This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the ICC 2007 proceedings.

A Novel Fuzzy Logic Vertical Handoff Algorithm with Aid of Differential Prediction and Pre-Decision Method

Liu Xia, Ling-ge Jiang and Chen He
Department of Electronic Engineering,
Shanghai Jiao Tong University,
Shanghai, P. R. China, 200240
{liuxia1623, lgjiang, chenhe}@sjtu.edu.cn

***Abstract*—In this paper, we propose a novel vertical handoff decision algorithm for overlay wireless networks consisting of cellular and wireless local area networks (WLANs). The target network is selected using a fuzzy logic-based normalized quantitative decision algorithm which, in addition to usual parameters such as the current received signal strength (RSS) and the available bandwidth, also takes a prediction of the RSS into account, resulting in a more accurate handoff. The RSS prediction is obtained using a differential prediction algorithm that has good accuracy. Furthermore, to reduce system load, a pre-decision method is employed before actual handoff decision to filter out users with high mobility or low RSS from using the WLAN. Simulation results show that the proposed algorithm can reduce the call-dropping probability as well as unnecessary handoffs in heterogeneous network environments.**

Keywords-fuzzy logic; differential prediction; pre-decision method; vertical handoff

I. INTRODUCTION

With the development of wireless communication technology, the wireless communication services is upgrading extremely fast. Today's wireless communication networks, which consist of an overlaid structure of different sizes and features, can be termed as Wireless Overlay Networks [1]. One of the most significant issues of the next generation network is overlay internet work management [2]. How to coordinate and interoperate the various types of networks has become a major concern in mobility management of next generation wireless systems [3].

In order to interconnect the different networks as mentioned above, vertical handoff is introduced and the optimized vertical handoff decision algorithm is required. Traditionally, horizontal handoff is defined as a handoff between base stations (BSs) that are using the same type of wireless network interface. This is a handoff for homogeneous wireless systems. Compared to horizontal handoff, vertical handoff is defined as a handoff between BSs that are using different wireless network technologies, such as Wireless LAN and 3G cellular networks [4]. This is a handoff for heterogeneous wireless systems. The traditional horizontal handoff research is emphasized on the received signal strength (RSS) evaluation of the mobile host (MH). However, in the case of vertical handoff, RSS evaluations and comparisons are insufficient for making an optimized vertical handoff decision. Many other metrics, such as service type, monetary cost, network conditions, system performance, mobile node conditions and user preferences, should be taken into consideration [5]. While RSS is the most important metric in vertical handoff and available bandwidth is a critical factor for network condition, we choose current RSS (CR) which is the actual value at each sampled time, predicted RSS (PR) and available bandwidth (B) as input parameters for our Fuzzy logic based Normalized Quantitative Decision (FNQD).

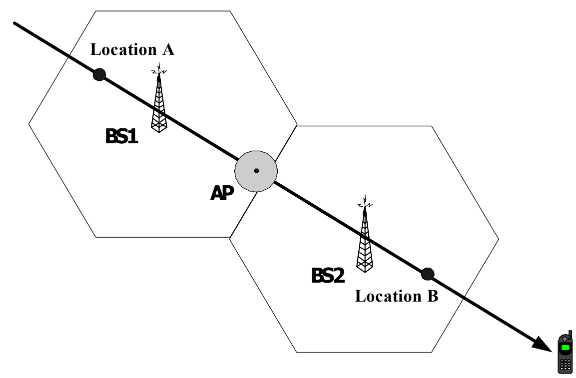

Figure 1. Mobile model in heterogeneous networks

In the proposed intelligent vertical handoff algorithm, we first use the predictor of forward differential prediction algorithm (FDPA) to predict the next time RSS. Then we take the pre-decision (PD) method with the predictor to filter the unnecessary data by velocity limitation and trigger the handoff by the predicted RSSs. After a handoff procedure is triggered, FNQD is implemented to quantitatively evaluate the performance of candidate networks. Finally, the optimized handoff decision is made by comparing the performance evaluation values of candidate networks.

Throughout the paper, we take the heterogeneous networks of WLAN and UMTS as shown in Fig. 1 to apply the proposed vertical handoff algorithm. The MH is moving from location A to B across the overlay network coverage. The rest of the paper is organized as follow. Section II reviews the related works of fuzzy logic theory based handoff algorithms. The developments of FDPA and PD method are described in Section III. In Section IV, the algorithm of FNQD is deduced in detail and its advantages are provided. Performance evaluations by simulations are presented in Section V. We discuss the future work and make final conclusions in Section VI.

II. Related Work

In heterogeneous environments, it is critical to design an efficient handoff algorithm for supporting seamless communication service. It is natural to apply fuzzy logic into the handoff decision phase because of the inherent strength of fuzzy logic in solving problems exhibiting imprecision. Ref [6] proposes a handoff decision based on fuzzy logic principle to decrease unnecessary handoff in the homogeneous cellular system. Fuzzy sets and enumerative fuzzy handoff rule base are established. But it is only considered the horizontal handoffs not applying for the vertical ones. In [7], an adaptive fuzzy based vertical handoff algorithm is presented to decide the RSS hysteresis values using user speed and traffic load. It only made handoff decision by RSS, while this is insufficient for vertical handoffs decision. Ref [8] provides a multi-criteria decision-making algorithm based on fuzzy theory for multiple access network selection. But it only gives the theoretic descriptions for mobility management without the performance evaluation for this strategy. The neuro-fuzzy predictor is used to predict the RSS in heterogeneous networks n [9]. Based on the fuzzy predictor, it has given the fuzzy inference mechanism to determine the possibility of handoff according to fuzzy decision algorithm. On the other hand, the system complexity has to be solved before it can be utilized widely.

In this paper, we implement the simple forward differential prediction and pre-decision method to get accurate handoff triggers. We do not use the fuzzy logic principle to decide the handoff hysteresis values like [7], but use it to evaluate the membership degrees of three input parameters in FNQD. Comparing the quantitative decision values of different networks can make the optimized handoff decision. The advantage of FNQD over traditional fuzzy handoff algorithms will be presented in Section V.

III. The developments of FDPA and PD method

In order to reduce call-dropping probability in vertical handoff, we introduce FDPA to predict the next time received signal strength. In this vertical handoff algorithm, PR is used to decide when to start a vertical handoff. If and only if the PRs in UMTS and WLAN are both fit to the RSS thresholds of the two networks, vertical handoff procedure will be triggered. Thus, handoff procedure will be started in advance even in fast fading environment. It can offset the time required to make a vertical handoff decision so as to reduce the call-dropping probability in some extent. Considering the limitation of MH complexity, we choose the forward differential prediction algorithm as the signal predictor due to its simplicity and efficiency. MH samples the RSS periodically in the procedure of moving. With a few sampled RSSs stored in the database of MH, PR can be achieved by FDPA. As the input sample size is only 2, it takes a short time to get the predictive result. The FDPA is developed as following:

$$\begin{aligned}\hat{r}(k+1) &= \alpha(k)\cdot I(k)+\beta(k)\\ &= [\alpha 1(k) \quad \alpha 2(k)][r(k) \quad r(k-1)]^T+\beta(k)\end{aligned} \tag{1}$$

in which, k is the current time; $I(k)$ is the input signal matrix at k, $I(k)=[r(k) \quad r(k-1)]$; $\alpha(k)$ and $\beta(k)$ describe the predict index matrix at the time k, $\alpha=[\alpha 1 \quad \alpha 2]$. We adopt the LMS algorithm to reach the optimal predicted index, that is, α and β are optimal to guarantee the error square minimal between the prediction values of $(k+1)$ and k. The index formulations are present as following:

$$\begin{cases}\alpha(k+1)=\alpha(k)+\mu\cdot e(k)\cdot I(k)\\ \beta(k+1)=\beta(k)+\mu\cdot e(k)\end{cases} \tag{2}$$

in which, $e(k)=d(k+1)-\hat{r}(k+1)$, μ is the fixed step size. As shown in Fig. 2, we predict the RSS in WLAN as an example. The FDPA is simple and accurate to predict the RSS trend of future time. It is a practical method for handoff procedure in wireless communication.

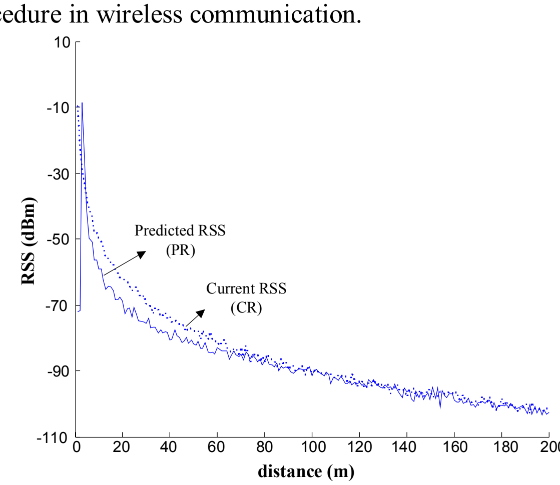

Figure 2. The curves of PR and CR in WLAN

Furthermore, the PD method with the FDPA predictor is used before the process of FNQD to reduce the system load and trigger vertical handoffs. We use mobile velocity (v) and PRs as the pre-decision metrics to filter part of input data for FNQD and accomplish the handoff trigger. This operation can eliminate quiet a few unnecessary handoff decisions. For example, when the user's velocity is larger than a specific value, vertical handoff from cellular network to WLAN should be avoided. If there is no the PD module before FNQD, each sampled data may start the handoff decision process including those beyond the mobile velocity limitation. By the PD processing, the data for FNQD is reduced dramatically so as to alleviate the system load.

We give the PD operation process of a MH moving from WLAN to UMTS in Fig. 3. PR_i (i=U or W) and v are taken as the PD input parameters. V_0 is the PD velocity

This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the ICC 2007 proceedings.

threshold; P_{rW} is the PD RSS threshold in WLAN; P_{rU} is the PD RSS threshold in UMTS. When MH is moving from WLAN to UMTS, the velocity threshold can filter the sampled data at first if its moving velocity is beyond the limitation. And this MH should choose UMTS at once without the need of FNQD. If its velocity is within the limitation, the next step is to execute the handoff trigger. When the PRs of WLAN and UMTS are both satisfied the handoff trigger requirements, the MT starts to perform FNQD.

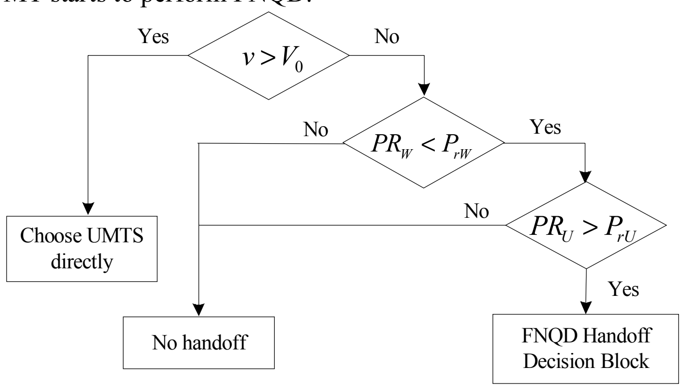

Figure 3. PD flowchart of vertical handoff from WLAN to UMTS

IV. Fuzzy Logic Based Normalized Quantitative Decision (FNQD)

After the processing of PD, the data arrive at the FNQD module. There are 3 sub-procedures in the proposed FNQD: Fuzzification, Normalization, and Quantitative Decision. The 3 input parameters are restated: current received signal strength at the MH from candidate networks, predicted received signal strength and available bandwidth unities of candidate networks. In FNQD, the input parameters are first processed by the fuzzification procedure. FNQD then normalizes the obtained membership degrees of the 3 input parameters, resulting in their normalized evaluation values (MNVs) respectively. Then FNQD carries out the handoff decision by the 3 MNVs to achieve a performance evaluation value (PEV). After the calculation process of FNQD, each candidate network gets its own PEV. The handoff decision scheme is the greater the PEV of a certain network, the higher the probability that the network becomes the target to handoff. The advantage of FNQD over traditional fuzzy handoff algorithms can be summarized as follows:

- FNQD is able to get the PEV of a certain candidate network. PEV tells the probability that the candidate network becomes the target one to handoff. There is no need to set aside some space to store the enumerative handoff rule bases, which may occupy a large memory of MH. For example, if 5 fuzzy sets are established for each of the 3 input parameters, the number of cases in rule bases will be $5^3 = 125$.
- The final vertical handoff decision is only based on the comparison of PEVs of the candidate networks. There is no need to execute defuzzy procedure with the rule bases, which may take a relatively long time.
- The FNQD can distinguish the target network explicitly among candidate networks. Since more and more wireless networks will become available in heterogeneous environments, it is possible that the rule bases established by traditional fuzzy logic algorithms may be too obscure to evaluate and select out the optimized candidate network, while the FNQD with better distinguishability can simply solves this problem.

A. Memberships of Input Parameters

Fig. 4 and Fig. 5 illustrate the membership functions of the input fuzzy variables. For the fuzzy variables CR and PR, we define T_{i-R1} to be the minimal RSS value of the candidate network i (i=U or W), that is, $T_{W-R1} = P_{rW}$, $T_{U-R1} = P_{rU}$; T_{i-R2} to be the maximal RSS value that can be provided by UMTS or WLAN. And they have five fuzzy sets (Very Weak, Weak, Medium, Strong, Very Strong) and fuzzy variable B has three fuzzy sets (Low, Medium, High).

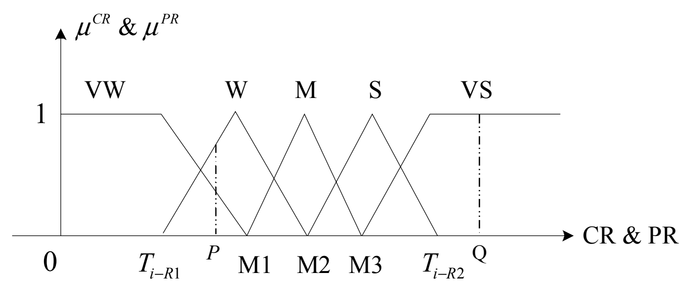

Figure 4. Membership Function of CR and PR

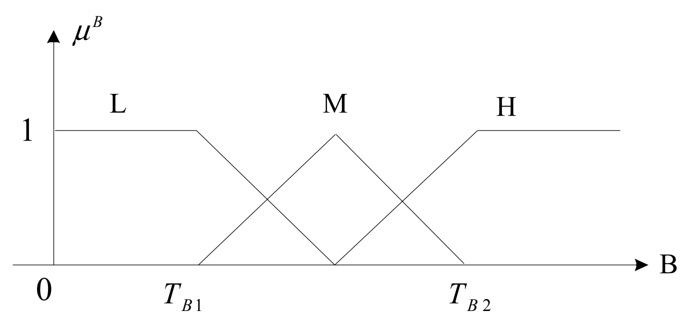

Figure 5. Membership Function of available bandwidth

In heterogeneous wireless networks, the fuzzy sets can be specified with different values according to the specific characteristics of the certain network. We give the membership function presentations of the three fuzzy variables: $[\mu_{i-VW}^{CR}, \mu_{i-W}^{CR}, \mu_{i-M}^{CR}, \mu_{i-S}^{CR}, \mu_{i-VS}^{CR}]$, $[\mu_{i-L}^{B}, \mu_{i-M}^{B}, \mu_{i-H}^{B}]$ and $[\mu_{i-VW}^{PR}, \mu_{i-W}^{PR}, \mu_{i-M}^{PR}, \mu_{i-S}^{PR}, \mu_{i-VS}^{PR}]$. If the real time measurement of CR in a candidate network is fed into its membership function, it can be classified into one (such as CR = Q in Fig. 4) or two (such as CR = P in Fig. 4) of the 5 fuzzy sets resulting in corresponding membership degrees. For example, when the input value is CR = P, the membership degree of P is $[0.4, 0.8, 0, 0, 0]$.

B. Membership Normalized Values (MNVs)

In order to normalize the membership degrees of CR, PR and B, specific normalized evaluations have to be assigned to each fuzzy set. The normalization indexes can be specified with different values according to the characteristics of a certain type of network in heterogeneous networks. Based on the membership degrees and normalized indexes of the fuzzy sets for each input parameters, the MNVs of CR, PR and B for each candidate network i can be calculated as follows.

The normalization index of CR and PR are given by

$$[N_{i-VW}^{CR}, N_{i-W}^{CR}, N_{i-M}^{CR}, N_{i-S}^{CR}, N_{i-VS}^{CR}] = [N_{i-VW}^{PR}, N_{i-W}^{PR}, N_{i-M}^{PR}, N_{i-S}^{PR}, N_{i-VS}^{PR}] = [\frac{r_i - T_{i-R1}}{4(T_{i-R2} - T_{i-R1})}, \frac{1}{10} + \frac{r_i - T_{i-R1}}{2(T_{i-R2} - T_{i-R1})}, \frac{1}{4} + \frac{r_i - T_{i-R1}}{2(T_{i-R2} - T_{i-R1})}, \frac{3}{5} + \frac{2(r_i - T_{i-R1})}{5(T_{i-R2} - T_{i-R1})}, \frac{r_i - T_{i-R1}}{T_{i-R2} - T_{i-R1}}] \quad (3)$$

The normalization index of B is given by

$$[N_{i-L}^{B}, N_{i-M}^{B}, N_{i-H}^{B}] = [\frac{b_i - T_{B1}}{2(T_{B2} - T_{B1})}, \frac{1}{4} + \frac{b_i - T_{B1}}{2(T_{B2} - T_{B1})}, \frac{b_i - T_{B1}}{T_{B2} - T_{B1}}] \quad (4)$$

For a candidate network i, the MNVs of CR, PR and B are given by (5)-(7) respectively:

$$\mathrm{MNV}_i^{CR} = [N_{i\text{-VW}}^{CR}, N_{i\text{-W}}^{CR}, N_{i\text{-M}}^{CR}, N_{i\text{-S}}^{CR}, N_{i\text{-VS}}^{CR}] \times [\mu_{i\text{-VW}}^{CR}, \mu_{i\text{-W}}^{CR}, \mu_{i\text{-M}}^{CR}, \mu_{i\text{-S}}^{CR}, \mu_{i\text{-VS}}^{CR}]^T \quad (5)$$

$$\mathrm{MNV}_i^{PR} = [N_{i\text{-VW}}^{PR}, N_{i\text{-W}}^{PR}, N_{i\text{-M}}^{PR}, N_{i\text{-S}}^{PR}, N_{i\text{-VS}}^{PR}] \times [\mu_{i\text{-VW}}^{PR}, \mu_{i\text{-W}}^{PR}, \mu_{i\text{-M}}^{PR}, \mu_{i\text{-S}}^{PR}, \mu_{i\text{-VS}}^{PR}]^T \quad (6)$$

$$\mathrm{MNV}_i^{B} = [N_{i\text{-L}}^{B}, N_{i\text{-M}}^{B}, N_{i\text{-H}}^{B}] \times [\mu_{i\text{-L}}^{B}, \mu_{i\text{-M}}^{B}, \mu_{i\text{-H}}^{B}]^T \quad (7)$$

C. Vertical Handoff Decision Making Using PEVs

After the calculation of MNV_i^{CR}, MNV_i^{PR} and MNV_i^{B}, the final performance evaluation value of network i (PEV_i) can be achieved by integrating the 3 MNVs together. The weights w^{CR}, w^{PR} and w^{B} have to be assigned for the three MNVs. The weights are adjusted to be proportional to the certainties of the respective network condition [10]. It should reflect the importance and relationships of the continuously changing under the wireless heterogeneous environment. The function of weights is to highlight the dominant-difference among candidate networks, that is, to magnify the dominant-advantage of certain candidate network. In addition, considering the complexity of MH, we choose the fixed weights for the MNVs. The weights are set by:

$$\omega = [\omega^{CR}, \omega^{PR}, \omega^{B}] = [0.5, 0.3, 0.2]$$

$$\text{where} \quad \omega^{CR} + \omega^{PR} + \omega^{B} = 1 \quad (8)$$

For a certain candidate network i, its PEV can be calculated as in (9).

$$PEV_i = \omega \times MNV^T = [\omega^{CR}, \omega^{PR}, \omega^{B}] \times [MNV_i^{CR}, MNV_i^{PR}, MNV_i^{B}]^T \quad i = W \text{ or } U \quad (9)$$

By comparing the PEVs of the candidate networks, the network with the largest PEV can be selected. And this is the final target network to handoff. Thus we can infer the handoff decision scheme as:

(a) When MH is moving from UMTS to WLAN

if $PEV_W > PEV_U$ *, then make handoff to WLAN, else stay in UMTS.*

(b) When MH is moving from WLAN to UMTS

if $PEV_U > PEV_W$ *, then make handoff to UMTS, else stay in WLAN.*

V. SIMULATION MODEL AND RESULTS

The simulation model of FNQD is a certain mobile telephone system. The moving route of a MH is assumed to be a certain direction from Location A to Location B as shown in Fig. 1, where the mobile velocity is obtained by GPS. The relevant parameters are present in TABLE 1.

TABLE Ⅰ. Simulation Parameters

Parameter	UMTS	WLAN
R	1000m	100m
P_t	1 Watt	100 mWatt
V_0	90km/h	
P_{rW}, $T_{W\text{-}R1}$	None	-105dBm
$T_{W\text{-}R2}$	None	-85dBm
P_{rU}, $T_{U\text{-}R1}$	-125dBm	None
$T_{U\text{-}R2}$	-105dBm	None
T_{B1}	0.2	
T_{B2}	0.6	

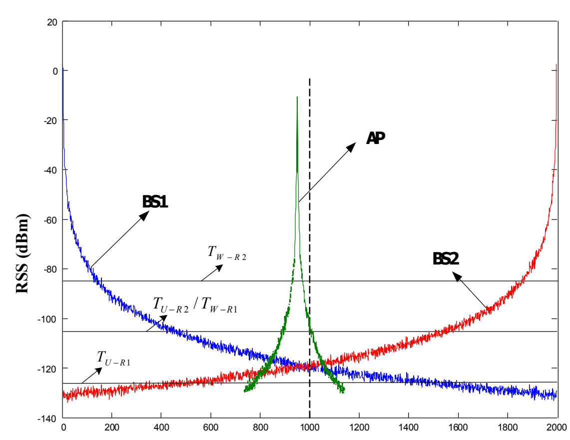

Figure 6. The RSS curve of MH in heterogeneous networks

With the movement of MH in the overlay network, the changing curves of current RSSs from BS1, BS2 and AP are shown in Fig. 6. Fig. 7 illustrates the available bandwidth of BS1, BS2 and AP, which are varying with the changing of MH location.

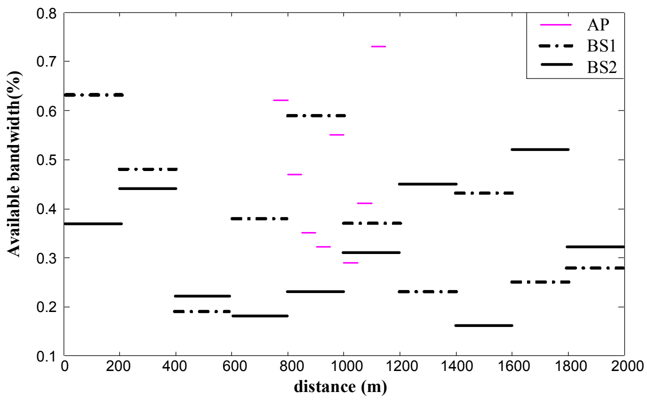

Figure 7. The curve of bandwidth changing in candidate networks

After the calculation of FNQD, the PEVs of the current and candidate networks are shown in TABLE 2. It has to be pointed out that the location of AP is not the midpoint of BS1 and BS2 as shown in Fig. 1; AP is nearer BS1 than BS2. Therefore in the first handoff procedure, the network condition for MH is better than that of the second handoff, that is, the PEVs of two networks in the first handoff are larger than those of the second handoff. And the locations where handoffs have occurred are shown in Fig. 8. It illustrates the proposed algorithm can execute accurate handoffs and eliminate the ping-pong effect.

TABLE Ⅱ Vertical Handoff Results of Candidate Networks

Handoff number	PEV_U	PEV_W	Handoff location	Decision results
1	0.46162	0.60976	874m (BS1&AP)	WLAN (AP)
2	0.30871	0.27375	1053m (AP&BS2)	UMTS (BS2)

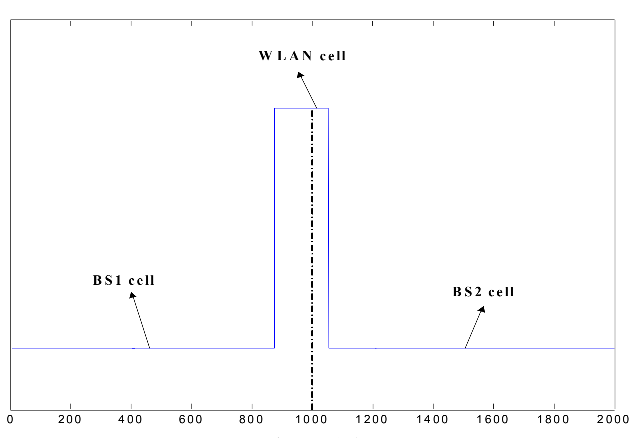

Figure 8. The result of vertical handoff decision based on FNQD

VI. CONCLUSIONS

In this paper, we have presented an intelligent vertical handoff algorithm in heterogeneous wireless networks. Our proposed vertical handoff algorithm considers some network parameters including velocity, current RSS, predicted RSS and available bandwidth unity of candidate networks. The forward differential prediction algorithm is used to get the predictive RSS, which can trigger a handoff in advance. And the pre-decision method is applied before the handoff decision module, which can filter the unnecessary data and provide accurate handoff trigger. Fuzzy logic principle based evaluation and decision algorithm FNQD is applied to the overlay network of UMTS and WLAN. The final optimized handoff decision can be made based on the resulted PEVs. FNQD algorithm can save the MH's memory to store the rule bases, saves the time to defuzzy within the rule bases, and distinguish the best one among various candidate networks. The simulation results show that the proposed vertical handoff scheme provides high performance to eliminate the ping-pong effect in the heterogeneous network. The handoff scheme can be carried out easily through simple intelligent software controller without complicated system hardware.

Our proposed vertical handoff algorithm is not taking network cost, service types and the other network factors into account. We plan to choose different factors as input parameters to see if these changes can affect the service quality in wireless communication networks. And for the space constraint, the performance evaluations of throughput, handoff delay and system load will not appear in this paper, we will discuss these problems further in other articles. What's more, we make the weights of PEVs fixed in FNQD algorithm. However, in order to meet the need of continuously changing wireless environment, the weights should vary dynamically. We plan to use neural method to intelligently decide the weights and satisfy the dynamic network conditions in the future work.

ACKNOWLEDGMENT

This research is supported by the National Nature Science Foundation of China Grant No. 60372076.

REFERENCES

[1] Randy H. Katz and Eric A. Brewer, "The case for wireless overlay networks", *Proceedings of SPIE Multimedia and Networking Conference*, San Jose, CA, 1996, pp.77-88.

[2] Upkar Varshney and Radhika Jain, "Issues in emerging 4G wireless network", *Computer*, vol. 34, no. 6, 2001, pp.94-96.

[3] Akyildiz I.F., McNair J., and Uzunalioglu H., "Mobility Management in Next Generation Wireless Systems", *Proceedings of the IEEE*, vol. 87, no. 8, 1999, pp.1347–84.

[4] M. Stemm and R. H. Katz, "Vertical handoffs in wireless overlay networks", *ACM Mobile Networking and Applications (MONET)*, vol. 3, no. 4, 1998, pp.335-350.

[5] McNair, J. and Fang Zhu, "Vertical handoffs in fourth-generation multinetwork environments", *IEEE Wireless Communications*, vol. 11, no. 3, 2004, pp. 8-15.

[6] Honman, B. and Benjapolakul, W., "A handover decision procedure for mobile telephone systems using fuzzy logic", *Proceedings of* IEEE Asia-Pacific Conference on Circuits and Systems, 1998, pp. 503-506.

[7] Majlesi, A. and Khalaj, B.H, "An adaptive fuzzy logic based handoff algorithm for interworking between WLANs and mobile networks", *Proceedings of the 13th IEEE ISPIMRC'02*, vol. 5, 2002, pp. 2446 – 2451.

[8] Bing Hongyan, He Chen and Jiang Lingge, "Intelligent signal processing of mobility management for heterogeneous networks", *IEEE Int. Conf. Neural Networks & Signal Processing*, China, 2003, pp. 1578-1581.

[9] Lin C. Jian, Tsai I-Ta and Lee C. Yung, "An adaptive fuzzy predictor based handoff algorithm for heterogeneous network", *IEEE Annual Meeting of the Fuzzy Information*, vol. 12, 2004, pp. 944-947.

[10] Jimenez D and Walsh N, "Dynamically weighted ensemble neural networks for classification", *IEEE International. Joint Conference on Neural Networks*, USA, 1998, pp. 753-756.