An Adaptive Scheme for Vertical Handoff in Wireless Overlay Networks*

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Abstract

Vertical handoff is the switching process between heterogeneous wireless networks. Discovering the reachable wireless networks is the first step for vertical handoff. After discovering the reachable candidate networks, the mobile terminal decides whether to perform handoff or not. We present an adaptive scheme for vertical handoff in wireless overlay networks. Our system discovery method effectively discovers the candidate networks for the mobile terminal. Moreover, we propose two adaptive evaluation methods for the mobile terminal to determine the handoff time that relies on the candidates' resources and the running applications. The simulation results show that the proposed system discovery method can balance the power consumption and the system discovery time. Furthermore, the proposed handoff decision method can decide the appropriate time to perform handoff.

1. Introduction

The wireless networks have provided convenient mobile services in resent years. Several different wireless technologies are developed for different purposes. For example, IEEE802.11 and HIPERLAN/2 are mainly designed for local area communication while GSM/GPRS and UMTS are designed for wide area communication. These technologies vary in terms of frequency band, bandwidth, data transmission latency, coverage range and so on. In general, most wireless networks with a smaller service area provide larger bandwidth and those with a larger service area provide smaller bandwidth. When a mobile terminal (MT) roams through these different wireless technologies, maintaining a consistent connection is important. Moreover, the seamless integration of different wireless technologies is critical. The seamless integration of several different wireless technologies has three main requirements. First, the vertical handoff process should be done automatically, without user's intervention. Second, the MT with multiple interfaces for different wireless technologies can automatically select the most appropriate wireless network. Third, the data-flow should be smoothly redirected to the new wireless network when the MT is roaming between different service providers.

The wireless overlay network is composed by several wireless networks with different wireless technologies. Traditionally, handoff process is performed between two base stations with same technology. This kind of handoff is defined as horizontal handoff. In contrast to horizontal handoff, vertical handoff is defined as the handoff between base stations with different wireless network technologies.

The vertical handoff process is generally divided into three steps. First, the MT must know which wireless networks are reachable. This step is called "system discovery." Second, the MT then evaluates the reachable wireless networks to make the handoff decision. This step is called "handoff decision." Third, if the MT decides to perform vertical handoff, it executes the vertical handoff procedure to be associated with the new wireless network. This step is called "handoff execution." In this paper, we focus on the problems of "system discovery" and "handoff decision."

System discovery is the process that the MT tries to search reachable wireless networks. A MT with multiple interfaces must activate the interfaces to receive the service advertisements which were broadcasted by different wireless technologies. The MT will know a wireless network is reachable if its service advertisements can be heard. The simplest way to discover reachable wireless network is always keeping all the interfaces on. However, activating the interface consumes power even without receiving/sending any packet. Therefore, to avoid keeping the idle interfaces always on is critical. Moreover, the MT should observe if the new wireless network is consistently better than current one before performing handoff. The MT should wait a "stability period" before performing handoff into the new wireless network. "Stability period" is defined as the period between the time of finding the better wireless network than current one and the time of starting to perform handoff into it. We proposed two adaptive handoff decision methods to dynamically adjust the stability period relying on the variances of received services of the MT. These methods are helpful to MTs to make the handoff decision. In order to ensure that performing handoff into the candidate network is worthwhile, the MT waits stability period before performing handoff. Stability period is defined as the period between finding the better wireless network and performing handoff

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into it. Our handoff decision method dynamically adjusts the stability period according to the network resources and the running applications on the MT.

The proposed handoff decision methods shorten the stability period if the services provided by the current wireless network becomes worse or the services provided by the new wireless network becomes better. Moreover, the proposed two methods extend the stability period if the difference of two wireless networks is not clear. The rest of this paper is organized as follows. In Section 2, we give an overview of previous works related to vertical handoff. In Section 3, we describe our adaptive scheme for vertical handoff in detail. Section 4 presents the performance improvements of the proposed scheme. Finally, in Section 5, we conclude and discuss the future works.

2. Related Works

2.1. Wireless Overlay Networks and Vertical Handoff

The wireless overlay network [1] is composed by several wireless networks with different technologies. In Figure 1, vertical handoff (shown in solid line) is the switching process between two different layers and horizontal handoff (shown in dash line) is the switching process in the same layer. Vertical handoffs are divided into two categories: downward vertical handoff and upward vertical handoff. The downward vertical handoff is MT switching from a larger cell into a smaller cell. On the contrary, the upward vertical handoff is MT switching from a smaller cell to a larger cell. Generally, the downward vertical handoff is less time-critical and the upward vertical handoff is time-critical. The MT needs to perform the upward vertical handoff as soon as possible if the received signal strength is fast decreasing. The MT may not to perform the downward vertical handoff immediately because the MT may pass through the wireless network in a short time.

2.2. System Discovery

The simplest method to discover the reachable wireless networks for a MT with multiple interfaces is always keeping all interfaces on all the time. However, the activated interfaces consume the battery power even without sending/receiving any packet. Therefore, an effective system discovery method is required. A faster system discovery time is also desired because the MT can benefit faster from the new wireless network. The power efficiency and the system discovery time are the most critical considerations for system discovery methods' performance.

The interface may be activated periodically to receive the service advertisements [1]. Intuitionally, the activating frequency will directly affect the system discovery time. The MT that activates the interfaces with high frequency may discover the reachable wireless network quickly but its battery may run out very soon. The MT that activates the interfaces with low frequency may increase the power efficiency but it may discover the reachable wireless networks slowly. There is a trade-off between the power efficiency and the system discovery time.

The position information of the MT and a Location-Service Server with precise service areas of wireless networks can assist the MT to discover reachable wireless networks [5]. The MT can discover the reachable wireless networks by querying the Location-Service Server with its current location. The Location-Service Server then reply the reachable wireless networks to the MT. This location-based system discovery method effectively decreases the unnecessary interface activating. However, constructing and maintaining the Location-Service Server with precise service areas is generally difficult because the database requires a complex measurement and the service area of a wireless network may vary dynamically.

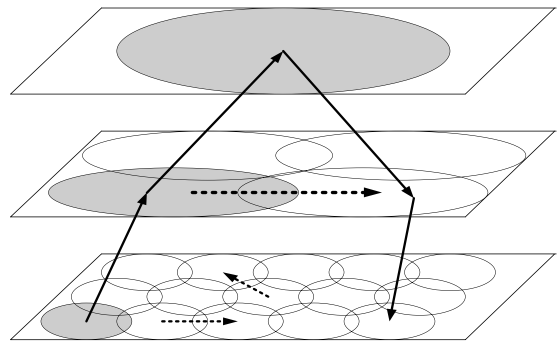

Figure 1. Vertical handoff and horizontal handoff

2.3. Vertical Handoff Decision

Making the vertical handoff decision is more complex than horizontal handoff decision. A quantified evaluating method with several factors is required in comparing two wireless networks. Ping-pong effect is a phenomenon that the MT is keeping on handoff between the two base stations to and forth. In the homogeneous environment, if the handoff decision is simply relied on received signal strength, the ping-pong effect may occur in the edge of two base stations' coverage. Similarly, the ping-pong effect may occur in heterogeneous environment if the decision factors change fast and the MT performs vertical handoff immediately after it finding a better wireless network than current one.

In the heterogeneous environment, a throughput optimization scheme for the vertical handoff was proposed in [4]. This scheme considered both upward and downward vertical handoff decisions are considered. In Figure 2, the dwell-timer functionality is presented. The notations used are defined as follows:

T_1: Each contiguous stretch of time that the underlay wireless network is reachable.

T_2: Each contiguous stretch of time that the underlay wireless network is not reachable.

S_1: The effective throughput of the underlay wireless network.

S_2: The effective throughput of the overlay wireless network.

T_D: Dwell time.

Δ: Handoff latency.

Ω: The ratio of S_1 to S_2. (S_1/S_2)

The upward vertical handoff is profitable when:

$$S_2 \times (T_1 - T_D - \Delta) > S_1 \times T_1$$
$$\Rightarrow \Omega = \frac{S_1}{S_2} < \frac{T_1 - T_D - \Delta}{T_1} \qquad (1)$$

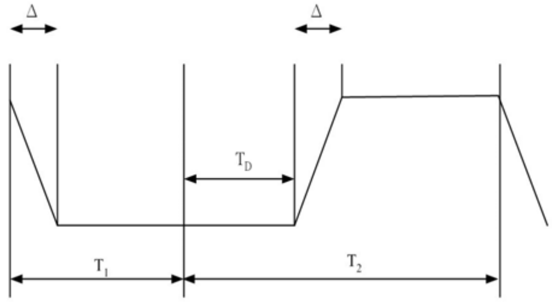

Figure 2. Dwell-timer functionality

This throughput optimal scheme makes the vertical handoff decision from the view of maximizing the throughput. However, this scheme doesn't take the demands of running applications and the moving speed of the mobile user into consideration. A policy-enabled handoff decision scheme was proposed in [2]. This scheme introduced a cost function that is composed by several parameters. The notations are defined as follows:

f_n: The cost function of wireless network n
w_i: The weight (importance) of factor i. ($\Sigma w_i = 1$)
B_n: The bandwidth that wireless network n can offer.
P_n: The power consumption of using the network device for network n.
C_n: The cost of wireless network n.
N(i): The normalization function of parameter i.

The cost of using a network n at a certain time is defined as Equation (2).

$$f_n = w_b \times N\left(\frac{1}{B_n}\right) + w_p \times N(P_n) + w_c \times N(C_n) \qquad (2)$$

If the MT transiently switches between wireless networks, the gain from using the better wireless network may be diminished by the handoff overhead and the handoff latency. Therefore, it is critical to observe if a wireless network is "consistently better" than current one. The stability period is defined as the period between finding a better wireless network and starting to perform handoff into it. The stability is designed to observe if the wireless network is consistently better. The MT will perform vertical handoff only when the wireless network is consistently better than current one in use for the stability period. Handoff latency $l_{handoff}$ is the period from the receiving time of the last data packet from the old wireless network to the receiving time of the first data packet from the new wireless network. Makeup time T_{makeup} is defined as the amount of time needed to make up the loss during the handoff latency. The stability period Ts is defined as Equation (3).

$$T_s = l_{handoff} + T_{makeup} \qquad (3)$$

The policy-enabled handoff decision scheme defined the stability by predicting the future situation by the recently past statistics. The handoff is worthwhile if the new wireless network consistently better than current on for Ts after performing handoff. As shown in Figure 3, Stage I is the stability period that is used for MT to observe if the wireless network is consistently better. If the wireless network is consistently better than current one, the MT decides to perform handoff and enters Stage II. In Stage II, the MT is performing handoff and can't receive any data packet. The MT starts to make up the loss due to handoff in Stage III. Finally, the MT will benefit from the new wireless network after entering Stage IV.

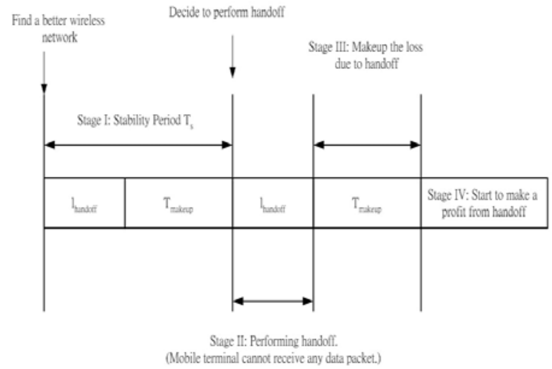

Figure 3. Stability period

For simplicity, we assume the bandwidth is the only considered factor. We start to derive the make up time T_{makeup}.

$$(B_{better} - B_{current}) \times T_{makeup} = B_{current} \times l_{handoff}$$
$$\Rightarrow T_{makeup} = \frac{l_{handoff}}{\frac{B_{better}}{B_{current}} - 1} \qquad (4)$$

The length of Stage II is affected by the association latency and flow redirect latency. The length of Stage III is affected by the difference of bandwidth of two wireless networks and the handoff latency.

3. Proposed Adaptive Scheme

3.1. System Architecture

The wireless overlay network is composed by several wireless networks with different wireless technologies. Wireless networks with different wireless technologies may be constructed by different operators. The MT with multiple interfaces is assumed to be able to access the most appropriate wireless network and roams between wireless networks of different operators. A Location-Service Server is established to record the available service in a specific position. Operators should publish the ideal coverage of managed wireless networks on the Location-Service Server. When a wireless network is newly established or removed, the operator should also update the Location-Service Server.

3.2. System Discovery Method

The simplest method to discover the reachable wireless networks is always keeping all interfaces on all the time. However, the activated interfaces consume the battery power even without sending/receiving any packet. Another simple system discovery method is periodically activating the interfaces without any hint. The MT using this method will activate its interfaces even when the wireless network is far from the MT.

The position information of the MT and a Location-Service Server which recorded the precise service areas of wireless networks can assist the MT in deciding when to activate its interfaces. However, constructing and maintaining the database with precise service areas is generally difficult because the database requires a complex measurement and the service area of a wireless network may vary dynamically.

In order to avoid unnecessary interface activating and discover reachable wireless networks as soon as possible, we proposed our ideal coverage concept and the adaptive system discovery method. The ideal coverage concept is shown in Figure 4. The ideal coverage is the smallest circle that covers the real coverage and the minimum coverage is the largest circle that can be included by the real coverage. The operator should publish the position information of the base station, the radius of ideal coverage and the radius of the minimum coverage on the Location-Service Server.

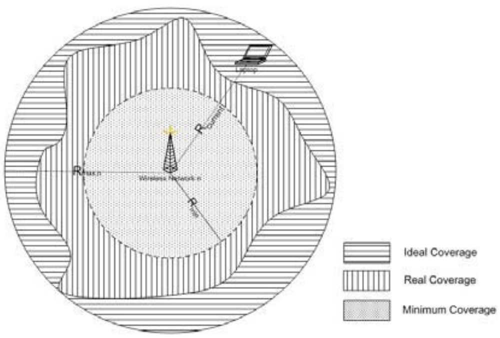

Figure 4. Ideal Coverage Concept

Because the reachable wireless network must be overlapped with current one, the MT obtains the possibly reachable wireless networks list (R_{max}, R_{min} and the position of the base station) whose ideal coverage is overlapped with current one. The mobile checks the current position and the possibly reachable wireless networks list periodically. If the MT finds that it is under the ideal coverage of a specific wireless network (except current one), it activates its corresponding interface by Equation (5). The notations are defined as follows:

$T_{interval}$: The interface activating interval
T_{max}: The upper bound of Tinterval
T_{min}: The lower bound of Tinterval
R_{max}: The radius of the ideal coverage
R_{min}: The radius of the minimum coverage
$R_{current}$: The distance between the base station and the MT

$$T_{\text{interval}} = (T_{\max} - T_{\min}) \times \frac{R_{current} - R_{\min}}{R_{\max} - R_{\min}} + T_{\min} \qquad (5)$$

The proposed adaptive system discovery method avoids the unnecessary interface activating because the MT will only activate its corresponding interface when it enters the ideal coverage. Because the probability to receive the service advertisement is increasing with the decreasing of $R_{current}$, our method also discovers the reachable wireless network faster than periodically interface activating.

3.3. Handoff Decision Method

After discovering the reachable wireless network, the MT starts to evaluate it. A utility function [2] is used to evaluate the wireless networks. The utility function quantifies the Quality of Service (QoS) provided by the wireless network from the view of running applications on the MT. We assume there is a performance agent that periodically announces the available resources information in the base station with beacons. The assumption is reasonable because the MT should be enabled to roam between different operators and the operators should advertise the services they can provide. As shown in Equation (6), the utility function of wireless network j from the view of mobile users is composed of several normalized factors fi,j that are multiplied with their weights wi (importance). The utility of unreachable wireless network is always zero. The normalized values of factors are restricted between 0 and 1.

$$Utility_j = \sum_i w_i \times f_{i,j} \qquad (6)$$

Different applications may assign different weight values for a particular factor. For example, bandwidth has different importance in Telnet and FTP applications, and the applications may assign different weight values for bandwidth. The maximum requirement and the minimum requirement for each factor should be defined by the application. The minimum requirement of a factor is defined as the least acceptable real value of the factor for the application. The normalized factor value is zero if the real factor value is less than or equal to the minimum requirement. On the other hand, the maximum requirement of a factor is defined as the maximum demand of the factor for an application. The application's performance will not be improved if the real factor value is larger than the maximum requirement. Equation (7) shows the mapping of real factor value and the normalized factor value of wireless network j.

$$\begin{aligned} &if(LB_i < R_{i,j} < UB_i) \Rightarrow f_{i,j} = \frac{R_{i,j} - LB_i}{UB_i - LB_i}, \\ &if(R_{i,j} \le LB_i) \Rightarrow f_{i,j} = 0, \\ &if(R_{i,j} \ge UB_i) \Rightarrow f_{i,j} = 1 \end{aligned} \qquad (7)$$

UB_i and LB_i are the maximum requirement and the minimum requirement of factor i and $R_{i,j}$ is the real value of factor i in wireless network j. The factors may be measured by the MT or announced by the base station. The general application-care factors (like Effective Bandwidth, Charge Model and Cost, Power Consumption, Moving Speed and Coverage, etc.) should be defined.

For example, a mobile is now associated with GPRS and a WLAN network is also reachable. After discovering the WLAN is reachable, the MT then makes the handoff decision relying on the utility ratio of the two wireless networks. The utility function of an application should be predefined. Assume a utility function contains effective bandwidth and movement speed as factors. The reasons of the utility ratio's change are listed in Table I.

If the MT discovers a wireless network with higher utility than current one, the mobile starts to observe if it is consistently better than the current one. We call the wireless network with higher utility as the target wireless network. As mentioned before, the MT observes the target wireless network for a stability period. The original form of the stability period in [2] is show as Equation (3). We rewrite it in Equation (8).

U_{wlan}/U_{gprs}	Reasons of the utility ratio's change
Increasing	Effective bandwidth of WLAN is increasing. The movement speed of the MT is decreasing.
Decreasing	Effective bandwidth of WLAN is decreasing. The movement speed of the MT is increasing.

Table I. Varying reasons of the utility ratio

$$T_{Stability} = l_{handoff} + \frac{l_{handoff}}{r-1}, \; r = \frac{Utility_{target}}{Utility_{current}} \qquad (8)$$

Stability period [2] is determined when the MT finds the target wireless network. However, the utilities of the target wireless network and current one may vary dynamically with user's movement, and the stability period should be adjusted according to currently measured utility. Therefore, we proposed the first adaptive handoff decision method that will perform vertical handoff only when the target wireless network excels the current one in utility evaluation results for N times. The interval between evaluation operations is determined by the last utility evaluation result. We assume the utility ratio for mth evaluation operation is r_m. The evaluation interval between mth evaluation operation and m+1th evaluation operation will be:

$$T_{interval} = \frac{l_{handoff}}{N} + \frac{l_{handoff}}{N \times (r_m - 1)} \qquad (9)$$
$$if\,(T_{interval} > T_{max}) \Rightarrow T_{interval} = T_{max}$$

T_{max} is the upper bound of $T_{interval}$. Therefore, the stability period of our method will be:

$$T_{stability} = \sum_{m=0}^{N-1} \left(\frac{l_{handoff}}{N} + \frac{l_{handoff}}{N \times (r_m - 1)} \right) \qquad (10)$$

When the utility ratio is invariable, the first adaptive handoff decision method has the same stability period as the non-adaptive stability period in [2]. However, when the utility ratio varies, the first adaptive handoff decision method can adjust the stability period according to the currently measured utility ratio. Every time when the MT obtains the evaluation result, it waits for the interval defined in Equation (9) and then starts the next evaluation. If the target wireless network becomes worse than the current one (i.e., r<1) in the utility evaluation result, the handoff procedure will not be executed. The MT also evaluates the reachable wireless network with a smaller utility with a predefined maximum evaluating interval.

The stability period in the first adaptive handoff decision method is adjusted relying on the measured utility ratios of the target wireless network to the current one. The utility ratio increases if the utility of the target wireless network is increasing or the utility of the current wireless network is decreasing. A MT may want to perform handoff as soon as possible if the utility ratio is increasing and may not want to perform handoff if the utility ratio is decreasing fast. The proposed method shortens the stability period if the utility ratio is increasing. On the other hand, if the utility is decreasing, the reason may be the target wireless becoming worse and worse or the current one becoming better and better in utility. A MT should observe the wireless network for a long time and then decide to perform handoff or not if the utility of the wireless network is fast decreasing.

The second adaptive handoff decision method is based on the ratio of two measured utility ratios. The basic idea is the same as the first adaptive handoff decision: the stability period should be shortened or extended if the utility ratio is increasing or decreasing. The notation we used is listed as follows:

T_{SO}: The original stability period in Equation (8)
T_{SR}: The remained stability period from current to the end of T_{SO}
P: The advertisement interval
Current_Index: The index number for the current measurement
Total_Index: The total number for the measurements before performing handoff
ε: The precision of the second adaptive handoff decision method

The initial state of the second adaptive handoff decision is presented in Figure 5. The utility ratio measured in the m^th measurement is r_m. The Total_Index is initialized with Equation (11) and is updated with every evaluating operation. Current_Index is initialized with zero and is increased one with every measurement operation. Assume that the Current_Index is m, the new Total_Index is updated by the pseudo-code in Figure 6.

$$Total\_Index = \left\lceil \frac{T_{so}}{P} \right\rceil \qquad (11)$$

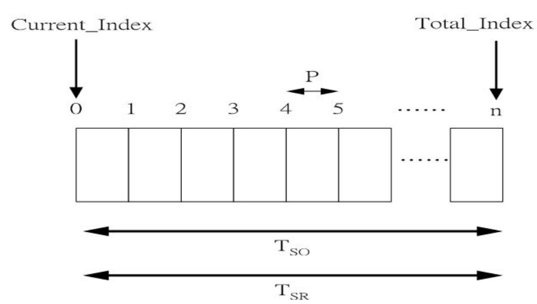

Figure 5. Initial state of the second adaptive handoff decision method

The total index is updated relying to the ratio of the r_m to the r_{m-1}. The ε is the precision of the second adaptive handoff decision method. If the ratio of two measured utility ratios varies in [-ε, ε], the stability period is not extended or shortened. If r_m/r_{m-1} is larger than 1, the new Total_Index will be decreased. On the other hand, if r_m/r_{m-1} is smaller than 1, the new Total_Index will be increased. Handoff will be performed only when Current_Index is equal to

Total_Index. As show in Figure 7, the stability period is adaptively adjusted by the measured utility ratios.

$$
\begin{aligned}
& if\left(\frac{r_m - r_{m-1}}{r_{m-1}} > \varepsilon\right) \\
& \qquad Total\_Index \leftarrow Current\_Index + \left\lfloor \frac{Total\_Index - Current\_Index}{r_m / r_{m-1}} \right\rfloor; \\
& else\ if\left(\frac{r_m - r_{m-1}}{r_{m-1}} < -\varepsilon\right) \\
& \qquad Total\_Index \leftarrow Current\_Index + \left\lceil \frac{Total\_Index - Current\_Index}{r_m / r_{m-1}} \right\rceil; \\
& else\ Total\_Index \leftarrow Total\_Index;
\end{aligned}
$$

Figure 6. Pseudo code for adaptive index

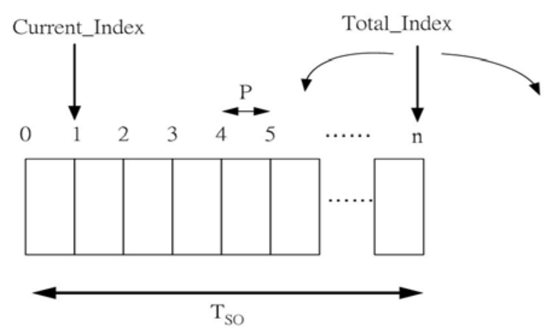

Figure 7. The adaptive stability period of the second method

3.4. The Proposed Adaptive Scheme

We propose a coverage concept to reduce the complexity to construct the Location-Service Server. The Location-Service Server with the ideal coverage concept records the ideal coverage of every wireless network instead of the precise service area of every wireless network. This coverage concept can help the operators to avoid the accurate measurements for every new established wireless network. Moreover, the adaptive interface activating method activates the interface relying on the distance to the base station. The probability of receiving the service advertisements is increasing with the decreasing of the distance between the MT and the base station. The adaptive interface activating shortens the interface activating interval when the MT is approaching the base station.

The first adaptive handoff decision method adaptively adjusts the stability period with adaptive measurement interval. The stability period is computed relying on several measured utility ratios instead of the first measured utility ratio. The second adaptive handoff decision also adaptively adjusts the stability period relying on the ratio of two measured utility ratios. The stability period is extended/shortened when the ratio of two measured utility ratios is smaller/larger than one. Both two adaptive handoff decision methods avoid unnecessary handoffs than the non-adaptive stability period method when the utility ratio is decreasing. Furthermore, both two adaptive handoff decision methods make handoff decision faster than the non-adaptive stability period method if the utility ratio is increasing. If the utility ratio is less than one, the wireless network should be evaluated every maximum evaluating interval.

4. Performance Evaluation

4.1. System Discovery Performance

The ideal coverage concept reduces the difficulties to establish and maintain the Location-Service Server. Moreover, the Location-Service Server that records the ideal coverage of every wireless network needs less disk space than the one that records the accuracy service area information. The Location-Service Server that records the accuracy service area for every wireless network needs to record every boundary point of the wireless network. With the ideal coverage concept, the Location-Service Server only needs to record the position of the base station, the radius of the ideal coverage and radius of the minimum coverage. The MT with multiple interfaces moving into the coverage of an underlay wireless network and compare the system discovery time and the accumulated interface activating time of proposed system discovery method, periodically interface activating method and simply keeping all interfaces on method. The simulation model is established according Figure 4. The real service boundary is normally distributed between R_{max} and R_{min}. The MT is moving in speed v. For simplicity, we let the MT move in the same direction but different starting point. The starting point is randomly selected. The system discovery time is defined as the time that MT first activates its interface after entering the real coverage. The accumulated activating time is the summation of interface activating time after the MT enters the ideal coverage.

We assume that the MT is now associated with GPRS and moving into the ideal coverage of a WLAN. The variables used are listed in Table II.

Variable Name	Value
TIME_PERIODICALLY	10 seconds
TIME_MAX	15 seconds
TIME_MIN	5 seconds
R_MAX	400 meters
R_MIN	100 meters
R_MEAN	250 meters
R_VAR	50 meters
BEACON_INT	0.1 second
ACT_TIME	0.2 second

Table II. Simulation parameters for system discovery

TIME_PERIODICALLY is the period between two activating operations in periodically interface activating method. TIME_MAX and TIME_MIN are the upper bound and the lower bound of the activating interval of the proposed adaptive system discovery method. R_MAX is the radius of the ideal coverage. R_MIN is the radius of the minimum coverage. R_MEAN is the mean radius of the real coverage and R_VAR is the stand variation for the normal distribution with mean R_MEAN. The beacon interval of the underlay wireless network is BEACON_INT and the interface will be activated for ACT_TIME to receive the beacon. The interface activating interval of proposed system discovery method is defined in Equation (5). Generally, a system discovery method with a fast system discovery time and less accumulated interface activating time is desired.

As shown in Figure 8, the proposed scheme discover a wireless network faster than the periodically interface activating method for about 2.5 seconds when the MT moves in a walking speed. The system discovery time of the proposed system discovery method is later than periodically when the MT moves in a high speed (14meters/second). Because TIME_MAX is larger than TIME_PERIODICALLY and the MT moves in a high speed that the wireless network is reachable in 2nd interface activating. However, when the MT moves in a high speed, performing handoff into a wireless network with a small coverage is not applicable.

The accumulated activating time is also a critical consideration for evaluating system discovery methods because it is in proportion to the power consumption. Therefore, a small accumulated activating time is desired. As shown in Figure 9, the accumulated activating time of periodically interface activating method and proposed system discovery method are negligible comparing to the simplest method that always keeps the interface on. The proposed system discovery method can therefore consume less power than the simplest method.

The simplest method that always keeps the interface on can discover the reachable wireless network fastest. The proposed method discovers the reachable wireless network about 2 seconds later than the simplest method in walking speed. The periodically interface activating method discover the reachable wireless network about 5 seconds in walking speed. However, the accumulated activating time of the simplest method is far larger than the other two methods. Consequently, the proposed adaptively interface activating method effectively balances the power consumption and the system discovery time.

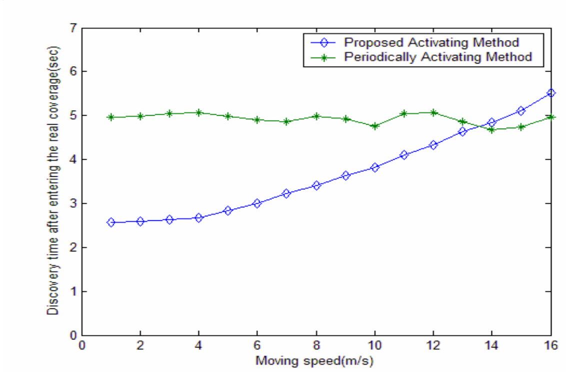

Figure 8. System discovery time and moving speed

4.2. Handoff Decision Performance

We simulate the both two proposed handoff decision methods and the non-adaptive stability period method in [2]. Notice that, the proposed adaptive handoff decision methods can extend or shorten the stability according to the newest measurement value. The utility ratio of the target wireless network to the current wireless network may dynamically change relying on the user's movement. The variables used are listing in Table III. The handoff latency is the period between the MT receiving the last packet from the original wireless network and the first packet from the new wireless network. The initial utility ratio is the utility ratio first evaluated. The service advertisement period is the interval between two service advertisements. The MT calculated the utility ratio after receiving the service advertisement. The handoff count N is the evaluating count before performing handoff in the first adaptive handoff decision method. The ε is the precision of the second adaptive handoff decision method.

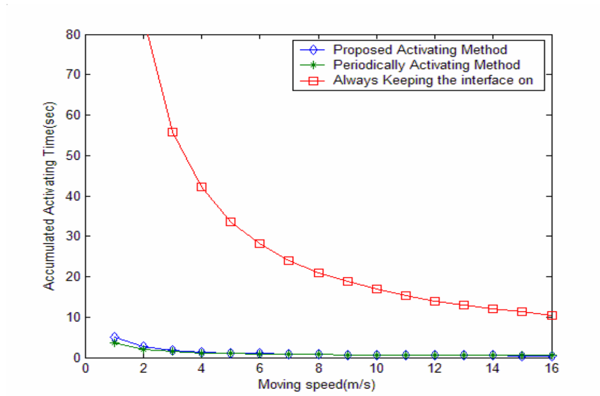

Figure 9. Accumulated activating time

Variable Name	Value
Handoff latency	0.5 second
Initial utility ratio R0	3
Service advertisement period	0.1 second
Handoff count N	5
Precision ε	5%

Table III. Simulation parameters for handoff decision

The varying rate is defined as $(r_m - r_{m-1})/r_{m-1}$ where r_m is the m^{th} measured utility ratio. We simulate the situation when the utility is decreasing or increasing with the mean varying rate (±1%). In Figure 10, both of two proposed methods had a smaller stability period (the waiting time before performing handoff) while the utility ratio is increasing. Moreover, the proposed handoff decision methods had a larger stability period if the utility ratio is decreasing. Therefore, performing handoff will be delayed if the utility ratio is decreasing. In Figure 11, the first adaptive handoff decision method can avoid performing handoff when the decreasing rate of the utility ratio is larger than 10% per measurement, the second adaptive handoff decision method can avoid performing handoff when the decreasing rate of the utility ratio is larger than 5.5% per measurement and the non-adaptive stability period method can avoid performing handoff when the decreasing rate of the utility ratio is larger than 15% per measurement. The second adaptive handoff decision method is very sensitive to the decreasing of utility ratio.

Figure 12 shows the maximum undetected utility decreasing rate for the proposed two methods and the non-adaptive stability method. The maximum undetected utility decreasing rate is the maximum decreasing rate that handoff still occurs. The proposed two handoff decision methods are more sensitive than the non-adaptive stability period handoff decision method even when the initial utility ratio is high. The second adaptive handoff decision method has a high sensitivity to the decreasing of the utility ratio.

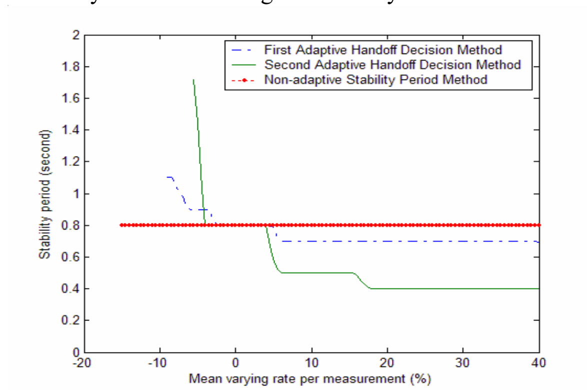

Figure 10. Utility ratio varying rate and the stability period

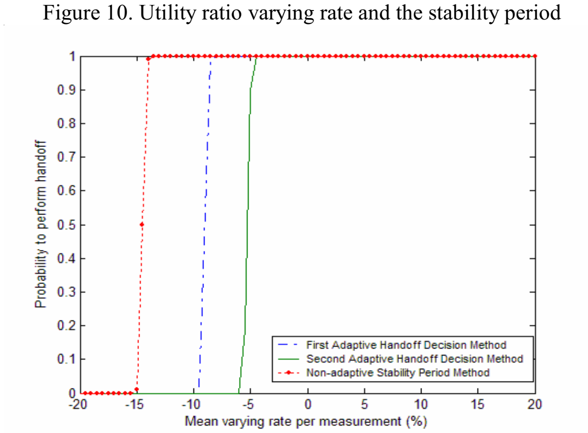

Figure 11. Handoff probabilities and the utility ratio varying rates

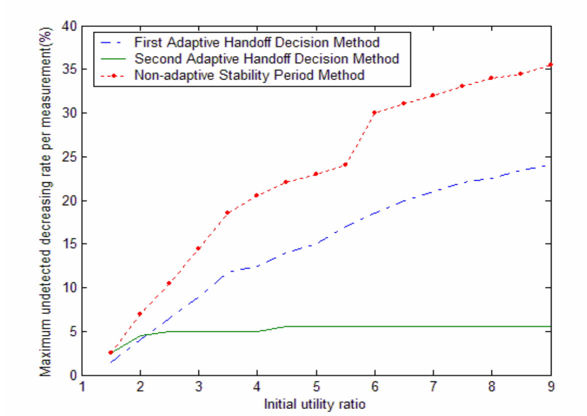

Figure 12. Maximum undetected decreasing rate

5. Conclusion

In this paper, we proposed an adaptive scheme for vertical handoff in wireless overlay networks, including both system discovery and handoff decision methods. The ideal coverage concept reduces the complexity to establish or maintain the Location-Service Server. The proposed system discovery method can balance the power consumption and system discovery time. Moreover, the proposed handoff decision methods can adaptively adjust the stability period and can reflect the variation of the utility ratio.

The ideal coverage concept avoids the complex measurements and the maintenance of the Location-Service Server. We propose an adaptive interface activating method that adjusts the interface activating interval relying on the distance between the MT and the base station. Our adaptive handoff decision methods can avoid performing handoff while the utility ratio is decreasing and shorten the stability period before performing handoff while the utility ratio is increasing. Specially, the second adaptive handoff decision has a significant improvement in the sensitivity to the change of the utility ratio. With the second adaptive handoff decision method, the unnecessary handoffs are avoided when the utility ratio is fast decreasing.

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