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An Adaptive Vertical Handoff Algorithm Based on UMTS and WLAN

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Abstract

According to the characteristics of heterogeneous networks and user demand for seamlessly connection, the necessity of handoff to WLAN was researched. First of all, in order to reduce the influence of shadow fading on received signal strength (RSS), a smoothing algorithm based on support functions was proposed. Then, considering the context of mobile terminals and networks, and by using probabilistic knowledge, we propose an adaptive vertical handoff algorithm based on compensating time. The simulation results show that, compared with two algorithms, the proposed algorithm can make more effective and accurate handoff decisions, reduce the ping-pong effect and interruption probability, thereby greatly improving handoff performance.

Keywords*: UMTS, WLAN, vertical handoff, compensating time*

1. Introduction

With the rapid development of wireless network and communication technology, different wireless network systems such as WiMax, WMAN, UMTS, and WLAN have appeared. As the development trend of next generation network, heterogeneous network integration is the integration of merits of different networks, in order to obtain the most satisfactory QoS.

Although there have been a lot of researches about vertical handoff algorithm [1-5], but they are mostly fixed threshold algorithms. In fact, network conditions pose an important influence on vertical handoff decisions. Literature [6] defines a vertical handoff criterion based on RSS, which will be adaptively adjusted based on mobile terminal movement speed, in order to effectively improve the hit rate and to reduce the unnecessary handoff. A cross layer handoff management mechanism for the scene of mobile users moving from WLAN to 3G is put forward in literature [7], where an adaptive threshold is adopted to effectively reduce the handoff failure and handoff error probability, but it doesn’t evaluate the necessity of mobile node (MN) access to WLAN. In literature [8], according to information such as mobile terminal movement speed and handoff delay, for MN, the necessity of access to WLAN and vertical handoff time of moving out of WLAN are estimated, thereby effectively reducing unnecessary handoff and connection interruption. However, the network context is not considered when analyzing the necessity of access to WLAN.

In order to reduce the shadow fading effect on RSS, and to improve the accuracy of the handoff decisions, we propose an algorithm based on support function to smooth RSS, whereas traditional algorithms mostly utilize the average or weighted average method. Meanwhile, based on UMTS and WLAN integration framework, incorporating the mobile terminals and the network context, and by using probability theory, this paper proposes a new adaptive vertical handoff algorithm based on compensating time, to analyze the necessity of access to WLAN, thereby making more effective and accurate handoff decisions.

2 Research Method

2.1. Related Work and Network Model

The topology model of heterogeneous network integration is shown in Figure 1, taking UMTS and WLAN network for example, wherein the UMTS and WLAN access points are

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referred to as base station (BS) and AP respectively, and the mobile station are moving from UMTS to WLAN at a constant speed.

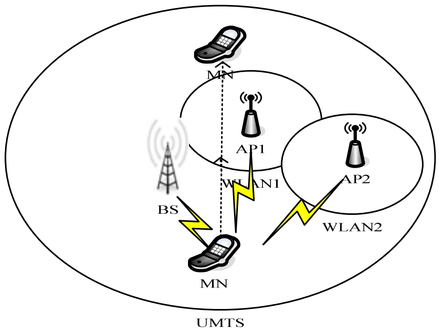

Figure 1. Heterogeneous Network Topology Model

In order to better realize seamless handoff, the vertical handoff algorithm put forward in this paper is operating on a cross layer vertical switch control model, as shown in Figure 2.

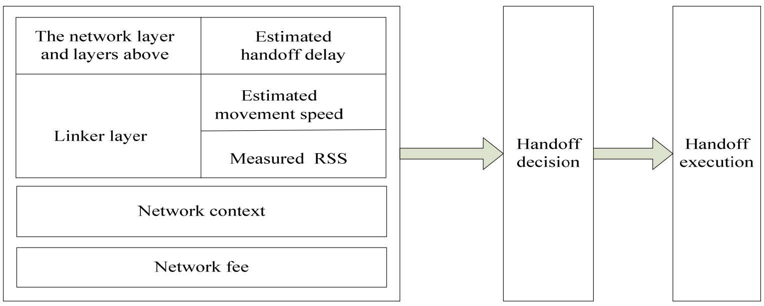

Figure 2. A Cross Layer Vertical Switch Control Model

RSS measurements: MN detects current RSS of access network with the help of network, when link quality is detected to decrease to a certain threshold, handoff is triggered.

$$RSS = P_{Tx} - P_{Lref} - 10\beta \log \frac{d}{d_{ref}} - f(\mu, \sigma) \tag{1}$$

Where P_{Tx} is transmitting power of WLAN base station, d_{ref} is the distance between reference point and the base station, P_{Lref} is the reference point of the path loss, β is a path loss index, which usually is 2-4db in the urban environment, and d is the distance between MN and the reference point. $f(\mu,\sigma)$ is the shadow fading which is Gaussian distribution with mean 0 and variance σ^2.

Speed estimation: By using GPS or the envelope of power spectral density of RSS, movement speed of MN is estimated.

Handoff time delay estimation: The handoff signal delay required by the network layer and layers above the network layer is estimated.

Handoff decision: By using information such as the handoff delay, terminal velocity, current network resources and RSS, make handoff decision based on proposed adaptive vertical handoff algorithm in this paper.

Handoff execution: By using the result of handoff decision, execute the corresponding registration.

2.2. The RSS Smoothing Algorithm Based on Support Functions

Due to the shadow effect, measurement of RSS will be floating, thereby impacting the performance of vertical handoff algorithm. In this paper, we adopt the smoothing algorithm based on support function to minimize measurement errors, thereby improving the decision accuracy.

In the terminal movement process, by using the uniform sampling on the received signal strength of UMTS and WLAN respectively, where T_s is the sampling interval and N is the window size, RSS sequence $RSS[k](k = 0,1,\cdots N-1)$ can be obtained, and $RSS[N-1]$ is the recent sampling result. By Equation (1), RSS sampled value at k_th sampling time can be expressed as follows:

$$RSS[k] = P_{Tx} - P_{Lref} - 10\beta \log \frac{d[k]}{d_{ref}} - f(\mu,\sigma) \tag{2}$$

After weighted average:

$$\overline{RSS}(k) = \sum_{i=0}^{N-1} w_i RSS[k-i] \tag{3}$$

Where w_i is the weight for RSS at time $k-i$ which satisfies the equation: $\sum_{i=0}^{N-1} w_i = 1$. Assuming that MN is a slow mobile user, movement within a certain time distance is limited, and correlation between adjacent data exists. Therefore, w_i is determined by using support function[9] in this paper, and the reliability of $RSS[i]$ is directly proportional to the degree of being supported by the rest data. The difference between $RSS[i]$ and $RSS[j]$ is d_{ij}, which can be expressed as:

$$d_{ij} = \left| RSS[k-i] - RSS[k-j] \right|, i, j = 0,2,\cdots N-1 \tag{4}$$

The support function is defined as:

$$r_{ij} = 1 - \frac{d_{ij}}{\max\{d_{ij}\}} \tag{5}$$

Where r_{ij} represents support relationship between $RSS[i]$ and $RSS[j]$, if $i = j$, then $r_{ij} = 1$. That is, the data is fully supported by itself. The support function in matrix form is as follows:

$$R = \begin{bmatrix} r_{00} & r_{01} & \cdots & r_{0N-1} \\ r_{10} & r_{11} & \cdots & r_{1N-1} \\ \vdots & \vdots & \vdots & \vdots \\ r_{N-10} & r_{N-11} & \cdots & r_{N-1N-1} \end{bmatrix} \tag{6}$$

In support degree matrix R, the influence factor of the i-th measurement data for other measurement data is $w_i(i = 0,\cdots,N)$, and $\sum_{i=0}^{N-1} w_i = 1$. $w = [w_0, w_1, \cdots w_{N-1}]^T$ and it can be calculated by equation:

$$\lambda_{\max} w = Rw \tag{7}$$

Where $\lambda_{\max}$ is the maximum value of eigenvectors, and w_i is the corresponding eigenvector. In combination with Equation (3), weighted average of $RSS[k]$ i.e. $\overline{RSS}[k]$ can be calculated.

2.3. The Vertical Handoff Decision Algorithm

When WLAN is detected to be available to a MN in the WLAN and UMTS overlapping coverage, the corresponding network entity can judge whether it can access to WLAN or not. Two factors need to be considered: one is WLAN availability, i.e. RSS must be greater than $RSS_{\min}$ and the other is the necessity of handoff to WLAN.

Because the coverage of WLAN is limited, MN movement speed is an important factor to judge the necessity of handoff to WLAN. When MN movement speed is high, once switching to WLAN, it will soon move through the AP covering radius and handoff back to UMTS. The 'ping-pong effect' lead to fluctuations in RSS and heavy interaction signaling in core network, thereby influencing business continuity, wasting signaling and network resources. To avoid such unnecessary handoffs, MN must have a certain dwell time in WLAN. If MN movement speed is very high, dwell time in WLAN is less than the handoff signaling delay, handoff failure emerges. Therefore, if the terminal velocity is small, handoff to WLAN is feasible; otherwise, still access to UMTS is a better choice. Conditions required for access to WLAN are as follows:

$$\begin{cases} \overline{RSS}[k] \geq RSS_{\min} \\ v \leq v_{\max} \end{cases} \tag{8}$$

Where $\overline{RSS}[k]$ is the RSS after smoothing at k_th sampling time, $RSS_{\min}$ is the minimum value of RSS that MN can communicate with WLAN, v represents movement speed of MN, and $v_{\max}$ is speed threshold. The corresponding algorithm analysis is shown in Figure 3.

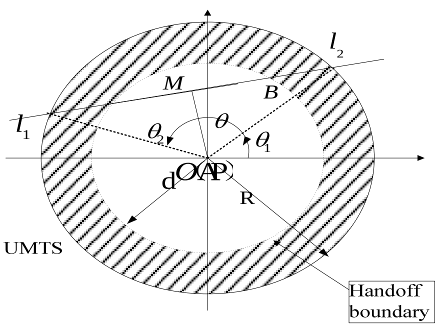

Figure 3. Analysis Diagram of Handoff Process

In Figure 3, MN moves in and out of WLAN at a constant speed along a straight line. l_1, l_2 are positions of MN moving in and out of WLAN respectively. l_1, l_2 can be selected at random within the WLAN coverage, along with corresponding angle θ_1 and θ_2, which are evenly distributed in $[0,2\pi]$. It's assumed that MN's RSS is $RSS_{\min}$ when at position l_1, and that it is RSS_{th_out} when at position B. In the process of MN moving away from AP, RSS is to decrease, and it decreases to $RSS_{\min}$ when moves to position l_2, where is the coverage edge of AP.

τ_1, τ_2 are estimated handoff delay for MN moving in and out of WLAN respectively. t is the residence time of MN in WLAN. If t is shorter than τ_1, that is, MN moves out of WLAN before the handoff process is completed, handoff failure emerges. Otherwise, if t is longer than

τ_1 but is shorter than the sum of τ_1 and τ_2 , 'ping-pong effect' emerges; Meanwhile, the handoff is unnecessary.

2.3.1. The Compensating Time

Considering that handoff process need extra signaling overhead, it is necessary for MN to handoff to WLAN, when it dwells in WLAN for a proper time. On the other hand, if the performance of WLAN is very good and handoff delay is small, a shorter residence time is enough for MN to be beneficial in WLAN. In order to evaluate necessity of vertical handoff, it's necessary to determine the shortest residence time for MN in WLAN, which comprises handoff delay for MN moving in and out of WLAN i.e. τ_1, τ_2 , and the compensating time ΔT . By this way, the shortest residence time is designated by $\Delta T + \tau_1 + \tau_2$ .The compensating time ΔT relates to τ_1, τ_2 , the network context [10] and network fee, as shown in Figure 2. The calculation of ΔT is complied with the following method.

Considering data transmission rates provided by wireless networks and fees for access to them, the revenue function for user i in the network j can be expressed as follows:

$$E_{i,j} = f(B_{i,j}, C_{i,j}) \tag{9}$$

Where $B_{i,j}$ is the bandwidth provided by network j to user i , $C_{i,j}$ is the fees required to pay for network j . The revenue function $E_{i,j}$ is the result of normalized and weighted summation of each parameter. According to the user's demand, the corresponding weights to each parameter which are referred to as $w_{i,B}$ and $w_{i,C}$ are assigned respectively. Also, these weights satisfy equation: $w_{i,B} + w_{i,C} = 1$ and can be adjusted appropriately according to users' business needs and preferences. For convenience, logarithm to the parameter of the formula:

$$E_{i,j} = w_{i,B} \ln B_{i,j} + w_{i,C} \ln C_{i,j} \tag{10}$$

Herein $E_{i,1}$, $E_{i,2}$ is defined as the revenue function of user i access to UMTS and WLAN respectively. Then for user i , the revenue difference between access to UMTS and WLAN can be expressed as:

$$\Delta E_i = E_{i,2} - E_{i,1} - E_{i,3} = w_{i,B} \frac{\ln B_{i,2}}{\ln B_{i,1}} + w_{i,C} \frac{\ln C_{i,2}}{\ln C_{i,1}} - E_{i,3} \tag{11}$$

Where $E_{i,3}$ represents handoff signaling overhead [11]. By Equation (10), we can see the greater ΔE_i is, i.e. the revenue for user i in WLAN is relative higher, the grater necessity of handoff to WLAN will be. If MN switches to WLAN for enjoying WLAN resource, the shortest time comprises compensating time ΔT and the handoff delay for moving in and out of WLAN i.e. τ_1 , τ_2 . Where compensating time ΔT can be determined by the following equations:

$$e^{E_{i,1}}(\Delta T + \tau_1 + \tau_{2)} = e^{E_{i,2} - E_{i,3}}(\Delta T + \tau_2) + e^{E_{i,1} - E_{i,3}} \tau_1 \tag{12}$$

$$\Delta T = \begin{cases} \infty, \Delta E_i < 0 \\ \dfrac{1 - e^{-E_{i,3}}}{e^{\Delta E_i} - 1} \tau_1 - \tau_2, 0 < \Delta E_i < \ln(\dfrac{1 - e^{-\Delta E_3}}{\tau_2} \tau_1 + 1) \\ 0, else \end{cases} \tag{13}$$

Where the signaling overhead resulting from vertical handoff is referred to as $E_{i,3}$, and it can be set to a fixed value greater than 0. By Equation (13), the greater ΔE_i is, the shorter the compensating time ΔT will be. If ΔE_i is a negative number, ΔT will be infinite and the vertical handoff is unnecessary; If ΔE_i is not too large, ΔT changes with ΔE_i and handoff delay; If ΔE_i is larger than a function value, ΔT can be ignored.

2.3.2. Speed Threshold

The speed threshold $v_{\max}$ in Equation (8) can be calculated by the following method. According to section 3.2.1, if MN's dwell time in WLAN is larger than $\Delta T + \tau_1 + \tau_2$, vertical handoff to WLAN is necessary. Herein p_a is defined as unnecessary handoff probability and it can be expressed as:

$$\begin{cases} p_a = p(t < \tau_1 + \tau_2 + \Delta T) \\ p_f = p(t < \tau_2) \end{cases} \quad (14)$$

Where t is estimated residence time in WLAN and the probability density function (PDF) for t can be determined by the following method.

The PDF and the joint probability density at position l_1 and l_2 can be expressed as:

$$f_{l_1}(\theta_1) = f_{l_2}(\theta_2) = \begin{cases} \dfrac{1}{2\pi}, \theta_1, \theta_2 \in [0, 2\pi] \\ 0, otherwise \end{cases} \quad (15)$$

$$f(\theta) = \begin{cases} \dfrac{1}{\pi}(1 - \dfrac{\theta}{2\pi}), 0 \le \theta < 2\pi \\ 0, otherwise \end{cases} \quad (16)$$

MN's movement distance $|l_1 l_2|$ can be expressed as:

$$(vt)^2 = 2R^2(1 - \cos\theta) \quad (17)$$

$$t = g(\theta) = \sqrt{\frac{2R^2}{v^2}(1 - \cos\theta)} \quad (18)$$

θ_{t_i} is the root for $t = g(\theta)$ can be expressed as:

$$f(t) = \sum_{t_i} \frac{f(\theta_{t_i})}{g'(\theta_{t_i})} \quad (19)$$

$$g'(\theta) = \frac{R \sin\theta}{v\sqrt{2(1 - \cos\theta)}} \quad (20)$$

$$|g'(\theta)| = \frac{R}{v}\sqrt{1 - \frac{v^2 t^2}{4R^2}} \quad (21)$$

$$f(\theta_{t_i}) = \frac{1}{\pi}(1 - \frac{\theta_{t_i}}{2\pi}) \tag{22}$$

The PDF of t can be calculated by Equation (19) can be expressed as:

$$f(t) = \begin{cases} \frac{f(\theta_{t_1})}{|g(\theta_{t_1})|} + \frac{f(\theta_{t_2})}{|g(\theta_{t_2})|}, t \le \frac{2R}{v} \\ 0, otherwise \end{cases} = \begin{cases} \frac{2v}{\pi\sqrt{4R^2 - v^2t^2}}, t \le \frac{2R}{v} \\ 0, otherwise \end{cases} \tag{23}$$

The distribution function of t can be expressed as:

$$F(T) = \int_0^T f(t)dt = \begin{cases} \int_0^T \frac{2v}{\pi\sqrt{4R^2 - v^2t^2}} dt, 0 < T \le \frac{2R}{v} \\ 1, T > \frac{2R}{v} \end{cases} \tag{24}$$

By the distribution function (24) and Equation (14), unnecessary handoff probability can be obtained:

$$p_a = p(t < \tau_1 + \tau_2 + \Delta T) = \begin{cases} \frac{2}{\pi}\arcsin\frac{v(\tau_1 + \tau_2)}{2R}, 0 < v < \frac{2R}{\tau_1 + \tau_2} \\ 1, v > \frac{2R}{\tau_1 + \tau_2} \end{cases} \tag{25}$$

The handoff failure probability is as follows:

$$p_f = p(t < \tau_1) = \begin{cases} 1, v > \frac{2R}{\tau_1} \\ \frac{2}{\pi}\arcsin(\frac{v\tau_1}{2R}), 0 < v < \frac{2R}{\tau_1} \end{cases} \tag{26}$$

By Equation (8), (25) and (26), the speed threshold can be obtained:

$$v_1 = \frac{2R}{\tau_1 + \tau_2 + \Delta T}\sin(\frac{\pi p_a}{2}) \tag{27}$$

$$v_2 = \frac{2R}{\tau_1}\sin(\frac{\pi p_f}{2}) \tag{28}$$

$$v_{max} = \min(v_1, v_2) \tag{29}$$

The proposed handoff algorithm flow chart is showed in Figure 4.

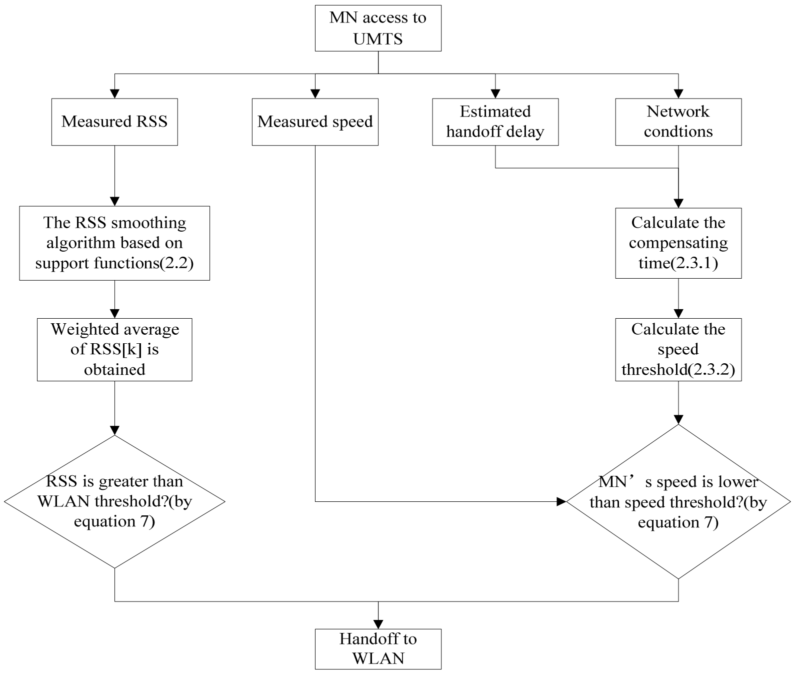

Figure 4. Handoff Algorithm Flow Chart

3. Results and Discussion
3.1. The RSS Smoothing Algorithm

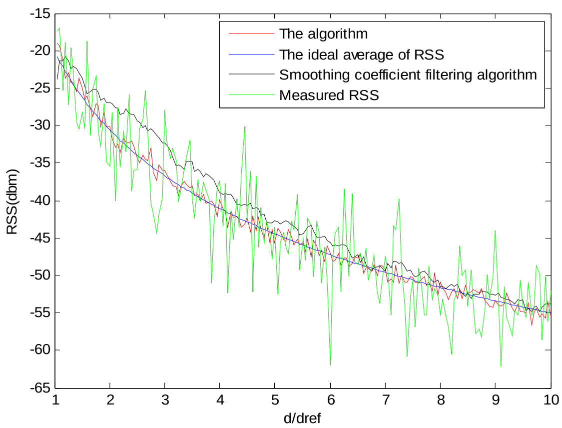

Figure 5. Variations in RSS with Distance between AP of WLAN and MN

To validate the efficiency of proposed RSS smoothing algorithm based on support functions, compared with the smooth coefficient filtering algorithm, the simulating example of variations in RSS with distance between AP and MN is given. As shown in Figure 5, the proposed algorithm can effectively reduce the influence of shadow effect on RSS.

3.2. The Vertical Handoff Decision Algorithm

In the literature [8], the HNE algorithm i.e. adaptive time threshold adjustment algorithm is adopted in the moving in WLAN scenario, while the traditional algorithm mostly adopt fixed RSS threshold. By using Matlab simulation, along with experimental parameters shown in Table 1, the handoff performance of three algorithms is compared with each other.

10000 random trajectories are generated within WLAN coverage, and MN movement speed ranges between $1km/h \sim 100km/h$ with an interval of $2km/h$. For each trajectory, a position l_1 and movement direction θ_1 are selected, when MN moves in WLAN, which are all with random uniform distribution within $[0,2\pi]$.

Table 1. System Simulation Parameters

Radius of WLAN R	150m
Transmission power of AP P_{Tx}	20dbm
Distance between AP and the reference point d_{ref}	1m
Pass loss at reference point P_{Lref}	40dbm
Pass loss index β	3.5
Standard deviation for shadow effect σ	4.3db
Handoff delay for moving from UMTS to WLAN τ_1	2s
Handoff delay for moving from WALN to UMTS τ_2	2s
Tolerable handoff failure probability p_f	0.02
Tolerable unnecessary handoff probability p_a	0.04

In order to evaluate handoff efficiency, herein an efficiency function U_i is defined:

$$U_i = e^{E_{i,2}-E_{i,3}}(N - N_{unnecessay}) + e^{E_{i,1}}(N_{unnecessay} - N_{failure} + 10000 - N) \quad (30)$$

Where $E_{i,2}$ and $E_{i,1}$ are revenue function in WLAN and UMTS respectively for user i, $E_{i,3}$ is signaling overhead resulting from vertical handoff, N is the total handoff times, $N_{unnecessay}$ is the unnecessary handoff times, and $N_{failure}$ is handoff failure times.

If $E_{i,3}$ is set to be a fixed value, for example $\frac{1}{2}\ln 2$, the compensating time in Equation (13) can be expressed:

$$\Delta T = \begin{cases} \infty, \Delta E_i < 0 \\ \dfrac{\tau_1}{2(e^{\Delta E_i} - 1)}, 0 < \Delta E_i < \ln\dfrac{3}{2} \\ 0, else \end{cases} \quad (31)$$

Figure 6 ~ 9 show handoff performance comparison for three algorithms in different network context. Where $\Delta E_i < 0$, As shown in Figure 6, compared with traditional algorithm, our proposed algorithm can effectively reduce handoff failure probability and unnecessary handoff probability to 0. Where $\Delta E_i = 0$, the handoff performance is shown in Figure 7.

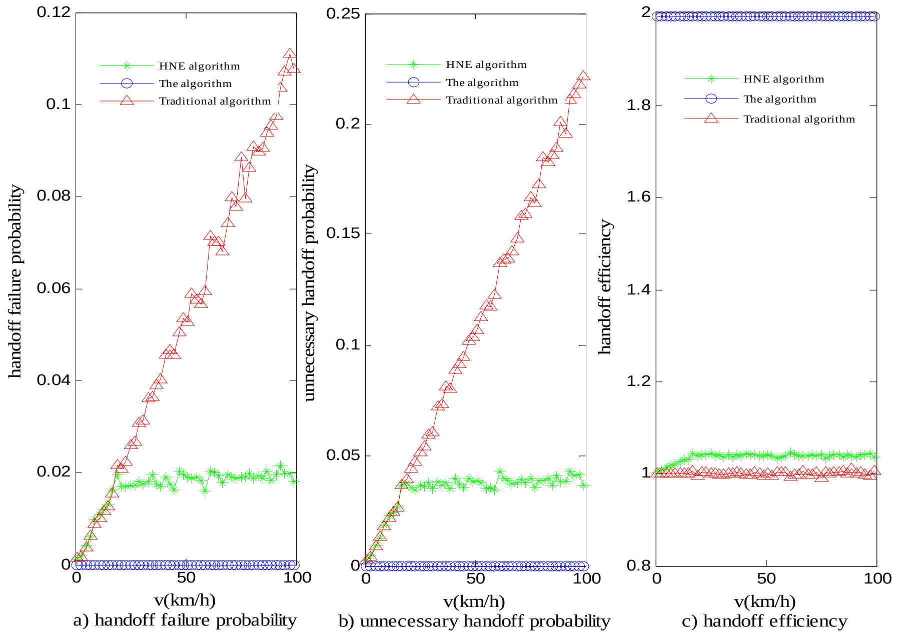

Figure 6. The Handoff Performance when MN Moves into WLAN, $\Delta E_i < 0$

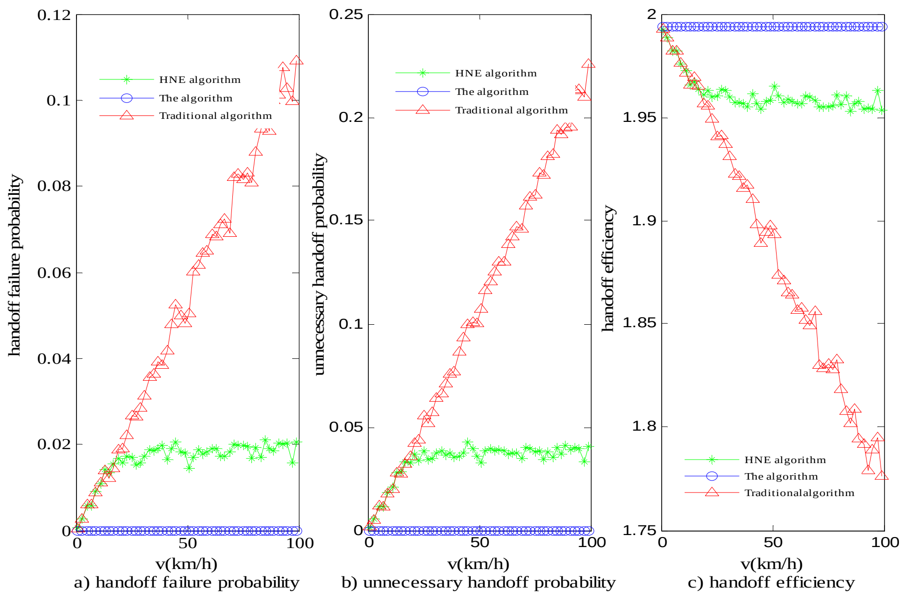

Figure 7. The Handoff Performance when MN Moves into WLAN, $\Delta E_i = 0$

Where $0 < \Delta E_i < \ln \frac{3}{2}$, as shown in Figure 8, the proposed algorithm can effectively reduce handoff failure probability, and improve handoff performance.

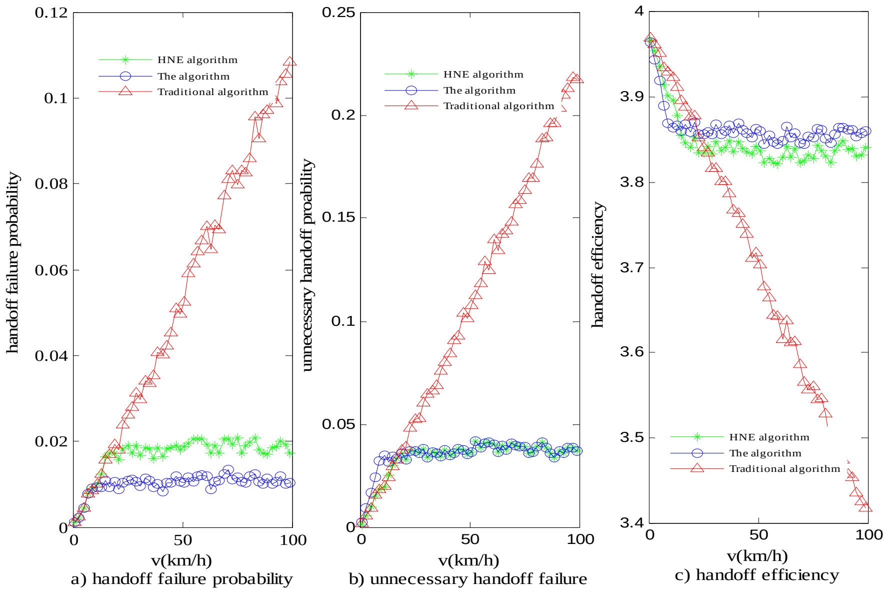

Figure 8. The Handoff Performance when MN Moves into WLAN, $0 < \Delta E_i < \ln\frac{3}{2}$

Where $\Delta E_i \geq \ln\frac{3}{2}$, as shown in Figure 9, the proposed algorithm can achieve the same level of handoff performance as HNE algorithm.

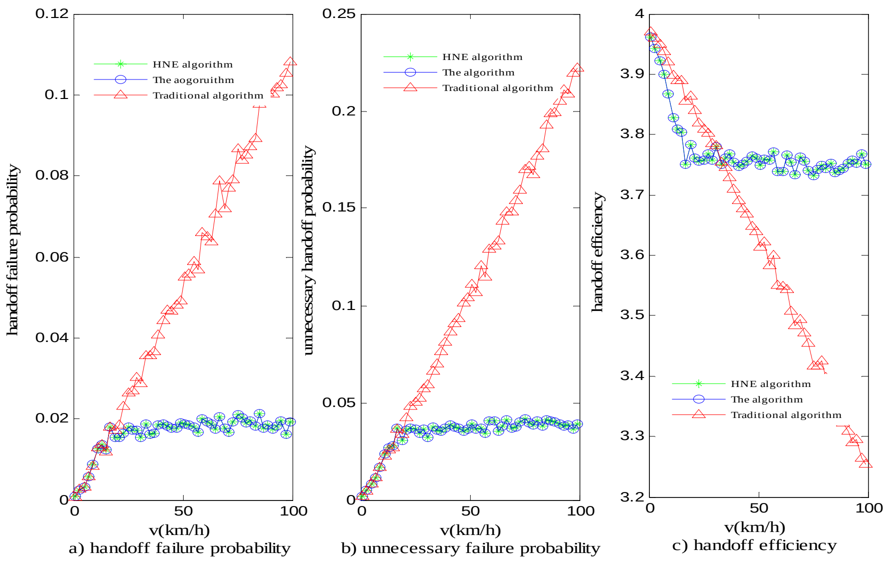

Figure 9. The Handoff Performance when MN Moves into WLAN, $\Delta E_i \geq \ln\frac{3}{2}$

In a word, compared with HNE algorithm and the traditional algorithm, our proposed adaptive speed threshold and compensating time algorithm can effectively reduce the 'ping-pong effect' and handoff failure probability, thereby making more accurate handoff decision.

4. Conclusion

In this paper, based on UMTS and WLAN integration framework, incorporating the mobile terminals and the network context, the necessity of handoff to WLAN is researched, and by using probability theory, the adaptive RSS threshold based on compensating time is calculated. Simulation results show its validity. Meanwhile, the proposed RSS smoothing algorithm based on support function can effectively reduce the influence of shadow effect on RSS and thereby improving the decision accuracy.

Acknowledgments

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