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碩 士 論 文

針對無線區域網路探討快速換手的機制

A Fast Handoff Scheme for Wireless LANs

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摘　要

爾來台灣廠商致力推動無線區域網路(WLAN)，使得無線區域網路的建置更加地普及，例如在機場、校園或是大型的購物中心等，均已建構無線區域網路。再者由於手持裝置的盛行，例如：個人數位助理、筆記型電腦以及平板電腦，使得使用者可以在移動中存取網路，而不再是局限在固定位置。並且隨著即時性的多媒體應用程式的快步增加，若要維持移動過程中連線的高品質，在無線存取點之間的換手機制必需要快速地進行。在本篇論文中，我們提出了一個以預測方式(forecasting scheme)為核心概念的方法，將其運用在無線區域網路上來達到快速換手的目的，這個方法主要的概念是根據使用者過去的行徑記錄。同時我們利用數學模式來描述使用者的移動行為。最後，由模擬結果更佐證了我們所提出的方法，在不同的移動模式下能夠減少換手程序的延遲時間進而達到快速換手的目標。

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Abstract

Over the last several years, wireless local area network (WLAN) has evolved rapidly in hot spot regions such as hotels, airports, campus, and shopping malls. With the popularity of portable devices, user mobility is tendency in the future. However, real-time multimedia applications need fast handoff mechanism especially when user is moving in order to maintain the quality of service. If the latency of handoff is long, the users of real-time multimedia applications will have excessive jitter. In this thesis, we propose a fast handoff method by using forecasting scheme. The concept of forecasting scheme is predicting the mobile station's next location based on mobile station's movement history. We also formulate a mobility model to describe the mobile station's moving behavior. The simulation results show that our approach can minimize the reassociation delay to accomplish fast handoff and achieve the requirement of real-time multimedia applications.

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Chapter 1

Introduction

Over the passed several years, wireless local area network (WLAN) has evolved rapidly. Because of their low cost and unregulated bandwidth, WLAN communication system has deployed over many hot spot regions such as hotels, airports, campus, shopping malls, and so on. Besides, with the popularity of portable devices, mobility computing is a tendency in the future.

In any time instance, a mobile station can only associate with a single AP. A mobile station might associate to another AP (Access Point) by considering mobility or signal strength quality. This process is referred to as a handoff. Today, the demanding of real-time multimedia applications become more and more popular so handoff between APs must be fast enough to keep the criteria of high quality of service. Fast handoff approach can be applied to shopping mall environment. For example, when a human stand in electric appliances area of shopping malls and executes the real-time application like Voice over IP (VoIP). When he leaves that area to another one, we can know where he will go and reserve the resource beforehand.

The protocol about inter-AP handoff, Inter-Access Point Protocol (IAPP) [1] is proposed to specify the rule about exchanging context of mobile station which is the session of mobile station and QoS related state information defined in other 802.11 standards between APs. In one word, it is used to perform context transfer during handoff.

Handoff procedure can be split into three phases: detection phase, search phase and execution phase. The probe delay is time spent by the mobile station to scan the next AP. After scanning operation, AP spends a period of time to authenticated mobile station. This is the time called authentication delay. And the latency occurred by reassociation procedure is called reassociation delay. Generally, the handoff time is about 1920ms different wireless card will have different value [2].

There are two approaches to accomplish the purpose of fast handoff. The first one is Pre-authenticated fast handoff [3, 4]. When a mobile station performs the authentication processes, its authenticating information will send not only to the currently AP, but also to other APs which are possible to be authenticated in the future. These APs are selected by the Frequent Handoff Region (FHR) selecting algorithm. But this method needs the authentication server to forward the key information to other APs selected by FHR and must train the motion of mobile station to know which place we have the most frequency to be. The other approach is proactive-caching strategy [5] which brings up the data structure, the neighbor graphs, to capture the user mobility topology dynamically. It helps to pre-place the context of mobile station at the next APs to ensuring that the context of mobile station has stored at one hop ahead. However this method causes so much traffic and consumes too memories of AP to cache data.

So, to short the handoff delay, most of the existing approaches are devoted to decrease the probe delay [2, 8] or authentication delay [3, 4], but we focus on reducing the reassociation delay to accomplish the fast handoff. In this thesis we propose a forecasting scheme to achieve the fast handoff. The concept of forecasting scheme is predicting the next location of mobile station based on moving history of mobile station. In order to decrease replicating number of contexts cached in the APs, the context is just transferred to only one possible AP or the adjoin neighbor APs. By avoiding transferring context to entire neighbor APs, we can have higher utility on cache of AP.

In the next chapter, we will give the related researches and background knowledge. And in Chapter 3, two useful models are given to predict the direction and moving distance of mobile station, our forecasting scheme which uses these two models for predicting is also describe in this chapter. In chapter 4 we describe our simulation models and give the simulation results comparing between our approach and pro-active caching one. Finally, we give a conclusion and our future work are given in Chapter 5.

Chapter 2

Relative Background Knowledge

First of all, we have an overview of handoff procedure and the Inter-Access Point Protocol (IAPP) [1]. Then we describe two existing systems for fast handoff, predictive authentication method [3, 4] and proactive caching strategy [5]. In the following sections, we will describe these methods one by one.

2.1 IEEE 802.11 Handoffs

A mobile station can associate with a single AP at a time. When mobile station moves and associates from the current-AP to a new one, the reassociation procedure is occurred. Considering the radio media, the reassociation procedure is the same as the association. But in the backbone network, APs may communication with each other via IAPP. Figure 2.1 shows the illustration of the reassociation procedure.

The mobile station can receive the signal strength from all the APs in the same Extended Service Set (ESS). When the mobile station detects the signal strength of another AP is better than current one, and then handoff procedure takes place.

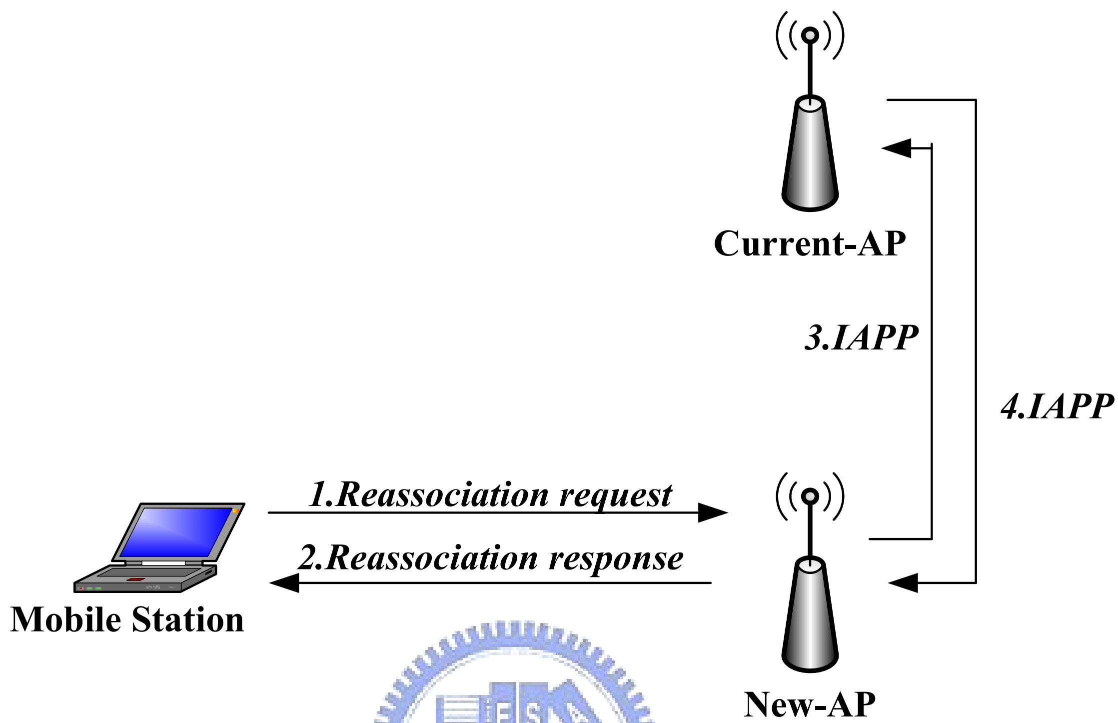


Figure 2.1: Reassociation procedure.

The handoff procedure can split into three sequential phases: detection phase, search phase and execution phase. The detection phase is to find the criteria of handoff. It happens at the time when the signal quality is not satisfied by mobile station. The search phase is choosing which AP to reassociate. The method to choose AP can use either the active scan (sending the probe request messages automatically) or the passive scan (listening the beacon messages which broadcasted by APs). Then a mobile station selects one suitable AP product-dependently (or we say based on hardware vendor designed), such as the best signal strength or another reason. Finally, the reassociation is performed is the execution phase. Figure 2.2 shows the illustration of those three phases during handoff procedure.

In the Figure 2.2, we use dash-line rectangles to represent the three phases. The handoff delay is the time used to deal with handoff. The probe delay is time that mobile station spends in scanning the next AP. After the probing operation, the authentication frame will be exchanged between mobile station and new-AP, and we call this duration as authentication delay. Once the mobile station has authenticated, new-AP and old-AP will exchange messages following the rules of IAPP, and this latency is reassociation delay. By considering the handoff procedure, most of existing approaches focus on reducing the probe delay [2, 8] or authentication delay [3, 4], but the key point of our approach is to minimize the reassociation delay to meet the goal of fast handoff.

2.2 Inter-Access Point Protocol (IAPP)

Inter Access-Point Protocol (IAPP) [1] is designed for the enforcement of unique association in a ESS and for secure exchange of the context of mobile station between current-AP and new-AP. The context contains the session of mobile station and QoS related state information defined in other 802.11 standards. This protocol allows all APs of the Distribution System (DS) interacting with each other, and using Transmission Control Protocol (TCP) over IP or User Datagram Protocol (UDP) over IP to clutch IAPP messages between APs. Based on security level, communication session keys between APs are distributed by a Remote Authentication Dial-In User Service (RADIUS) server.

In order to achieve fast handoff, we will using these messages, *Add-Notify*, *Move-Notify* , and *Cache-Notify*. When the mobile station associates to an AP, that AP broadcasts the *Add-Notify* message to other APs in the same ESS and sends a *Layer2 update frame* to the DS to update its forwarding table. Upon receiving *Add-Notify* message, these APs update association table. When the mobile station reassociates to the new-AP, that AP sends the *Move-Notify* message and requests the old-AP to exchange context of mobile station with him. After reassociating the new-AP, it sends the *Cache-Notify* message to its neighbor APs to store the context of mobile station at one hop ahead.

For the IAPP entity to function correctly, RADIUS server is used to obtain the security information and protect the communication between IAPP entities. And the RADIUS server also supports the address mapping between the MAC address and the IP address of the APs that is necessary for IAPP communication.

The send-security-block message is sent by using the IAPP over TCP/IP. This message is sent from the new-AP to the old-AP which mobile station was previously associated. The reason of using TCP is it supports the retransmission mechanism and the essential reliability on data exchanging.

2.3 Pre-authenticated Fast Handoff

This approach is based on a predictive authentication method. Since re-authentication during handoff procedure can introduce long handoff latency, and it will affect on the quality of service in real-time multimedia applications. This principal is when mobile station performs authentication procedures not only for the currently used AP, but also for multiple APs. These multiple APs are selected by the Frequent Handoff Region (FHR) selecting algorithm which is a centralized neighbor selection algorithm which we will discuss later.

The Frequent Handoff Region (FHR) is a set of adjacent APs. This algorithm requires three factors to determine: replacement of AP, movement pattern and its class of service. The FHR algorithm selects the APs which mobile station is likely to move to before long. The first step is designing a bi-directional graph of AP layout and each edge has a weight represented the handoff ratio. And it establishes an N by N weight matrix. (N denotes the number of APs)

The next step is to select frequent handoff region based on service class level of mobile station . If the value of service class level is high, the FHR algorithm will choose more neighbor APs for maintaining the quality of service. When the mobile station sends the *Authentication Request* to one authentication server, the authentication server sends the *Authentication Reply* to the mobile station and the neighbor APs selected by FHR.

Although the predictive authentication method accomplishes the fast handoff purpose, it has some drawbacks:

1. It requires more efforts to set up the authentication server which forwards the key information to other APs selected by FHR.

2. This method needs training the motion of mobile station to know which place or path is frequently used so that the weight matrix can be established.

3. The FHR scheme can not quickly capture the dynamic change of topology of APs.

2.4 Proactive-caching Strategy

The major principle of proactive-caching is storing up the context of mobile station to next APs to achieve fast handoff. The most part of this scheme is how to select the next APs. According to the description of authors, we are unable to predict the motion of mobile station. Therefore, they brings up a data structure, neighbor graphs, to take over the user mobility topology dynamically of a wireless LAN. It assists to pre-place the context of mobile station at the next APs in order to ensure that has stored at one hop ahead.

Support we have a motion path between two APs, i and j. If it is possible for a mobile station to perform a reassociation procedure between them, we say AP_i and AP_j are neighbors. Furthermore, an edge link two vertices in AP neighbor graph represents the existing reassociation relationship between them. The neighbors APs in the neighbor graph represent the next APs.

When the mobile station reassociates to new-AP, it will send the *Cache-Notify* which carry the context of mobile station to the all neighbor APs. And they put the context into the cache. Once the mobile station moves next time, its context has already stored at the new-AP. So the context does not exchange during reassociation procedure and it will help to minimize the reassociation delay.

Although the proactive-caching strategy accomplishes the fast handoff purpose, it has some drawbacks:

1. It causes much traffic in the network while forwarding the context of mobile station to the entire neighbor APs.

2. It consumes too much cache space of AP

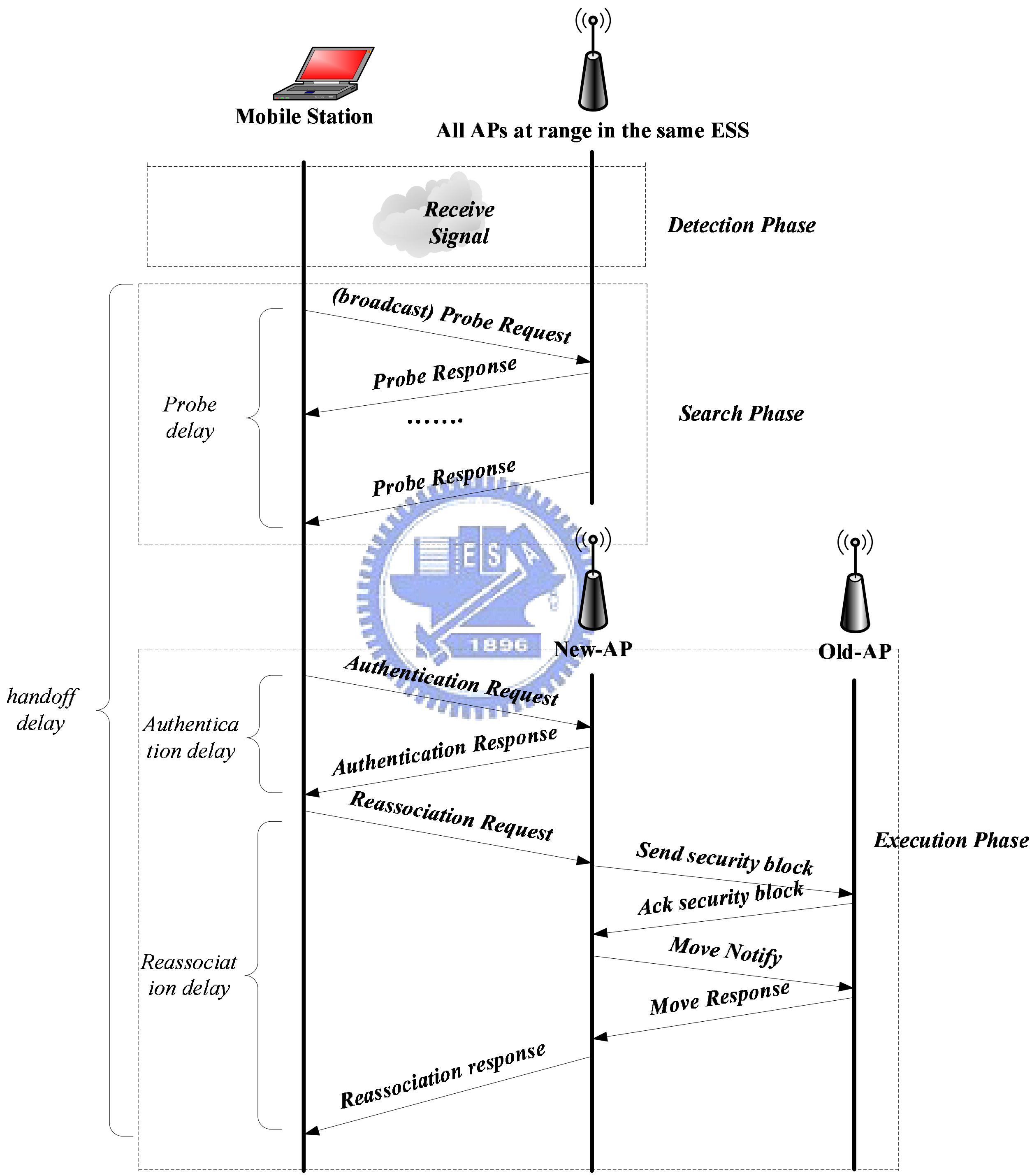


Figure 2.2: Three phases of handoff procedure.

Chapter 3

Proposed Forecasting Scheme for Fast Handoff

Before discussing the theoretical issues about the fast handoff technique, we describe some useful models. The important parts of this section are forecasting model and directional model. We propose some approaches to raise the hit ratio of cache and to decrease the traffic and cache expense of APs.

3.1 Forecasting Model

The first thing, we need to know is the human's step distance of each movement is limited and is not variant too much. Therefore, we utilize the horizontal models [9] to model the step distance. Figure 3.1 shows the illustration of the horizontal models for human's step distance. At every time slot has the demand average value which is step distance in this paper.

The forecasting method for horizontal models is moving average model [9]. The moving average model is using the demand average values of the last N time slots as the forecasting value in the future. We define that M_T is moving average

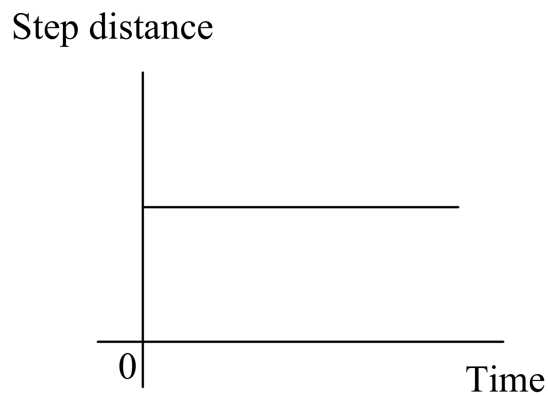


Figure 3.1: A The horizontal models for human's step distance.

value at time T as prediction value by the following equation (3.1)

$$M_T = \frac{x_{T-N+1} + \ldots + x_{T-1} + x_T}{N} \tag{3.1}$$

x_T is the demand average value at T and N is a predefined constant. The forecasting value at τ^{th} time slot in the future denotes $\hat{x}_T(\tau) = M_T$.

If T is larger than N, we can simplify equation 3.1 to

$$M_T = M_{T-1} + \frac{x_T - x_{T-N}}{N} \tag{3.2}$$

If T is smaller than N, then

$$M_T = \frac{x_1 + x_2 + \ldots + x_T}{T} \tag{3.3}$$

In the moving average model, a variable N will affect the accuracy of forecast result. The expected value of forecasting error, $e_{(x)} = x_{T+x} - \hat{x}_T(x)$, is equal to zero while N becomes more and more large, the standard deviation,$\sigma_{e(x)}$, is toward to small value, as well as the forecasting result will be better.

The standard deviation is $\sigma_{e(x)} = \sqrt{\frac{N+1}{N}}\sigma$ where σ is the standard deviation of record. Table 3.1 shows the effect of the various Ns.

	N				
	4	5	6	7	8
Standard deviation	1.25σ	1.2σ	1.17σ	1.14σ	1.125σ

Table 3.1: The forecast result be affected by N.

In the Table 3.1, we can obtain the degree of accuracy between $N = 8$ and $N = 6$ is 3.8%. This indicates the error of forecasting reducing 3.8%.

We utilize a simple example to explain the moving average model. The positioning system helps us to get the location of mobile station. In this example, we compare the step distance which positioning system estimated and this distance which forecasting scheme computed. The result has some difference between actual situation and estimation of positioning system since the signal strength is not stability. It may be influenced by many factors, such as human moving, environment changing and so on.

Assume that human has one unit of step distance every time slot, the $N = 6$ and $\tau = 1$ represents a predicting step value of next time slot. Table 3.2 shows the results which one computed from following equations.

If $T < N$,

$$M_1 = \hat{x}_1(1) = \frac{x_1}{T} = \frac{1}{1} = 1$$

$$M_2 = \hat{x}_2(1) = \frac{x_1 + x_2}{T} = \frac{1+2}{2} = 1.5$$

and so on.

If $T > N$,

$$M_6 = \hat{x}_6(1) = \frac{x_1 + x_2 + x_3 + x_4 + x_5 + x_6}{N} = \frac{1+2+1+0+2+2}{6} = 1.33$$

$$M_7 = \hat{x}_7(1) = M_{T-1} + \frac{x_T - x_{T-N}}{N} = M_6 + \frac{x_7 - x_1}{6} = 1.33 + \frac{1-1}{6} = 1.33$$

$$M_8 = \hat{x}_8(1) = M_{T-1} + \frac{x_T - x_{T-N}}{N} = M_7 + \frac{x_8 - x_2}{6} = 1.33 + \frac{2-2}{6} = 1.33$$

and so on and then

$$M_{10} = \hat{x}_{10}(1) = M_{T-1} + \frac{x_T - x_{T-N}}{N} = M_9 + \frac{x_{10} - x_4}{6} = 1.17 + \frac{2}{6} = 1.5$$

Time	Positioning system		Moving average ($\hat{x}_T(1) = M_T$)
	Location	Step distance (x_T)	
1	4		
2	3	1	1
3	5	2	1.5
4	6	1	1.33
5	6	0	1
6	8	2	1.2
7	10	2	1.33
8	9	1	1.33
9	11	2	1.33
10	11	0	1.17
11	13	2	1.5

Table 3.2: The list of step distance.

Therefore, the moving average model predicts the location of mobile station make location tracking smoother. The moving average model cooperates to select which one is closer to the previous location and eliminates the step distance error and makes the human trajectory smoother. The Figure 3.2 shows the line chart of step distance comparing with positioning system and moving average model. We can find that the moving average model tends towards the actual step distance.

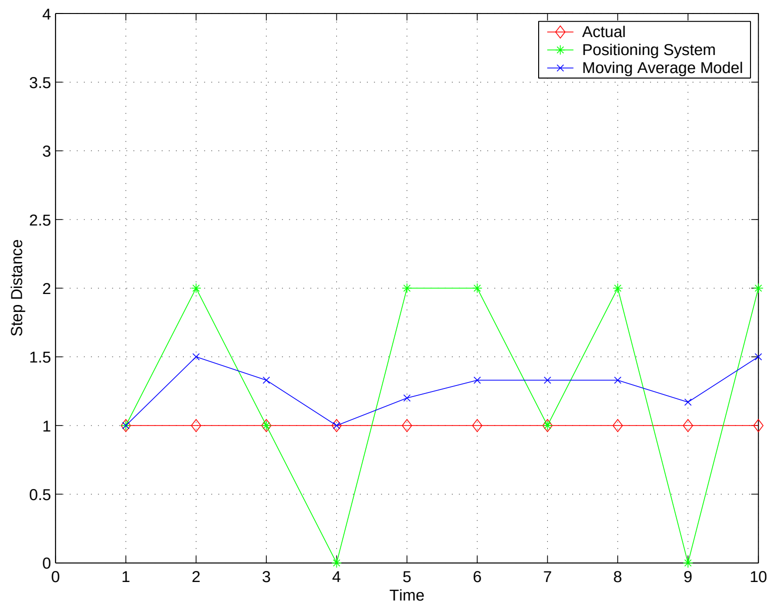


Figure 3.2: The line chart of steps distance comparison.

We can predict the next location of mobile station and pre-place the context of mobile station to the next APs. After then, the context of mobile station can store at one hop neighbor so that we can have the benefit of fast handoff.

3.2 Movement Pattern

We define a movement pattern to record the movement history of mobile station within T_n, where n is the number of movement record. The P_n denotes the movement pattern, $P_n = \{p_1, p_2, .., p_n\}$,$i \in n$, where $p_i = (d_i, l_i)$ at T_i, d_i is representing a moving direction and l_i is representing a location coordinate as (x, y). $d_i \in \{north, northeast, east, southeast, south, southwest, west, northwest\}$.

3.3 Directional Model

The direction model [6] is characterized by the following features:

1. At one trip, the mobile station will have some favor on some particular direction.

2. If the mobile station discontinues the currently favor direction, it will uniformly take another one of the directions.

Assume the time domain is discrete. Let m be the probability that a mobile station moves, $1-m$ be the probability of remains at the same location.We define the directionality parameter, a, to represent the favor direction in user mobility and directional quantity to represent the quantity of moving direction except favor direction denotes q. With reference to Figure 3.3, let $\frac{ma}{q+a}$ be the probability of moving in the favor direction, example of here the favor direction is north and in our environment the q is equal to 7, so its probability is $\frac{ma}{7+a}$. Let $\frac{m}{q+a}$ be the probability of moving in one of the other directions, so their probability are $\frac{m}{7+a}$. Therefore, total probability of eight directions is equal to m. If the next moving direction of mobile station is the same as the previous one, value of a will increase gradually. At the start time or while mobile station changing its direction, the value of a reset to 1.

3.4 Neighbor Graphs

Refering to the novel and efficient data structure, the neighbor graphs, which captures the user mobility topology dynamically of a wireless LAN [5]. It assists

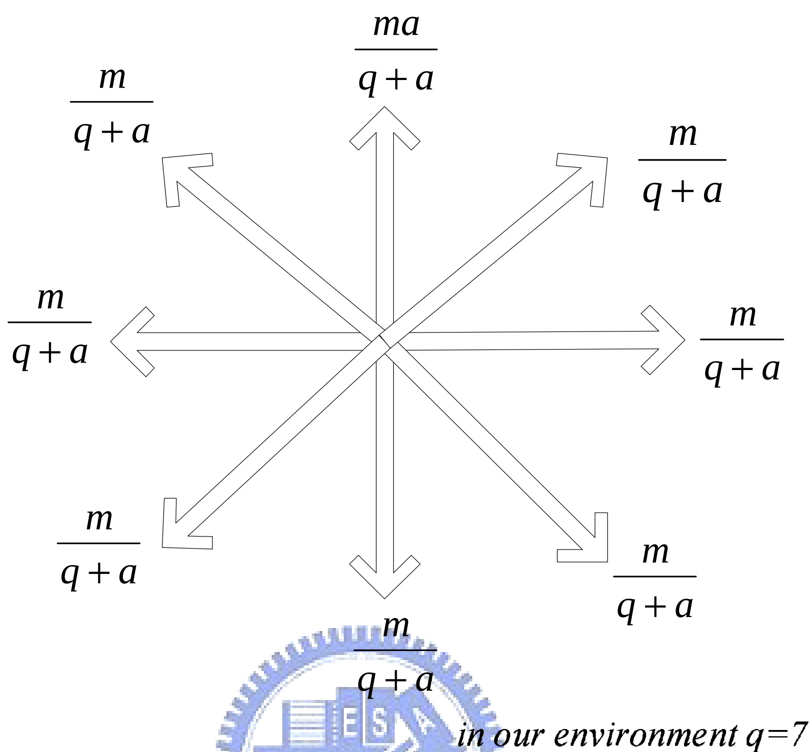


Figure 3.3: Directional model.

to pre-place the context of mobile station at the next APs to ensure the context has stored at one hop ahead. A neighbor graph is an undirected graph with edge representing a mobility path between vertices.

The neighbor graph captures the reassociation relationship within APs. For example, a moving path that a mobile station is possible to perform the reassociation procedure between two APs, denotes AP_i and AP_j, we can say they are neighbors. Furthermore, the two vertices linked together with an edge in the AP neighbor graph. The neighbors of certain AP are the set of the next APs which the mobile station will reassociate in the next moving. Figure 3.4 shows the illustration of the AP placement (a) and the homologous neighbor graph (b). The dash line represents the motion of mobile station and the point represents AP.

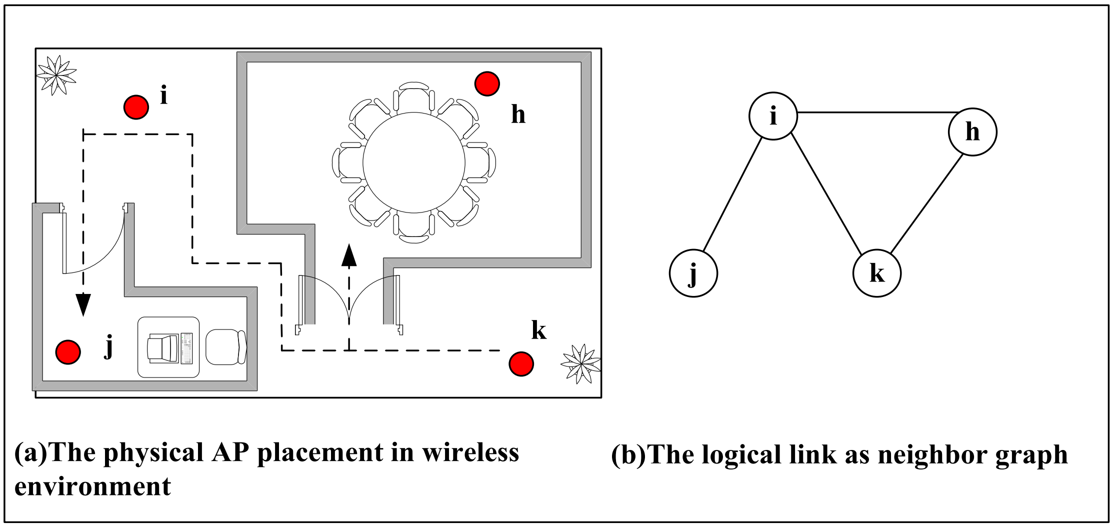
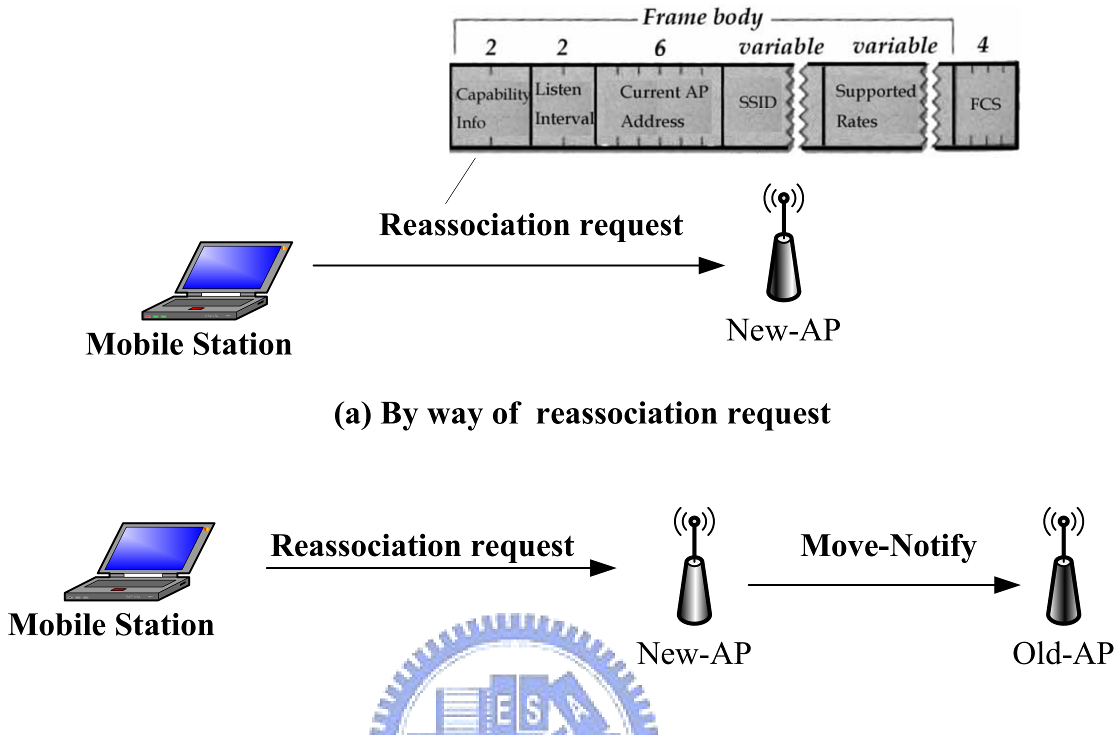


Figure 3.4: The AP placement and the homologous neighbor graph.

The reassociation relationship depends on the depolyment of APs, signal strength and other environment topological elements. But the major reason is the physical distance between APs.

We translate the topology as a undirected graph $G = \{V, E\}$ where V is the set of APs, denotes $\{AP_1, AP_2, \ldots, AP_n\}$ and the E is representing two APs have reassociation relationship. The set of all neighbors of AP_i in G denotes as $Neighbor(AP_i) = \{AP_k \in V, (AP_i, AP_k) \in E\}$.

Each AP maintains the individual neighbor graph. The method of establishing the neighbor graph has two ways: first, we use 802.11 reassociation request packet. Since the 802.11 reassociation request packet contains the BSSID of current-AP representing as Figure 3.5(a). Second, an AP receives the Move-Notify message from new-AP via IAPP representing as Figure 3.5(b), and then adds the new-AP to the list of neighbors.



(a) By way of reassociation request

(b) By way of Move-Notify

Figure 3.5: The manners of establishment neighbor graph.

3.5 Forecasting Scheme for Fast Handoff

The major principle of forecasting scheme for fast handoff is predicting the next location of mobile station and calculating the probability that station will handoff to the neighbor APs.

The concept of forecasting scheme has two steps. The first step is using the movement history of mobile station to predict the next location, and mark it in corresponding to the neighbor graph. The length of edge between vertices is proportion of physical AP distance. Figure 3.6 shows the illustration of the predicting potential location.

Assuming the initial location of mobile station is L_1 and has associated to

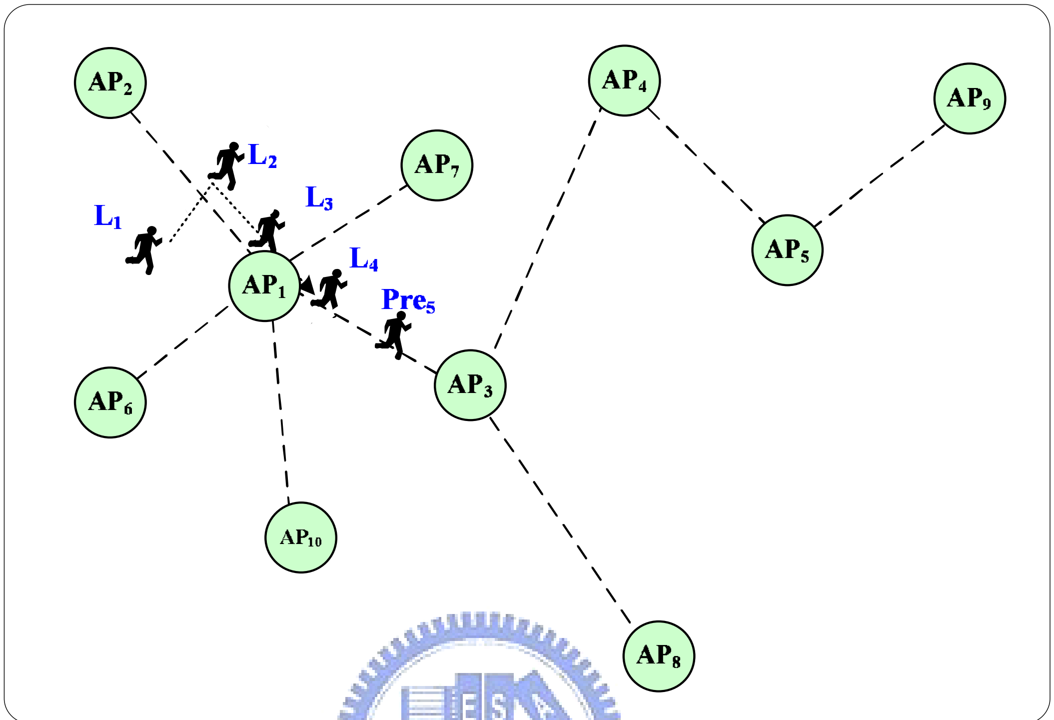


Figure 3.6: An illustration of the predicting next location.

AP_1. It is continuous moving through L_2, L_3 to L_4. When the mobile station lies in L_4, according to directional model, the probability of southeast direction is $\frac{m(a+1)}{7+(a+1)}$. Assume the distance is unit of step, we obtain from L_1 to L_2 is 1.5 steps, L_2 to L_3 is 2 steps, L_3 to L_4 is 1 step. Based on moving average model (assume $N = 6$), since $T < N$ (in this example $T = 3$), the estimation of next distance is $\frac{1.5+2+1}{3} = 1.5$, so the next location is $L_4 + 1.5$ steps where Pre_5 is.

The second step is calculating the probability of handoff to the neighbor APs. The main point of this method is comparing the distance from mobile station to neighbor APs and directional model. At first, as prediction location is the center of a circle, and drawing the circle until cover the entire neighbor APs of current-AP and the radius of circle is an arithmetic progression. Second, every neighbor AP has assigned an area probability. The assignment rule is $\frac{num-level+1}{num}$, where num is the total number of circle, and $level$ is layer of circle. The level of inner circle is equal to 1 and increase progressively to the outer circle i.e., the AP that closer mobile station has higher area probability. Figure 3.7 shows the illustration of the area probability of neighbor APs. There are four circles, and the level is from 1 to 4.

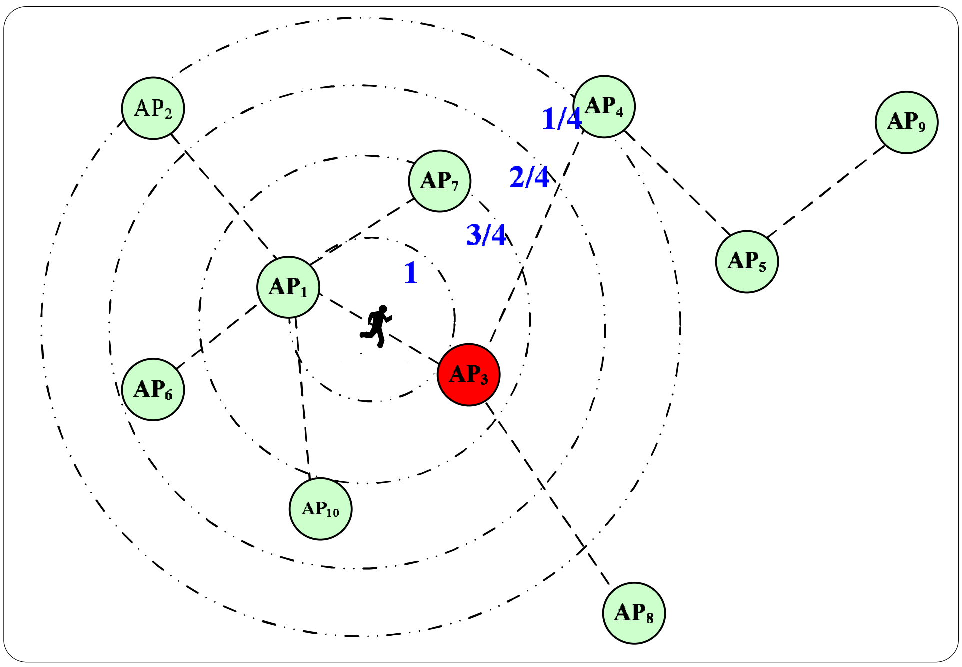


Figure 3.7: The illustration of the area probability of neighbor APs.

As discussed in previous section, we can calculate the probability of handoff to the neighbor APs by using the directional probability and the area probability of AP, we denotes as $P_{(location,AP_i)}$.

$$P_{(Pre_5,AP_2)} = \frac{1}{4} * \frac{m}{7+(a+1)}$$

$$P_{(Pre_5,AP_3)} = \frac{3}{4} * \frac{m(a+1)}{7+(a+1)}$$

$$P_{(Pre_5,AP_6)} = \frac{2}{4} * \frac{m}{7+(a+1)}$$

$$P_{(Pre_5,AP_7)} = \frac{3}{4} * \frac{m}{7+(a+1)}$$

$$P_{(Pre_5,AP_{10})} = \frac{2}{4} * \frac{m}{7+(a+1)}$$

The AP with maximum probability is the next one to which mobile station will handoff in the next moving. Above example, shows that the probability of AP_3 is maximum, and we forward the context of mobile station to it. We call the AP which has context is a candidate AP.

3.6 Forecasting Compensation

Forecasting scheme described in the perfection situation is suffice for the purpose of fast handoff. But if mobile station changes moving direction unexpectedly, forecasting scheme is not suggested. According to a principle from [7], "There should be a destination for the trip. So there will be a tendency in the roaming direction of mobile station". If we want to reduce the error of forecasting, we could increase the candidate APs. Therefore, we assign a priority value to every direction and forward the context to them based on this priority. The priority of direction of prediction location is the highest, and the priority of near adjacent direction is second sequence. The opposite direction is the lowest because the mobile station had passed through. Figure 3.8 shows the illustration of the priority assignment.

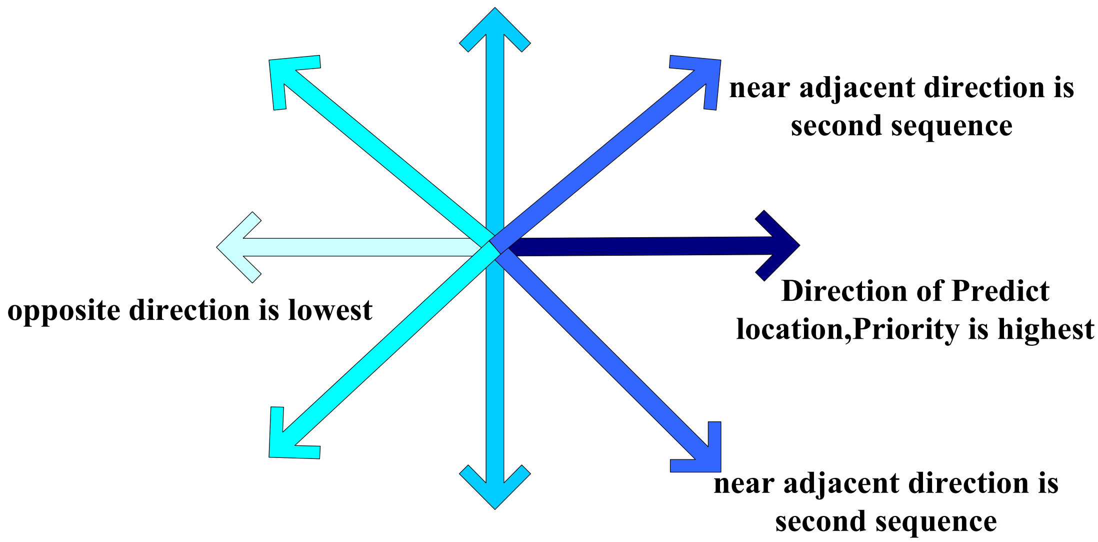


Figure 3.8: Priority assignment.

We propose a compensation method to redeem the error of forecasting. This method not only forwards context to the AP that has maximum probability, but also forwards to the adjacent neighbor APs. Depend on priority of neighbor APs, if mobility of mobile station is quite randomly and we can increase the candidate APs based on priority. In general, we just choose the second sequence, i.e., adjacent APs. Above the last example, except for AP_3, we also forward the context of mobile station to AP_7 and AP_{10} at the same time. Figure 3.9 shows the illustration of the choosing adjacent neighbor APs.

3.7 Characterizing the Cache Misses

Since reassociation relationships are captured in the neighbor graph, and context of mobile station is forwarding to the next AP. With the ideal case, we could expect a 100 percent cache hit ratio for the reassociation procedure, if the

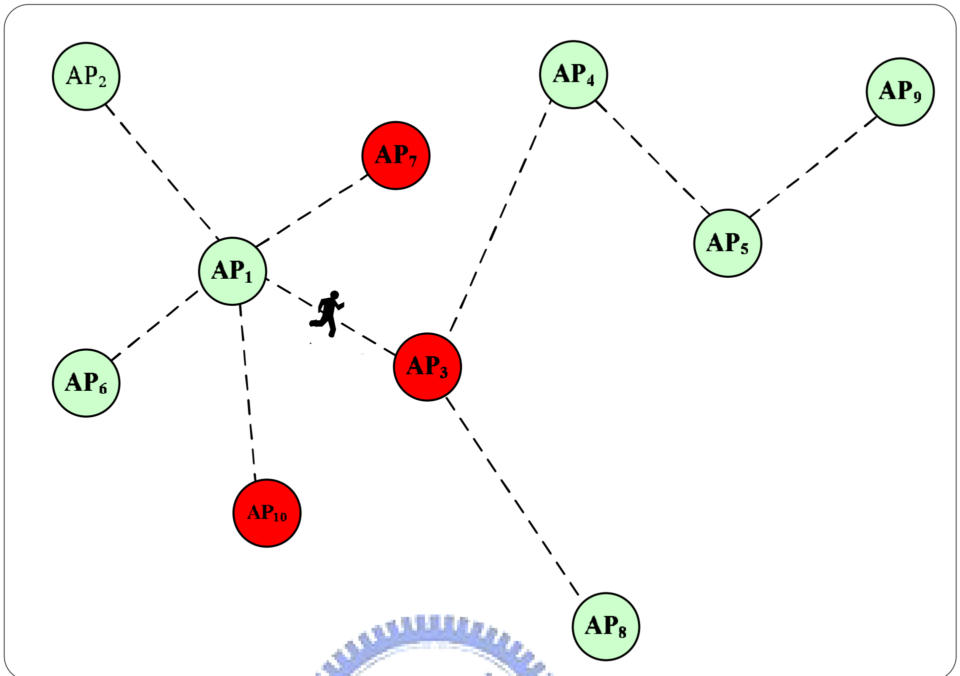


Figure 3.9: An illustration of forecasting scheme compensation.

cache size is unlimited and trajectory of mobile station is predicted by us. Once the cache hit occurs, it means the handoff delay does not exist because new-AP and old-AP do not have to exchange more messages.

The following assumption brings us three kinds of cache misses during a reassociation procedure:

1)Handoff to non-neighbor APs:

At the initial state, the neighbor graph of handoff has not established, so, any reassociation will suffer a cache miss. Suppose a reassociation procedure occurs within two APs, if these two APs do not connect in the neighbor graphs have a cache miss. After then, the neighbor graph will add the reassociation relationship of these two APs.

2)Context of mobile station dispossessed by LRU replacement:

The cache space of AP is limited and the LRU (Least Recently Used) replacement method is used to manage the cache. So, if the cache is full and a new context has to insert, the previously stored contexts of others will be dispossessed by this AP. If the context of mobile station is dispossessed by new-AP for the lacking of cache space, a reassociating action will lead to cache miss. If the number of mobile stations is too many, this phenomenon will occur frequently. And we investigate in the simulation session; this factor will affect the cache hit ratio.

3)The prediction result is faults:

If the mobile station changes movement direction frequently, the directional model will not suit for this situation. To conqure this problem, another approach called forecasting compensation, is given to reduce the probability of this factor.

3.8 Example of Practice

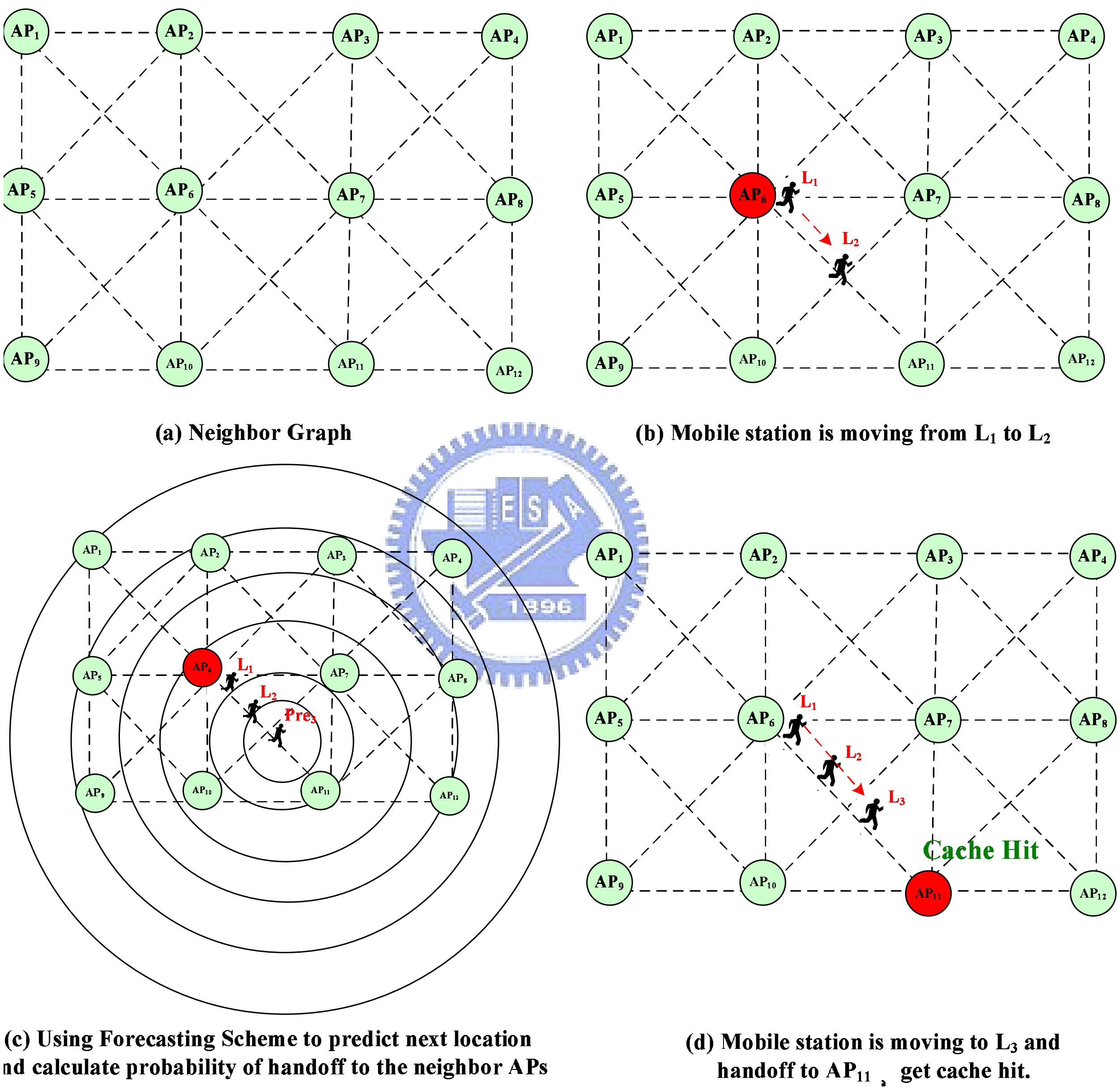
Figure 3.10 shows the example of practice of cache hit. Initially, we assume the neighbor graph is 4 by 3 grids. At beginning, the mobile station lies in L_1 and has associated to AP_6, shown as Figure 3.10(a), the dash lines present the possible reassociation relationship between APs. After time passing, the mobile station is moving to L_2, shown as Figure 3.10(b). At this moment, forecasting scheme is used to predict the next location, and the result is Pre_3, shown as Figure 3.10(c). In the example, the directionality parameter, a, is equal to 1, and the probability of every direction is $\frac{m}{7+a}$. The probability of handoff to the neighbor APs, $P_{(Pre_3,AP_i)}$, is list following:

AP	$P_{(Pre_3,AP)}$	AP	$P_{(Pre_3,AP)}$
AP_1	$\frac{1}{6} * \frac{m}{7+a}$	AP_7	$\frac{4}{6} * \frac{m}{7+a}$
AP_2	$\frac{2}{6} * \frac{m}{7+a}$	AP_9	$\frac{2}{6} * \frac{m}{7+a}$
AP_3	$\frac{2}{6} * \frac{m}{7+a}$	AP_{10}	$\frac{4}{6} * \frac{m}{7+a}$
AP_5	$\frac{2}{6} * \frac{m}{7+a}$	AP_{11}	$\frac{5}{6} * \frac{ma}{7+a}$

Table 3.3: The probability of handoff to the neighbor APs.

According to Table 3.3, the current-AP forwards the context of mobile station to AP_{11} because it has maximum probability. If the mobile station is moving to L_3 in the next time, shown as Figure 3.10(d), and then we have the cache hit.

Figure 3.11 shows the example of cache miss. The conditions (as neighbor graph, mobile station is moving from L_1 to L_2) are the same as the cache hit assumption, and current-AP forwards the context of mobile station to the AP_{11}. But if mobile station changes direction suddenly and locate on L_3 in the next time, and then we get the cache miss. If we employ the compensation scheme forwarding context, the context will be forwarded not only to AP_{11}, but also both to AP_7 and AP_{10}, we should get the cache hit.



(a) Neighbor Graph

(b) Mobile station is moving from L_1 to L_2

(c) Using Forecasting Scheme to predict next location nd calculate probability of handoff to the neighbor APs

(d) Mobile station is moving to L_3 and handoff to AP_{11} , get cache hit.

Figure 3.10: The example of practice of cache hit.

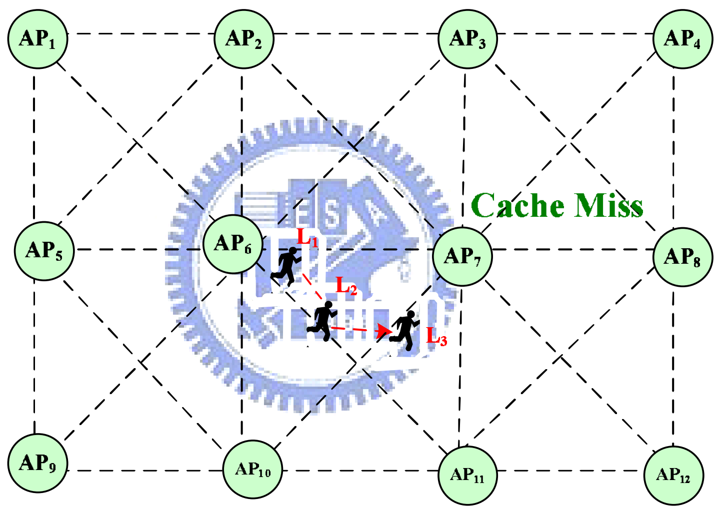


Figure 3.11: The example of practice of cache miss.

Chapter 4

Analysis and Simulation Results

Because of the different purpose of products,memory resource of APs are variant. If the AP acts as a pure bridge or gateway, its cache size is usually 1MB to 2MB. The reason is manufactures the factor of wish to lower their products cost. While AP acts as a router, its cache size is usually larger than the former, and size is about 4MB to 8MB. The AP can only buffer limited contexts of mobile station in its cache. Hence, we use the LRU (least recently used) replacement method to manage the cache capacity.

In this chapter, we describe the simulation model and assumptions in the first section, and present the simulation results to demonstrate the performance of forecasting scheme and compare with proactive-caching in second one.

4.1 Simulation Model

Before describing our simulation, we give the simulation model and some basic assumptions:

1)AP deployment:

The AP deployment must be designed at the large-scale wireless LAN environment, so that the whole target space has radio coverage (i.e., no coverage gaps) and the assignment of APs as far apart to minimize overlap [10]. We suppose our testbed at a single-floor and building layout is an array pattern that either linear (as a corridor) or rectangular (as an airport and a mass shopping mall). An example of AP deployment in a single-floor is shown in Figure 4.1, (a) is representing the AP deployment for linear array and (b) is example for rectangular array.

2)Neighbor graph shape:

As discussed earlier, the AP deployment has two kinds manners based on building layout. Coordinating the neighbor graph also has two classes shown in Figure 4.2. First class is operating for linear array represent in Figure 4.2(a) and the second class for rectangular array is shown in Figure 4.2(b). The dash lines present the reassociation relationship between APs. Here we assume that neighbor graph does not change after APs are deployed.

3)User mobility model:

Three mobility models are need to examine our scheme. They are normal walk [11], random walk and random direction mobility model [12]. In order to imitate the actually moving behavior of human, we specify a normal walk mobility model. In random walk mobility model, the moving direction during continuous moving is independent to its historical moving this makes random walk mobility model un-match the reality of moving. In contrast, the moving direction of continuous moving in normal walk mobility model is supposed to be high dependent to the historical moving direction.

Assume the mobile station moves in unit steps on a Euclidean plane. Let Y_i denote the moving direction of step i. Let Z_n denote the coordinate of the mobile station after n^{th} movement; initially we set $Z_0 = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$,and $Y_0 = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$. Then $Z_n = \sum_{i=1}^{n} \begin{pmatrix} \cos(\sum_{j=1}^{i} \Theta_j) \\ \sin(\sum_{j=1}^{i} \Theta_j) \end{pmatrix}$.

The probability distribution of Θ depends on individual behavior. If the movement is either one dimensional with two reverse directions, e.g., 0 and Π, or two dimensional with eight directions, i.e., $\Theta = 0, \pm\frac{\Pi}{4}, \pm\frac{\Pi}{2}, \pm\frac{3\Pi}{4}, \Pi$, and this model is two dimensional. For our neighbor graphs framework, the one dimensional is applying to linear array, and the two dimensional is applying to rectangular array.

The random walk mobility model is erratic movement that the moving of mobile station is unpredictable and it is a memoryless mobility pattern because it has no knowledge about the past direction and speed.

In normal walk and random walk mobility model, when mobile station reaches the boundary of simulation area, it continuously travels and reappears on the opposite side of the simulation area.

In random direction model, instead of moving for some period of time, each mobile station moves until it reaches the boundary of the simulation area. When it meets this boundary, it will reflected back into the simulation area in the direction of either $-\Theta$, if it is on a vertical edge, or $(\Pi - \Theta)$, if it is on a horizontal edge.

4.2 Simulation Result

In this section we present the results that the forecasting scheme performs under difference factors. We observe the effect of cache size, the number of users and mobility model on the cache hit ratio in forecasting scheme and forecasting compensation. Once the cache hit occurs, it means the handoff delay does not exist because new-AP and old-AP do not have to exchange more messages. Furthermore

	Cache Size					
	25	30	35	40	45	50
Proactive Caching	24%	32%	35%	39%	46%	51%
Forecasting Scheme	49%	54%	58%	63%	63%	64%
Forecasting Scheme Compensation	56%	60%	62%	70%	77%	82%

Table 4.1: The effect of cache size compare with three approaches.

we compare the performance of proactive-caching with our approach.

Assume the neighbor graph has established for rectangular and linear array, and initial location of mobile station is assigned randomly, keeping the user mobility steps is 200 and the neighbor graph the same has 100 vertices.

1)Effect of cache size on hit ratio:

Figure 4.3 and Table 4.1 show the hit ratio with different in three approaches. If normal walk mobility model is used, 200 users are assumed to be in a rectangular array. Obviously, an increasing the cache size directly impacts on the cache hit ratio and performance of proactive-caching is the worst.

Figure 4.4 shows the hit ratio with different in forecasting scheme and proactive-caching. By using normal walk mobility model is used, users' number is also assumed to be 200 in the linear array of neighbor graph. At this layout, the result of prediction is almost correct under those constrain, but the cache size obstruct the cache hit ratio. The forecasting scheme is still better than proactive-caching.

Figure 4.5 shows the relation between hit ratio and cache size of AP. Cache size of AP is defined as percentage of the number of mobile station's context that

AP can buffer. Two schemes, forecasting compensation and proactive-caching, are compared in this figure. The data points were taken for the number of users varying from 200 to 500, the cache size as a percentage of the number of users. Hence a 20 percent cache size is sufficient for a hit ratio of 73 percent while a cache size of 25 percent gives a hit ratio of around 80 percent.

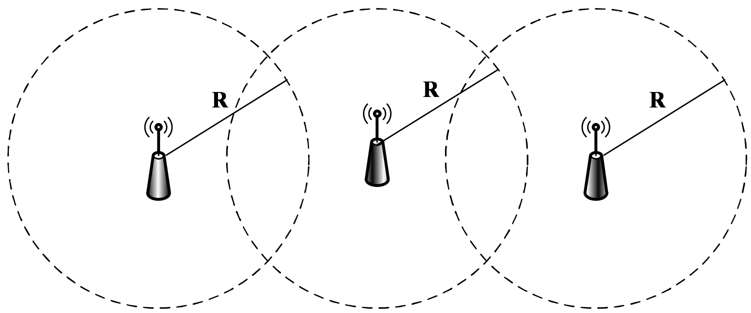
2)Effect of the number of users on hit ratio:

User number impacts on the performance directly. Figure 4.6 shows the inference of users' number on hit ratio in each of three approaches. And we can find that performance of proactive caching is the worst. Therefore, our forecasting scheme and forecasting compensation are more suitable than proactive-caching in great quantity of user condition.

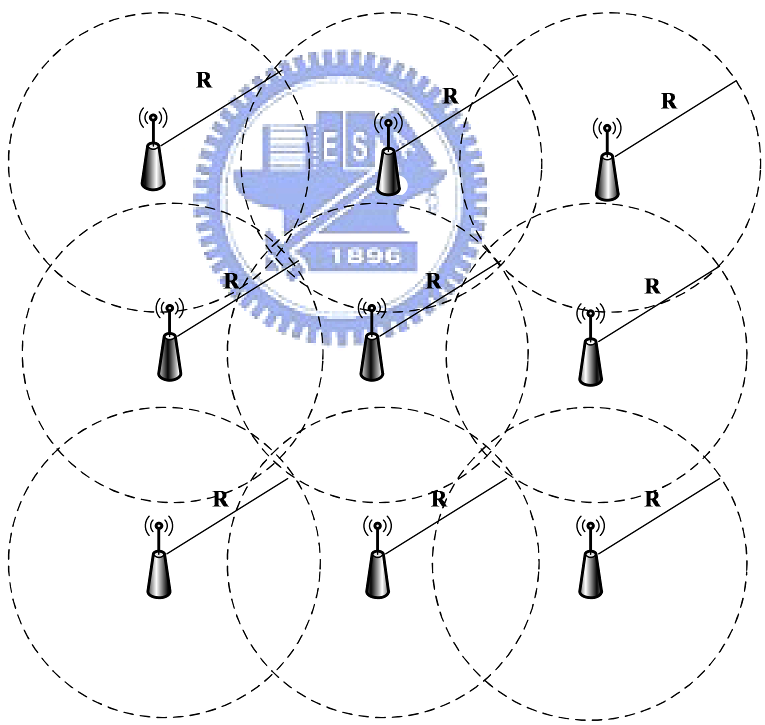
3)Effect of mobility model on hit ratio:

We simulate our approach on three mobility model. And the result of normal walk mobility model is shown in Figure 4.3. Figure 4.7 shows the hit ratio of random walk mobility model. Obviously, the proactive-caching scheme is better than forecasting one, it results from the randomly choosing of new location, the forecasting scheme is not suitable for this case. However, the performance of proactive-caching is still falling behind the forecasting compensation.

Figure 4.8 shows the effect of random direction mobility model on the hit ratio. Since the random direction mobility model describes the mobile station is moving with the same direction until reaching the simulation area. Hence the forecasting scheme is more suitable for this mobility model than others.

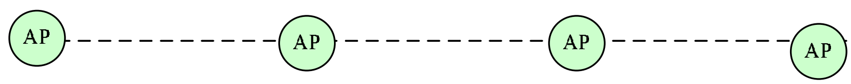


(a): AP deployment for linear array in a single-floor building.

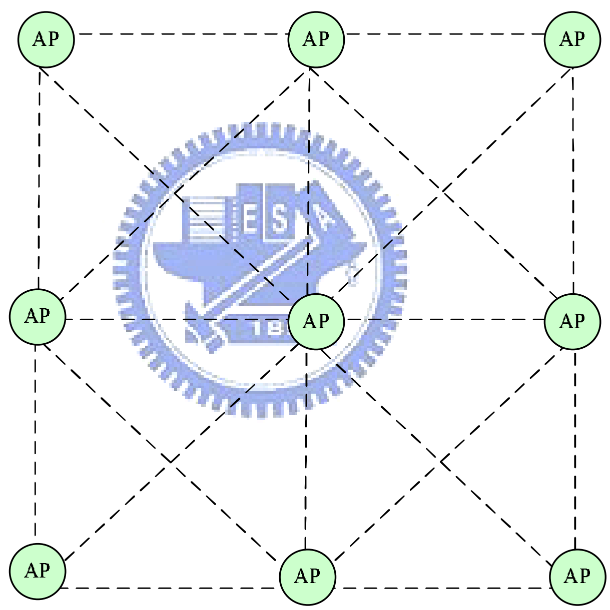


(b): AP deployment for linear array in a single-floor building.

Figure 4.1: An example of AP deployment in a single-floor building.



(a): Coordinating neighbor graph for linear array.



(b): Coordinating neighbor graph for rectangular array.

Figure 4.2: Coordinating neighbor graph.

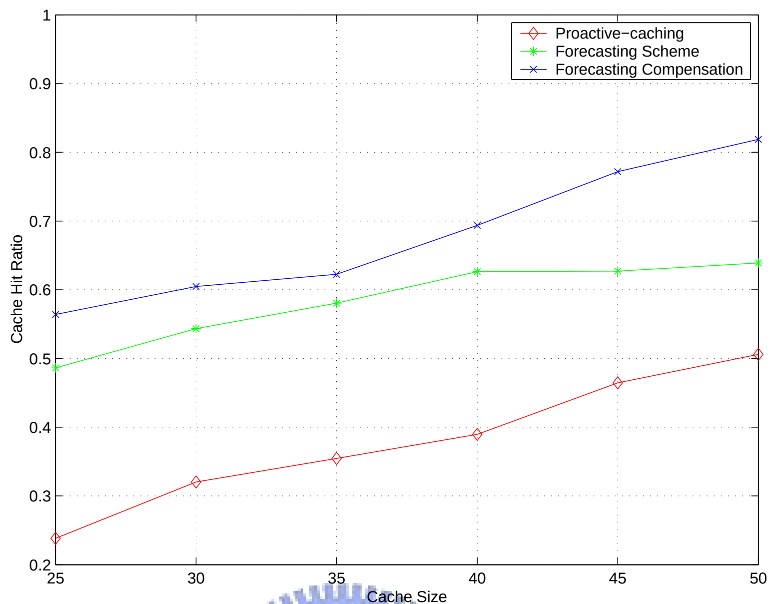


Figure 4.3: Effect of cache size on hit ratio for different approaches(Rectangular array)

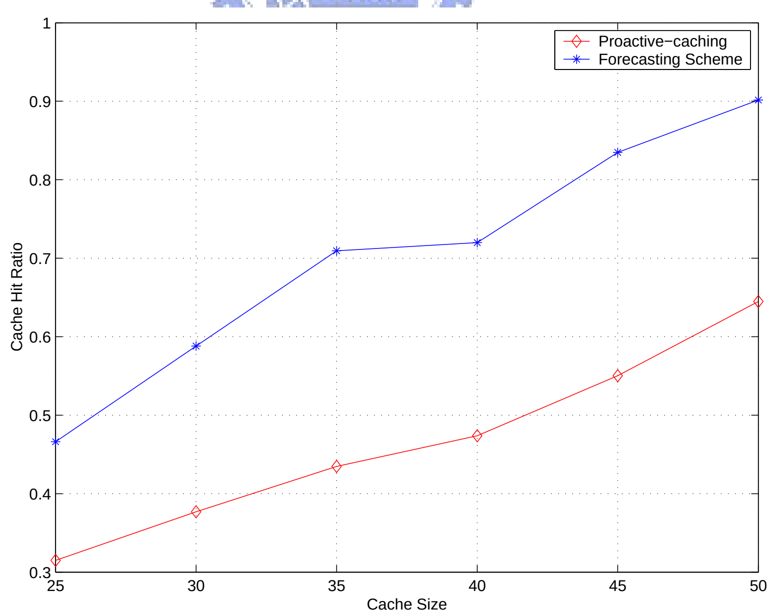


Figure 4.4: Effect of cache size on hit ratio for different approaches(Linear array).

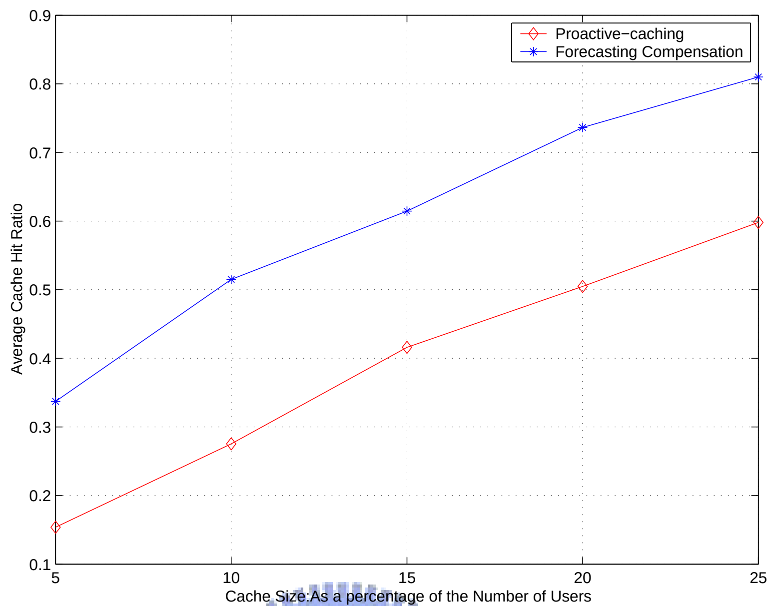


Figure 4.5: Effect of the cache size as a percentage of the number of users on the hit ratio.

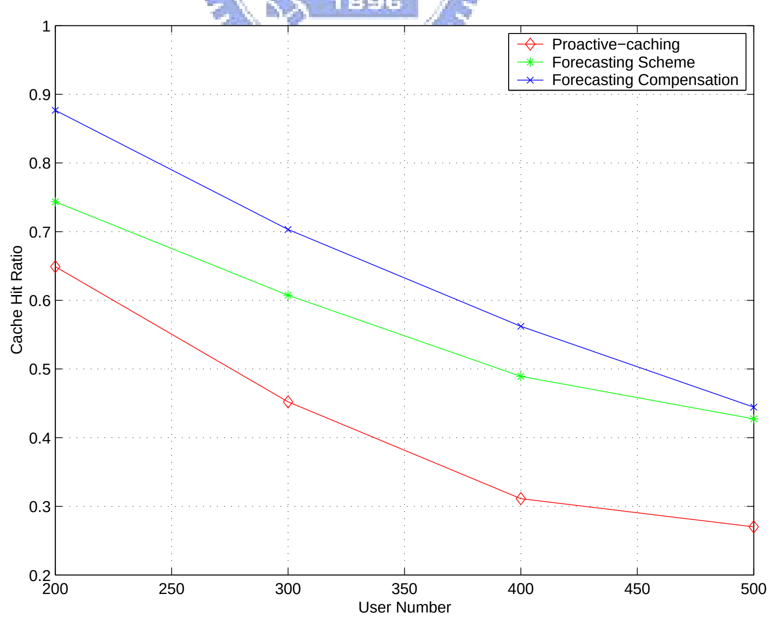


Figure 4.6: Effect of the number of users on the hit ratio compare with three approaches.

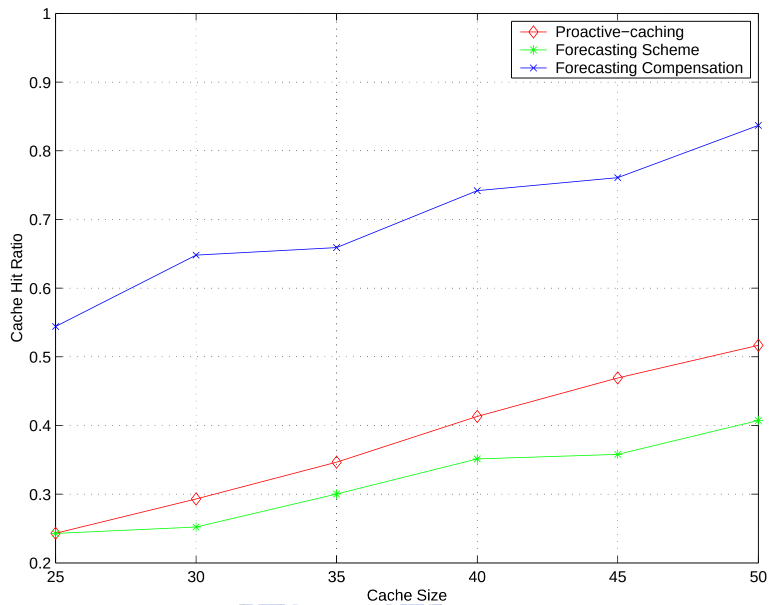


Figure 4.7: Effect of the random walk mobility model on the hit ratio.

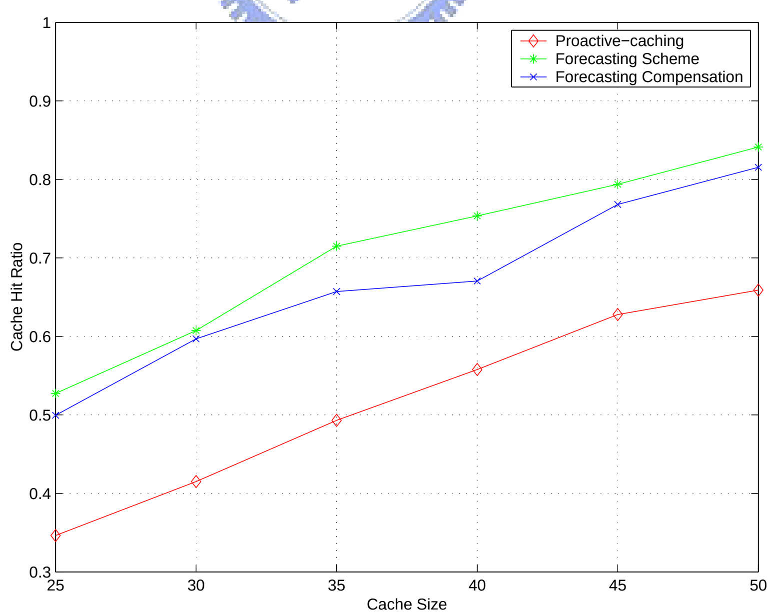


Figure 4.8: Effect of the random direction mobility model on the hit ratio.

Chapter 5

Conclusion and Future Work

In this thesis, a fast handoff scheme has been presented. We utilize forecasting scheme and a data structure, neighbor graph, which captures the user mobility topology dynamically. The forecasting scheme is based on user's movement history. Here, we do not trace the motion of mobile station to know which place or path is frequently used and we can reduce consuming the cache of AP.

We propose a compensation method to redeem the error of forecasting. The major concept of compensation method is that not only forward context to the AP with maximum probability also forward the context to its adjacent APs such as the AP with second sequence priority.

In our simulation, a 20 percent cache size is sufficient to reach 73 percent hit ratio while 25 percent cache size gives about 80 percent hit ratio. Comparing with proactive-caching fast handoff approach, our approach can achieve a better cache hit ratio.

In fact, there are other factors that affect the fast handoff and we do not investigate in this paper. Here, we just consider to the reassociation delay, the probing procedure is another dominating factor in handoff latency, because it latency is more than 90 percent of the overall latency. In the future, we will utilize forecasting scheme based on user's movement history, and use this information to reduce the probe delay and authentication delay. By this way, we can greatly reduce the handoff latency and make the handoff procedure seemly.

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