Vertical Handoff Decision Algorithm in Heterogeneous Wireless Network Based on Queuing Theory

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Abstract— **A smart vertical handoff decision algorithm based on queuing theory is proposed in this paper. Vertical handoff in heterogeneous wireless network is crucial to the future wireless communication. The algorithm formulates the heterogeneous wireless area and handoff procedure using queuing theory and proposes a new network selection index called new handoff blocking probability to evaluate the network performance. A RSS-based mechanism is considered to avoid the Ping-Pong effect. Also the network architecture is regulated to manage the wireless resource effectively. The experimental results show that the proposed algorithm outperforms the traditional algorithm with low handoff blocking probability and a better load balance of the whole wireless environment.**

Keyword—**Heterogeneous wireless networks, Queuing theory, Wireless resource management, Vertical handoff**

I. INTRODUCTION

WITH the rapid development of wireless technologies, the evolution of mobile communication result in an increasing number of heterogeneous networks. The future wireless networks are imaged as a combination of multiple wireless access networks like WIFI, WiMAX, Universal Mobile Telecommunications System (UMTS) and LTE, which can provide mobile users with Always Best Connected (ABC) services [1]. Mobile users will more likely face the environment in which a number of wireless networks coexist for a long period of time [2]. So it is crucial to integrate heterogeneous networks and offer mobile users better services. In such wireless network environment, the universal seamless handoff between heterogeneous wireless technologies is a challenging problem. Facing this problem, the architecture for 4th Generation (4G) wireless networks aims to integrate various heterogeneous wireless access networks over an IP backbone [3].

In heterogeneous wireless networks, handoff can be divided into two categories: horizontal handoff (HHO) and vertical handoff (VHO) [5].A HHO is made among different access networks when changing a connection from one access point (AP) to another or one base station (BS) to another, that is to say, the network have the same link-layer technology. While a vertical handoff happens between access networks with different link-layer technologies, such as changing a connection between an AP and a BS. Compared with the horizontal handoff, the vertical handoff is more complex for application. One of the main challenges for vertical handoff is how the handoff strategy determines the "best" network from the available heterogeneous candidate networks [4]. In this way handing off to a different network can be regarded as a multiple attribute decision making (MADM) problem. And in the progress of MADM, it is necessary to estimate the weights of the factors comprehensively, so as to make a good trade-off between the performance optimization of single MN and efficient utilization of whole wireless environment.

The rest of the paper is organized as follows: we briefly review the related works about vertical handoff decision algorithms In Section II. In Section III, a vertical handoff decision algorithm based on queuing theory is proposed. Then Section IV shows the performance evaluation of our proposed algorithm. Finally, a conclusion is summarized in Section V.

II. RELATED WORK

The received signal strength (RSS) is usually used in traditional vertical handoff algorithms. MADM is a popular method to select a target network from a set of candidate networks that have many attributes to consider. Some of MADM methods are: 1) SAW (Simple Additive Weighting); 2) TOPSIS (Technique for Order Preference by Similarity to Ideal Solution); 3) AHP (Analytic Hierarchy Process); 4) GRA (Grey Relation Analysis) [6]. Then some other handoff algorithms are proposed and can be summarized as following. (1) Fuzzy logic, fuzzy logic is proposed to represent the imprecise information of the conditions about the heterogeneous networks and to adapt dynamically to evaluate multiple attributes simultaneously [7]. (2) AHP (Analytic Hierarchy Process), AHP decomposes the network selection problem into several sub-problems and assigns a weight value

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to each sub-problem [8]. Then, the network with the highest performance score is selected. (3) SSF (Strongest Signal First), in this model RSS is the only affecting factor of selecting access network.

Although various vertical handoff algorithms are proposed, some problems remain unsolved. Some algorithms, such as SSF, tend to adopt a simple decision algorithm to maintain a faster handoff procedure. But the simple decision-making mechanism may not help to select a suitable network and may also yield serious Ping-Pong effect. Others regard the handoff decision procedure as a multiple attribute decision making problem [9-11, 16] and tend to solve the problem by searching for the optimal solution. These algorithms emphasize on the optimized network for single MN (mobile node) and neglect the evaluation of the whole wireless environment, which may cause the unbalanced loads distribution, serious time delay and the increasing number of handoff dropping. To overcome these problems, our algorithm is proposed. In this paper we formulate the whole heterogeneous wireless environment and handoff procedure using queuing theory. And a RSS-based mechanism is considered to avoid the Ping-Pong effect. We also regulate the network architecture to manage the wireless resource effectively. Then, we propose a new network selection index called new handoff blocking probability to evaluate the network performance. Finally a smart vertical handoff decision algorithm based on queuing theory is proposed.

III. The Proposed Scheme

In heterogeneous wireless networks, the coverage environment can be divided into two areas: cellular coverage area and WLAN hotspots area. The WLANs are typically configured as small cells within the "cellular coverage area" of GPRS/UMTS or LTE, which is relatively larger compared with WLAN hotpots [12]. The cellular coverage area is covered by a set of overlapping BSs $B=\{b_1,b_2\cdots b_M\}$ and a set of WLAN APs $A=\{a_1,a_2\cdots a_N\}$. In our algorithm, the cellular coverage area is implemented in a vertical handoff decision system (VHDS). The VHDS consists of two parts: multiple vertical handoff decision transducers (VHDT) and a central vertical handoff decision controller (CVHDC). VHDTs are located in each access network in order to provide real-time network conditions and handoff requests of networks in the cellular area. CVHDC execute the vertical handoff decision for the whole wireless region after analyzing the collected message from VHDTs. The signaling interaction between CVHDC, VHDT and access networks will be obtainable by the media independent handoff (MIH) which is defined in IEEE 802.21 [13].

VHDS maintains the sets A and B which covers the cellular coverage region as a list S of candidate access points. All available WLAN APs in set A and BS in set B are added into S. In addition, we define $U=\{u_1,u_2\cdots u_K\}$ as the set of all the mobile nodes (MN) which have the probability to access the network in the cellular coverage region. Only these K MNs are considered in this model and each MN is either requesting a handoff (or just turned on and require channel) or remains connected to an AP ($\in A$) or BS ($\in B$). Then, we divide the set U into two subsets at a certain time: $U_h(t)$ and $U_r(t)$.

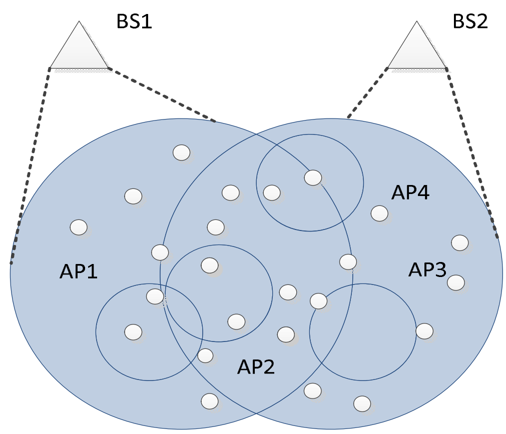

Figure.1. simulation topologies of heterogeneous networks

$$U_h(t)=\{u_{h1},u_{h2}\cdots u_{h(t)}\} \tag{1}$$

In equation (1), $U_h(t)$ stands for the set of MNs which request handoff at the certain time t and $h(t)$ is the number of set $U_h(t)$.

$$U_r(t)=U-U_h(t)=\{u_{r1},u_{r2}\cdots u_{r(t)}\} \tag{2}$$

Accordingly, $U_r(t)$ is the complementary set of $U_h(t)$ and represents the MNs which will remain the connection to the current networks at the certain time. $r(t)$ is the number of set $U_r(t)$.

In this scene, the bandwidth change problem can be formulated by queuing theory. It is noted that the vertical handoff decision algorithm is deployed in each AP or BS. And each AP or BS has the limitation to the available bandwidth which means that the channels provided by the network is limited by each network and only certain number of connection can be maintained. To simplify the problem, we assume that only La channels and Lb channels are allocated by each AP or BS respectively. Fig.1 shows the decision-making epochs of CVHDC.

The sequence $T=\{t_1,t_2\cdots t_z\}$ represents successive time epochs, where the variable t_z denotes the current time epoch. For each network i, the handoff arrival rate sequence $X_i=\{x^i{}_1,x^i{}_2\cdots x^i{}_{z-1}\}$ and the service complete rate sequence $Y_i=\{y^i{}_1,y^i{}_2\cdots y^i{}_{z-1}\}$ will be stored and CVHDC will make the decision at t_z based on them.

For the traffic characteristics, the handoff decision and channel allocation process of a network a_i or b_i can be formulated as $M/M/n/n$ model. To dynamically adjust the process of network selection, we make the variable n dynamically respect the available channels $La_{(av)}$ and $Lb_{(av)}$ which are not occupied by MNs for AP and BS, respectively. The arrival of handoff requests for channels follows a Poisson distribution with mean λ_i and the service holding time is assumed in a negative exponential distribution with mean $1/\mu_i$ for each network i. These assumptions are common in the many researchers [14, 15]. However, in our model we will dynamically adjust the λ_i and μ_i according to the real-time network condition sequences X_i and Y_i which is

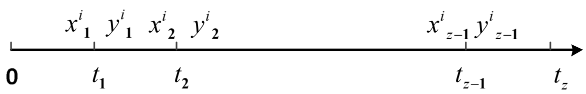

Figure.2. Successive time epochs of network

stored in CVHDC. So λ_i and μ_i will change in each time epoch and can be redefined to $\lambda_i(t_{z-1})$ and $\mu_i(t_{z-1})$ as function (3) and (4).

$$\lambda_i(t_{z-1}) = (1/t_{z-1})\sum_{k=1}^{z-1} x_k \tag{3}$$

$$\mu_i(t_{z-1}) = (1/t_{z-1})\sum_{k=1}^{z-1} y_k \tag{4}$$

The network in the cellular coverage area does not have holding queue, so the handoff will be blocked if all n channels of target network is occupied. Thus, we can define the probability which the network i is fully occupied as the new handoff blocking probability (NHBP) P_i which is derived from the new call blocking probability. P_i is defined according to the queuing theory as function (5). And we also propose the max blocking probability of the entire area by function (6).

$$P_i = (\lambda_i(t_{z-1})/\mu_i(t_{z-1}))^n (n!\sum_{j=0}^{n}((\lambda_i(t_{z-1})/\mu_i(t_{z-1}))^j / j!))^{-1} \tag{5}$$

$$P_b = MAX_{1\le i\le M+N}(P_i(E)) \tag{6}$$

The variable P_b is the max blocking probability of the entire cellular coverage area before the CVHDC makes the handoff decision at t_z. And our algorithm is aiming at minimizing the max blocking probability of the entire cellular coverage area.

To describe the connection status between MNs ($\in U$) and networks ($\in A \bigcup B$), a matrix $C(t) = \{c_{ij}\}_{(M+N)\times K}$ for the cellular coverage area is proposed. c_{ij} is equal to 1 only when there is a connection between network a_i or b_i and the MN u_j and 0 otherwise.

We also define the possible association matrix at t_z as

$C'(t_z) = \{c'_{ij}\}_{(M+N)\times K}$:

$$c'_{ij} = \{0,1\} \tag{7}$$

$$c'_{ij} = 0 \quad RSS_{ij} < \begin{cases} \theta_a & \text{for } 1 \le i \le N \\ \theta_b & \text{for } N+1 \le i \le N+M \end{cases} \tag{8}$$

$$\sum_{i=1}^{N+M} c'_{ij} = 1 \tag{9}$$

In the possible association matrix $C'(t_z)$, c'_{ij} is defined as 1 in two situations. One is that the MN u_j remains connected to the current network a_i or b_i. Another is that the MN u_j will hands off to the candidate network a_i or b_i .Each MN in the set $U_h(t)$ may have multiple candidate networks which satisfy the RSS thresholds θ_a (for AP) or θ_b (for BS), so the possible association matrix may also be multiple. Accordingly, we define $\chi(t_z)$ as the set of possible association matrices of t_z .For each possible association matrix $C'(t_z)$ in $\chi(t_z)$, we will generate a handoff matrix by the function (10):

$$H(t_z) = C'(t_z) - C(t_z) = \{H_{ij}\}_{(M+N)\times K} \tag{10}$$

$H(t_z)$ denotes the originate network i and the target network j of the handoff of MN u_k with the value h_{ik} = -1 and $h_{jk} = 1$. $h_{\alpha\beta}$ is equal to 0 only when the MN u_β remains the current connection. For the certain network i , we calculate the number of -1 and 1 in the i row of $H(t_z)$ as x_{off} and x_{in}, which denotes the number of MNs leaving and accessing the network. Then the model can be reformulated as following. For each network i :

$$\lambda_i(t_z) = (1/t_z)(\sum_{k=1}^{z-1} x_k + x_{in}) \tag{11}$$

$$\mu_i(t_z) = (1/t_z)(\sum_{k=1}^{z-1} y_k + x_{off}) \tag{12}$$

$$P_i(\mathrm{E}) = (\lambda_i(t_z)/\mu_i(t_z))^n (n!\sum_{j=0}^{n}((\lambda_i(t_z)/\mu_i(t_z))^j / j!))^{-1} \tag{13}$$

And for any possible association matrix $C'(t_z) \in \chi(t_z)$,

$$P_b(C'(t_z)) = MAX_{1\le i\le M+N}(P_i(E)) \tag{14}$$

Thus an algorithm aimed at minimizing expected new handoff blocking probability is proposed as follows:

$$\text{Min-P: } Min_{\forall C'(t_z)\in\chi(t_z)}(MAX_{1\le i\le M+N}(P_i(E)) \tag{15}$$

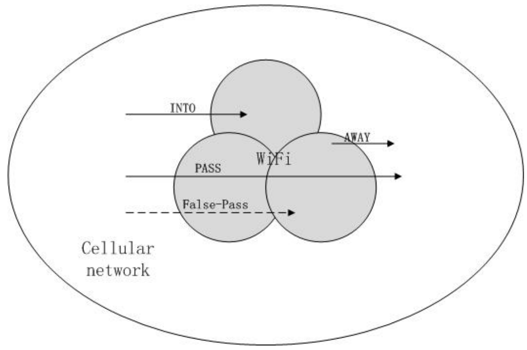

Figure 3. Handover modes

To avoid the Ping-Pong effect, a RSS-based mechanism is considered. We give four following modes to describe the movement of MN in Fig. 3. INTO mode: MN moves into some WLAN network from cellular network. AWAY mode: MN moves away from WLAN to cellular network. PASS mode: MN moves through WLAN networks from cellular network to the same cellular network in short time. False-Pass mode: MN moves into WLAN at a high speed, then moves at a low speed even stays in WLAN It is the supplement of PASS mode.

In the proposed algorithm, when MN is connecting to WLAN, MN detects RSS of the around APs to select the best AP. We use the generally applied radio communication model [9], defined as:

RSS=P_0-32.44-20lgf_c-20lg$d$-ShadowFading+FastFading (16)

Where P_0 (dBm) is the transmitting power of BS or AP, f_c (MHz) is the carrier frequency and d (km) is the distance from MN to BS or AP.

IV. Simulation Results And Analysis

In this section, our algorithm is evaluated by simulation compared with the AHP algorithm and SSF (Strong-Signal First). To ease our illustration, we just consider the situation in which there are two kinds of networks 3G and 802.11b. And the above two integrated heterogeneous wireless networks represent the set B and the set A in our algorithm respectively. The simulation topologies of heterogeneous wireless networks are shown in Fig.1. The cellular coverage area is covered by two overlapping 3G BSs and four 802.11b hotpots. The maximum bandwidth of BSs and APs are predefined as 3mbps and 7 mbps, respectively. Besides, the bandwidth requested by each MN is constant 0.2mbps. So according to the service request of MN, we can divide the BS and AP in 15 and 35 Channels. Then the model can be formulated as *M/M/35/35* and *M/M/15/15* for each BS and AP.

At the beginning of the simulation, MNs are evenly distributed over the coverage area. The MNs move around during the entire simulation time. We utilize a random mobility method to characterize the movement of MNs in the coverage environment. All the attributes (including RSS) for each MN and AP or BS association are reselected after each such movement. For simplicity, it is assumed in the simulations that each BS or AP will satisfy the MN's RSS threshold if it is within the coverage area of that BS or AP.

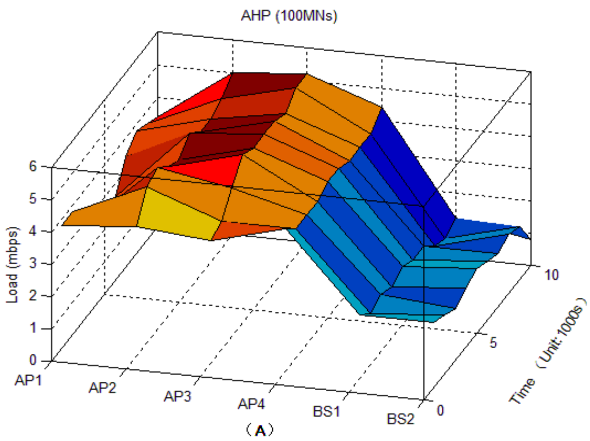

Figure.4. Load status for the AHP algorithm, when there are 100 MNs

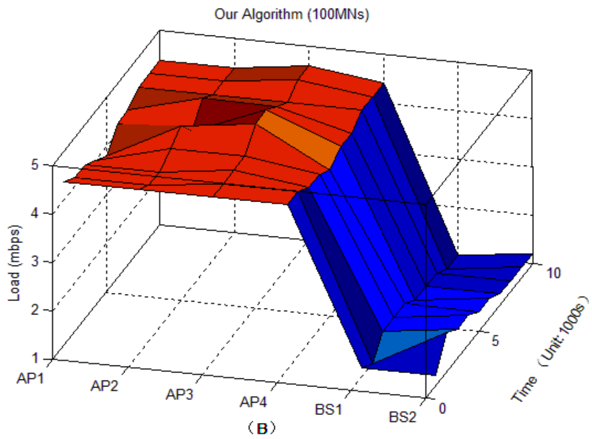

Figure.5. Load status for the our algorithm, when there are 100 MNs

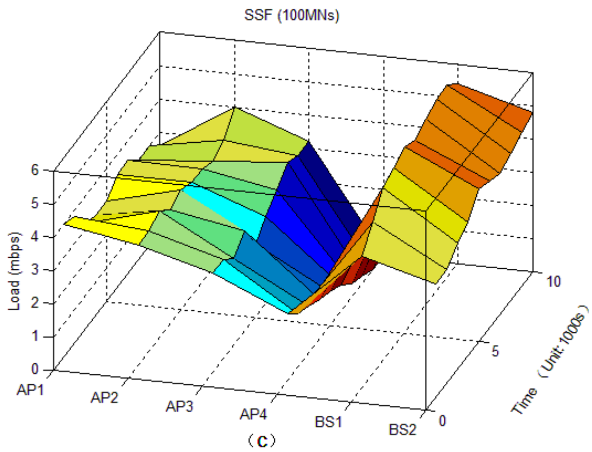

Figure.6. Load status for the SSF algorithm, when there are 100 MNs

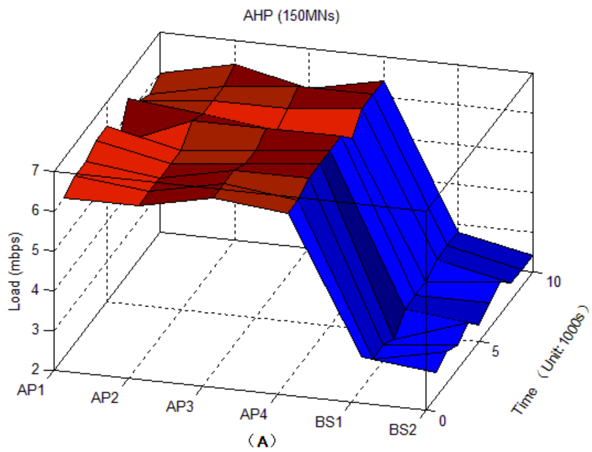

Figure.7. Load status for the AHP algorithm, when there are 150 MNs

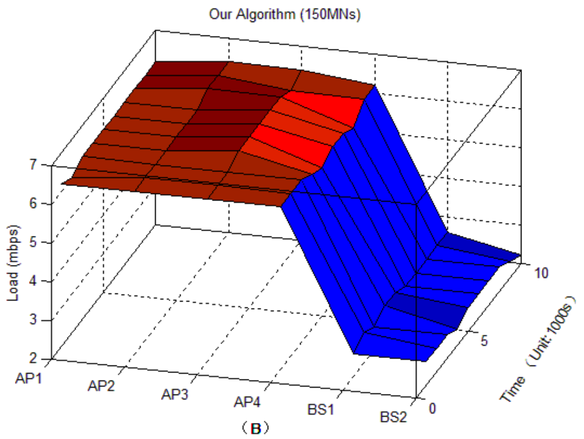

Figure.8. Load status for the Our algorithm, when there are 150 MNs

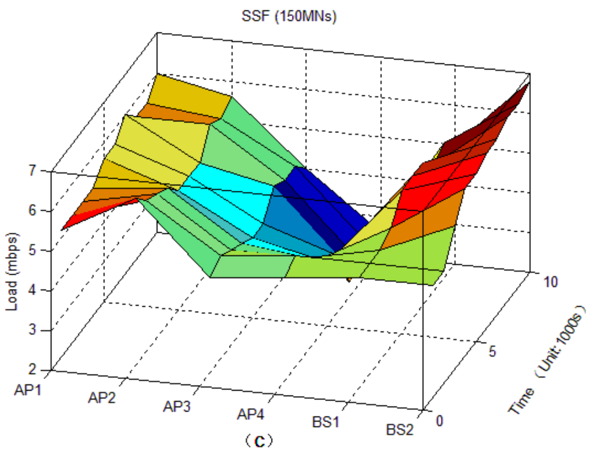

Figure.9. Load status for the SSF algorithm, when there are 150 MNs

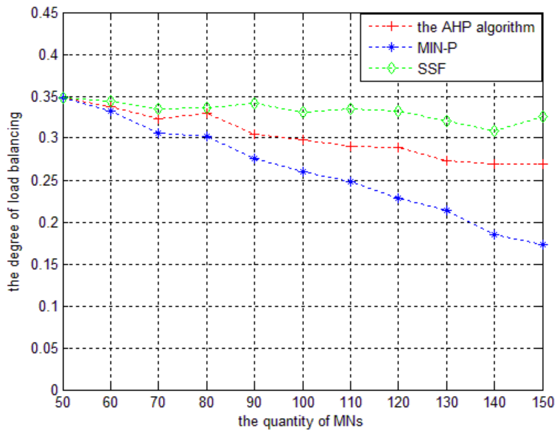

Figure.10. Load status for the SSF algorithm, when there are 150 MNs

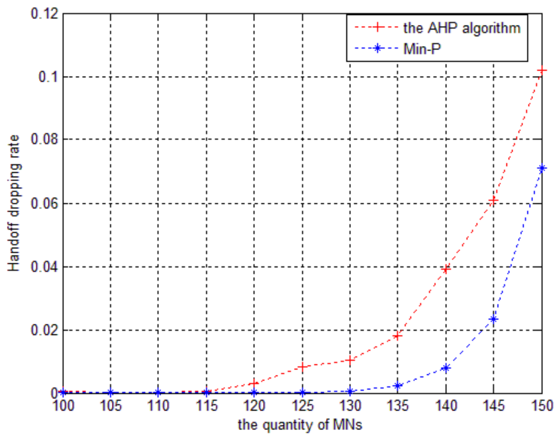

Figure.11. the maximum of handoff dropping probability in networks when MNs increase

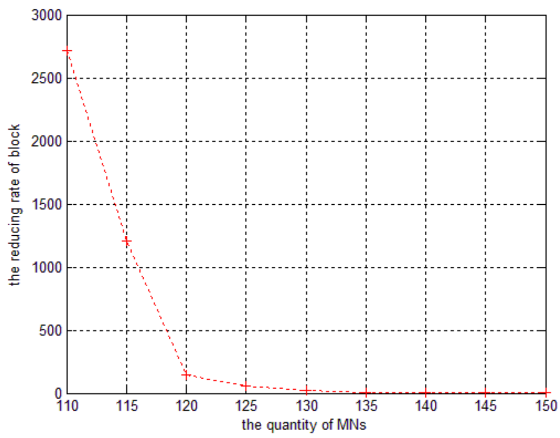

Figure.12. ratio of reducing the handoff dropping probability between the AHP algorithm and our algorithm

We evaluate the load balancing performance of our algorithm, the AHP algorithm and the SSF (Strong-Signal First) method. The lower the value is the better performance of load balancing the algorithm gets. Two independent simulations run with a duration of 1000s with the number of MNs 100 and 150, respectively.

In Fig. 4 to 6, we plot the overall load at each AP and each BS versus the simulation time for the first test case with 100MNs active in the test area. Similarly, the overall loads for the second test case with 150 active MNs are plotted in Fig. 7 to 9. These figures show how the load is distributed among heterogeneous networks. In different cases, the same result occurs. Our algorithm achieves the best performance in terms of the distribution of load, the AHP algorithm comes second and the SSF method performs worst.

From Fig. 10, it is easy to find out that when the quantities of connected MNs increase, the AHP algorithm and our algorithm both get a better load balance. However, the performance of SSF may perform even worse. In all case, our method gets better performance than the AHP algorithm and the SSF method.

Fig. 11 shows the maximum of handoff dropping probability in the six candidate networks when classifying the traditional AHP algorithm and our algorithm; the quantities of MNs increase from 100 to 150. The red plots in Figures 10 correspond to the traditional AHP algorithm and the blue plots correspond to ours. It could be seen that the maximum of handoff dropping probability in the six candidate networks increases monotonically when the connected MNs of the whole simulation area increase, which comply with the real situation. And it is also visible that when the quantity of connected MNs and the loads of the simulation area vary, our method always shows the improvement of reducing the maximum of handoff dropping probability over the traditional AHP algorithm.

More specially, in Fig. 12, we can also evaluate the multiples of reducing the max handoff dropping probability the between traditional AHP algorithm and our algorithm.

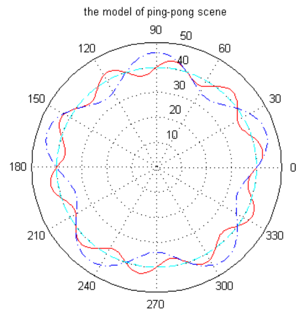

Figure 13. The simulation model of Ping-Pong scene under regular motion

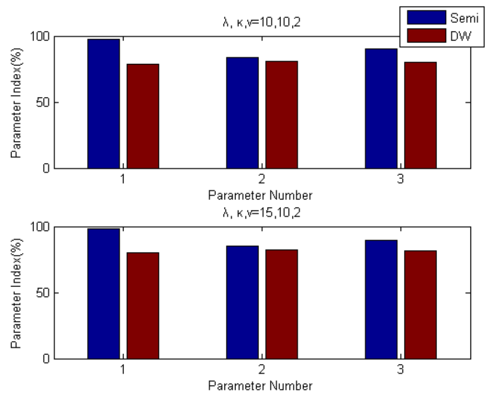

Figure 14. The simulation result1 in the Ping-Pong scene

The results show that our algorithm always outperforms the traditional AHP algorithm though the ratio of reducing handoff probability decreases sharply when the loads of the whole area increase.

Ping-Pong effect is considered in this algorithm. Ping-Pong means the interval is short between MN's continual vertical handovers. MN in this scene moves in state of Ping-Pong motion, i.e. has a to-and-fro movement in the edge of WLAN area. For simplifying, the WLAN area is assumed to have one AP. The AP's RSS is proportional to the polar coordinates equation of motion of MN, which is defined as:

$$r = 40 + \lambda \sin(k\theta) \tag{16}$$

where λ and k are trace coefficients. Fig. 13 presents the simulation model, including the motion traces in different λ and k. MN moves at constant speed according to the trace.

The model is used to evaluate the comprehensive performance of vertical handover algorithms in Ping-Pong motion, including selection of handoff time and the probability of Ping-Pong effect.

When the distance from MN to AP is not less, MN is supposed to choose WLAN, else, choose the cellular network. In that case, we say MN $\in U_h(t)$ hits the network. Hit ratios of cellular network and WLAN network are given in the simulation result to distinguish the algorithm performance into WLAN and out of WLAN.

In Fig. 14 and Fig. 15, parameter number 1 represents hit ration of WLAN, 2 is hit ratio of the cellular network, and 3 is the total hit ratio. From the results in Fig.14 and Fig.15, the performance of the proposed algorithm is higher than Dwelling-time algorithm on the whole.

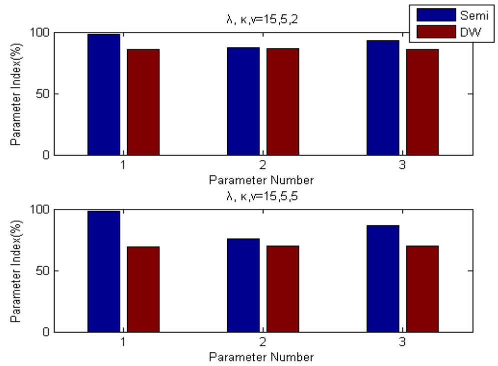

Figure 15. The simulation result2 in the Ping-Pong scene

V. CONCLUSION

In this paper, we focus on the metrics selection for the VHD and propose an index named new handoff blocking probability to evaluate the network performance. We also formulate the network architecture by adding VHDS (including VHDT and CVHDC) to manage wireless resources effectively. A method is used to avoid Ping-Pong effect. Then a smart vertical handoff decision algorithm is proposed based on queuing theory. The performance results based on detailed simulations show that our algorithm performs much better than the conventional AHP algorithm and SFF method. The proposed algorithm not only ensures the accuracy in network selectivity but also reaches the balance of load distribution over APs and BSs and effectively reduces the probability of handoff dropping.

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