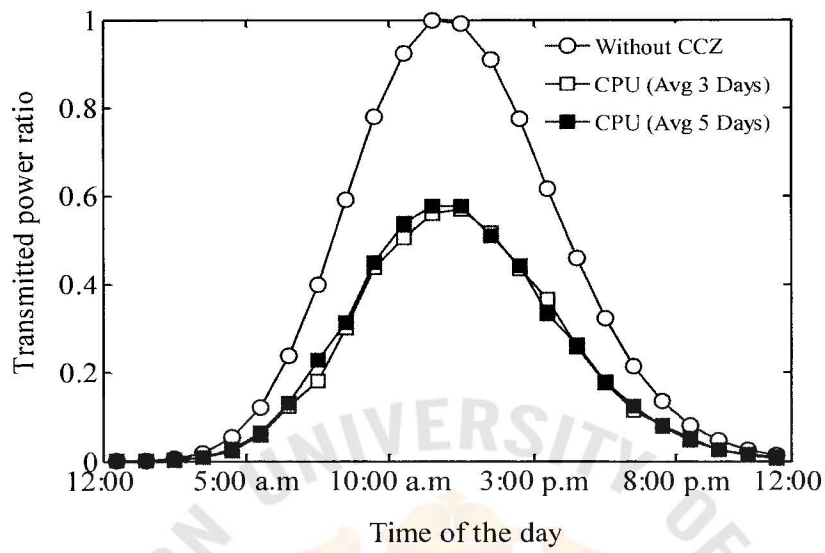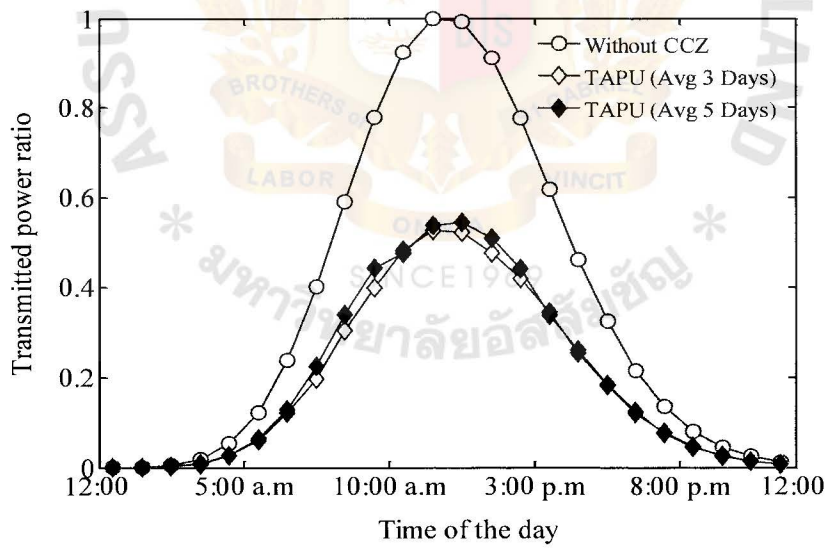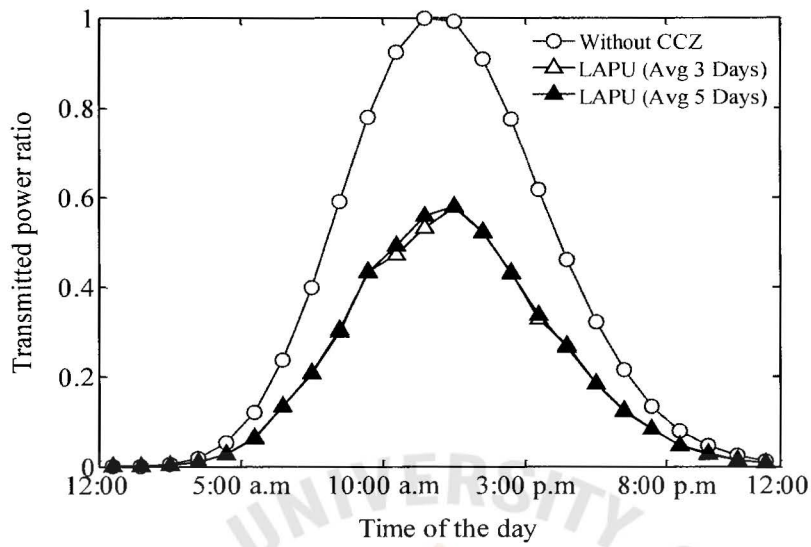
(c)

Figure B-8 Comparison of power saving capability in continuous cell

zooming algorithm in sector-based cell network

(a) with CPU in 3-day and 5-day operations

(b) with TAPU in 3-day and 5-day operations

(c) with LAPU in 3-day and 5-day operations

Figure B-9 Comparison of outage ratio in continuous cell zooming algorithm

in omni-directional cell network with TAPU in 3-day and 5-day operations
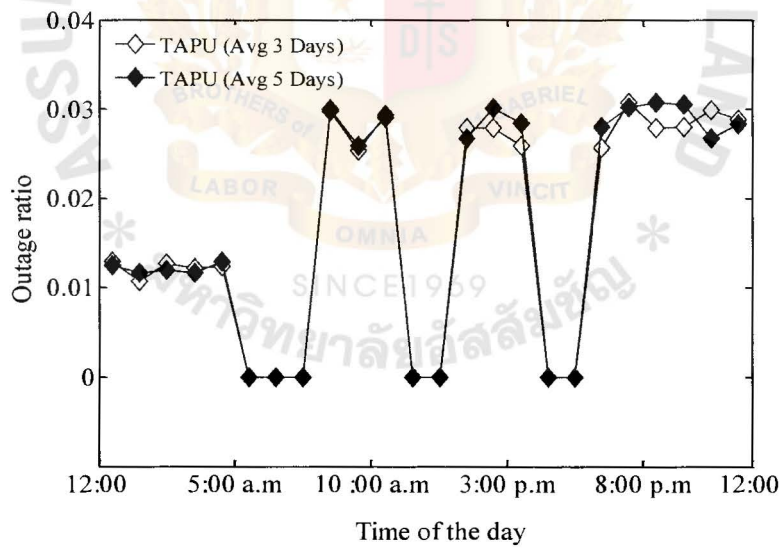
Figure B-10 Comparison of outage ratio in continuous cell zooming algorithm

in sector-based cell network with TAPU in 3-day and 5-day operations
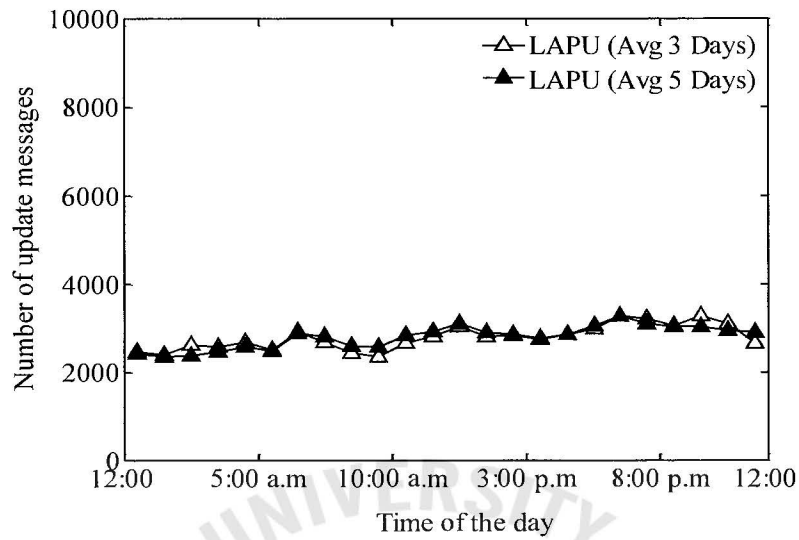
Figure B-11 Comparison of the number of update messages in continuous cell
zooming algorithm in omni-directional cell network with LAPU in 3-day and
5-day operations
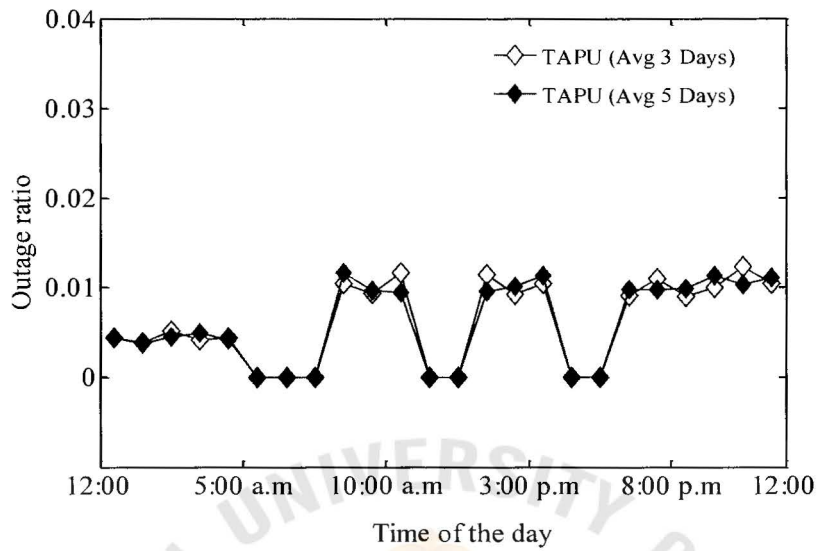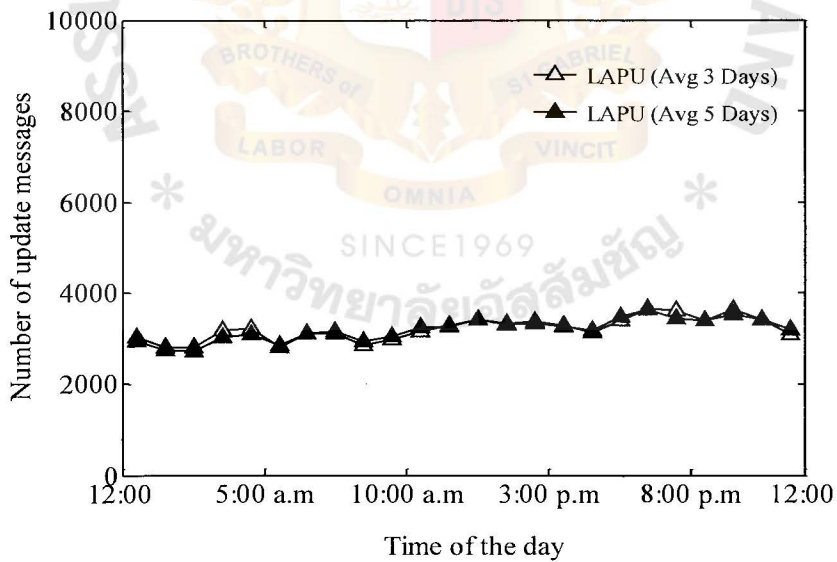

Figure B-12 Comparison of the number of update messages in continuous cell
zooming algorithm in sector-based cell network with LAPU in 3-day and
5-day operations

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APPENDIX C

MATLAB Programs

C.1 Program for Source Code Verification

```
close
clc
clear

% Step (1)Initializing Network

% The following command lines set the network area (single cell)
% in which mobile stations can go around

Rnet=500;
R_grid=Rnet;
Rad_grid=360;
MTG=zeros(R_grid,Rad_grid);

%-----------------------------------------------------------------

% Step (2) Set a Certain Number of Users to Random Locations in
%          the Network

% The following command lines set initial random locations of
% predefined number of users.

NUser=15;
for i=1:NUser;
    x1=1;
    while x1==1;
        RAD=randi(R_grid);
        TDA=randi(Rad_grid);
        if MTG(RAD,TDA)==1
            x1=1;
        else
            x1=2;
        end
    end
    MTG(RAD,TDA)=1;
    x=RAD*cosd(TDA);
    y=RAD*sind(TDA);
    plot(x,y,'bo');
    hold on
end
```

The following command line describes cell zooming configuration
from initial condition.

```
R=0;
for i=1:R_grid
    for j=1:Rad_grid;
        if MTG(i,j)==1;
            if i>R;
                R=i;
            end
        end
    end
end

ang=0:0.01:2*pi;
xp=R*cos(ang);
yp=R*sin(ang);
nxp= xp;
nyp= yp;
plot(xp,yp,'g','LineWidth',2)
```

Step (3)(4)(5) Move Users to Random Direction / Find out the
               Farthest User/ Perform Cell Zooming Condition

```
Tf=0;              Starting point in a day (start at beyond midnight)
for t=1:1440;    set time duration for the whole day (in minute)for
                 looping
    close
```

The following command lines find out and record the current
locations of users.

```
l=0;
for i=1:R_grid;
 for j=1:Rad_grid;
    if MTG(i,j)==1;
        l=l+1;
        MTL{l}=[i j];
    end
 end
end
```

The following command lines define the random number of
moving users and assign to random users.

```
Ts=(t/60)+Tf;
if Ts>24
Ts=(t/60);
end

if Ts<=5;
    MF=0.1;
elseif Ts>5 & Ts <=8
    MF=1;
elseif Ts>8 & Ts <=11;
    MF=0.5;
```

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```
elseif Ts>11 & Ts <=13;
    MF=1;
elseif Ts>13 & Ts<=16;
    MF=0.5;
elseif Ts>16 & Ts<=18;
    MF=1;
elseif Ts>18 & Ts <=24
    MF=0.5;
end

MT=[1:NUser];
MMT=round(MF*NUser);
NM=randi(MMT);

for i=1:NM
    n=length(MT);
    s=randi(n);
    MU(i)=MT(s);
    MT(s)=[];
end


% The following speed range is the possible speeds of
% each user in a day.

Speed=[1 5 10 15 20 25 30 35 40 45 50];   % m/s

% The following command lines let the randomly selected
% users move to random directions with random speeds.

for i=1:NM
    LOC=MTL{MU(i)};
    RAD=LOC(1);
    TDA=LOC(2);
    MTG(RAD,TDA)=0;
    AS=randi(11);
    D=Speed(AS);
    TDAL=randi(360);
    xl=RAD*cosd(TDA)+2*D*cosd(TDAL);
    yl=RAD*sind(TDA)+2*D*sind(TDAL);
    RAD=round(sqrt(xl^2+yl^2));
    if RAD>R_grid
        RAD=R_grid;
    elseif RAD==0;
        RAD=1;
    end
    if sign(xl)==1 & sign(yl)==1
            TDA=round(atand(yl/xl));
    elseif sign(xl)==-1 & sign(yl)==1
            TDA=round(180+atand(yl/xl));
    elseif sign(xl)==-1 & sign(yl)==-1
            TDA=round(atand(yl/xl)+180);
    elseif sign(xl)==1 & sign(yl)==-1
            TDA=round(360+atand(yl/xl));
    end
    if (TDA==0)
        TDA=360;
    end
    MTG(RAD,TDA)=1;
end
```

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The following command lines plot the new locations
of all mobile users in the network after their movements.

```
for i=1:R_grid;
 for j=1:Rad_grid;
    if MTG(i,j)==1;
        x=i*cosd(j);
        y=i*sind(j);
        plot(x,y,'bo')
        hold on
    end

 end
end

pt=1;      % Set update interval. It is changeable.

% Update Process

% In CPU, all user update at every predefined period.
% Thus no command lines for update process are specially
% included.


if rem(t,pt)==0;    % Set periodic update interval (minute)

% The following command lines perform new cell zooming
% after update process (after knowing new farthest user
% location in each cell).

R=0;
for i=1:R_grid
    for j=1:Rad_grid;
        if MTG(i,j)==1;

            if i>R;
                R=i;
            end

        end

    end
end
ang=0:0.01:2*pi;
xp=R*cos(ang);
yp=R*sin(ang);
nxp= xp;
nyp= yp;
plot(xp,yp,'g','LineWidth',2)
ROuto(t)=0; % Outage is zero at whenever update

else

% The following command lines record the number of outage
% users during cell zooming period.
```

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```
    Outo=0;
    for i=1:R_grid
        for j=1:Rad_grid;
            if MTG(i,j)==1;
                if i>R
                    Outo=Outo+1;
                end
            end

        end
    end

    plot(nxp,nyp,'g','LineWidth',2)
    ROuto(t)=Outo/NUser;
    end

axis equal
ts=num2str(t);
text(450,450,ts)    % Show the time
MYM(t)=getframe;    % Create movie frame (it is optional)


%------------------------------------------------------------


% Step (6) Evaluate Transmitted Power for each
%          Traffic Arrival Time

% The following command line calculate the transmitted power...


P_Call =440;        % Peak number of calls per hour in a day.

PU=P_Call/10;       % There are ten inter-arrival in each hour.

if rem(t,6)==0;     % Traffic arrives at every 360 seconds
    g=t/6;
    POWER;          % It is sub-routine M file for the evaluation
                    % of transmitted power for current cell zooming
                    % condition mentioned above

    clear Ri RU Rzo i j m n
                    % Clear zoomed cell information before next
                    % traffic arrival time
end

end
xlswrite('POWER1',Pr1,1,'B');        % Save transmitted power
xlswrite('Outage',ROuto',1,'B');     % Save outage ratio


%------------------------------------------------------------

% Step (7) Evaluate Transmitted Power ratio
% This step is performed outside.
%------------------------------------------------------------

% Step (8) Plot the Results
% This step is performed outside.
%------------------------------------------------------------
```

C.2 Programs for CPU, TAPU and LAPU

In this section, some important parts of CPU, TAPU and LAPU programs are mentioned. However, it should be noted that the programs are not complete since these programs are too long to be mentioned here. The first important point is initializing network which consists of 7 cells. This part is the same for CPU, TAPU and LAPU.

```
close
clc
clear

% Initializing Network

% The following command lines set the network area (7 cells) in which
% mobile stations can go around...

Rnet=956;
MTG=zeros(Rnet,360);
for RAD=600:Rnet;
 for TDA=1:360;
    x=RAD*cosd(TDA);
    y=RAD*sind(TDA);
    if TDA>=1 & TDA<60;
       R=sqrt((x-525)^2+(y-303.1089)^2);
       if R>350;
          MTG(RAD,TDA)=2;
       end
    elseif TDA>=61 & TDA<120;
       R=sqrt((x)^2+(y-606.2178)^2);
       if R>350;
          MTG(RAD,TDA)=2;

       end
    elseif TDA>=121 & TDA<180;
       R=sqrt((x+525)^2+(y-303.1089)^2);
       if R>350;
          MTG(RAD,TDA)=2;

       end
    elseif TDA>=181 & TDA<240;
       R=sqrt((x+525)^2+(y+303.1089)^2);
       if R>350;
          MTG(RAD,TDA)=2;
       end
    elseif TDA>=241 & TDA<300;
       R=sqrt((x)^2+(y+606.2178)^2);
       if R>350;
          MTG(RAD,TDA)=2;
       end
```

```
    else
        R=sqrt((x-525)^2+(y+303.1089)^2);
        if R>350;
            MTG(RAD,TDA)=2;

        end
    end
  end
end
```

Then, all other steps are the same as the program for source code verification. However, the difference is that inspection or analysis in CPU, TAPU and LAPU must be performed for 7 cells but not for a single cell. Thus, it is much more complicated than single cell.

The essential part in TAPU is changing update interval time according to time of the day as follows.

```
% For TAPU, update interval changes with the local time...
    % Thus, the following command lines set the update interval for
    % respective update interval...

    if Ts<=5;
        pt=5;
    elseif Ts>5 & Ts <=8
        pt=1;
    elseif Ts>8 & Ts <=11;
        pt=3;
    elseif Ts>11 & Ts <=13;
        pt=1;
    elseif Ts>13 & Ts<=16;
        pt=3;
    elseif Ts>16 & Ts<=18;
        pt=1;
    elseif Ts>18 & Ts <=24
        pt=3;
    end
```

Finally, a distinct part contained in LAPU is update process. For that process, the inner radius of update region must be predefined. Then, at every update interval, the positions of the all the users in 7 cells must be inspected to count the number of

update users. The number of messages in each cell must start from zero at each

period. Finally, it needs to sum up all the messages in the network in each period.

```
The following command lines set the update interval and find out
the locations of users in each cell with respect to the cell center
at every update interval.

pt=1;        % Update interval
Rf=233;      % Two-third cell edge
if rem(t,pt)==0
    Npuo1=0; Npuo2=0; Npuo3=0; Npuo4=0; Npuo5=0; Npuo6=0;Npuo7=0;
    Npuoi1=0;Npuoi2=0;Npuoi3=0;Npuoi4=0;Npuoi5=0;Npuoi6=0;Npuoi7=0;

    Npus11=0; Npus12=0; Npus13=0; Npusi11=0; Npusi12=0; Npusi13=0;
    Npus21=0; Npus22=0; Npus23=0; Npusi21=0; Npusi22=0; Npusi23=0;
    Npus31=0; Npus32=0; Npus33=0; Npusi31=0; Npusi32=0; Npusi33=0;
    Npus41=0; Npus42=0; Npus43=0; Npusi41=0; Npusi42=0; Npusi43=0;
    Npus51=0; Npus52=0; Npus53=0; Npusi51=0; Npusi52=0; Npusi53=0;
    Npus61=0; Npus62=0; Npus63=0; Npusi61=0; Npusi62=0; Npusi63=0;
    Npus71=0; Npus72=0; Npus73=0; Npusi71=0; Npusi72=0; Npusi73=0;

    ...

    ...

    ...

    Npuoo(t)= Npuo1+Npuo2+Npuo3+Npuo4+Npuo5+Npuo6+Npuo7;
    Npuss(t)= Npus11+Npus12+Npus13+Npus21+Npus22+Npus23+Npus31
             +Npus32+Npus33+Npus41+Npus42+Npus43+Npus51
             +Npus52+Npus53+Npus61+Npus62+Npus63
             +Npus71+Npus72+Npus73;
end
```