Vertical Handoff Algorithm Based on Type-2 Fuzzy Logic in Heterogeneous Networks

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***Abstract*—**Currently, to ensure seamless roam across heterogeneous wireless technologies, efficient vertical handoff algorithms are required to enhance QoS and offer reliable pervasive computing environment. This study reviews traditional and classical artificial intelligent approaches adopted for vertical handoff across heterogeneous networks. A type-2 fuzzy multi-parameter based vertical handoff decision algorithm is proposed. The proposed algorithm considers five parameters of network and user, and applies a multi-mode smart terminal based speed adaptive vertical handoff policy. The speed adaptive policy overcomes the update drawbacks of the fixed, single network discovery methods by using RSS in the network discovery phase. Simulation results show that the proposed algorithm can effectively improve the network update speed, lower network blocking probability, and assure the effectiveness and fairness of handoff compared with vertical handoff algorithm based on traditional fuzzy logic.

***Index Terms*—**heterogeneous network, vertical handoff, speed adaptive, type-2 Fuzzy logic

I. Introduction

Nowadays, With the growth of pervasive computing and wireless communication applications, there are large varieties of wireless technologies such as WiFi, UMTS, WiMAX, and etc[1,2]. Next generation networks concept proposes a heterogeneous structure consist of these different technologies. Since these wireless technologies overlap with each other, they can be in cooperation in order to fulfill user ubiquitous access requirements. For example, the intelligent transportation network will be broadband network and can support high-speed mobile broadband data services. However, no one network can provide all types of desired services, e.g. wide coverage, high bandwidth and low access costs. The WiMAX network supports high-speed mobile broadband data services and provides a wide network coverage area, low access cost, whereas cellular network provides lower data rates over a larger coverage area. We can integrate the mobile WiMAX network into the existing cellular network. On the condition of the multi-mode smart terminal (M-ST), heterogeneous networks above can performe as part of the intelligent transportation network and support users with real-time convenient transportation and communication services.

Handoff is the mechanism by which an ongoing connection between a mobile terminal and a correspondent terminal is transferred from one point of access network to another[3-7]. Thus, to roam seamlessly in heterogeneous network, there is a crucial need of an efficient and perfect vertical handoff decision algorithm over and above the horizontal handoff. The main objective of handoff algorithm is to maintain best-connected scenario along with good quality of service (QoS). In heterogeneous networks, handoff can be separated into two parts: *horizontal handoff* (HHO) and *vertical handoff* (VHO). A horizontal handoff is made between different access points within the same link-layer technology such as when transferring a connection from one BS to another or from one AP to another. A vertical handoff is a handoff between access networks with different link-layer technologies, which will involve the transfer of a connection between a BS and an AP. In general, the VHO process can be divided into three main steps: *access network discovery*, *handoff decision*, and *handoff execution*[2]. During the access network discovery phase, M-ST have to determine which access networks can be used and the services available in every network. During the handoff decision phase, the M-ST determines which network it should connect to. During the handoff execution phase, connections need to be rerouted from the existing network to the new network in a seamless manner. During the VHO procedure, the network discovery and handoff decision is the most important steps that affect terminal's QoS.

This paper is an extended for 7 literature, increased the survey of vertical handoff and multi-mode smart terminal switching process, at the same time, weakening the normalization requirement of parameters. The contributions of this paper can be summarized as follows:

- A novel M-ST, which senses the available network environment and adapt to its working parameters in order to camp on an appropriate BS or AP, is developed. And most of the smart terminal in motion face distinct network updating problems, speed adaptive policy in the M-ST is proposed.

Manuscript received April 20, 2013; revised June 15, 2013; accepted June 20, 2013. This work was supported in part by the National Natural Science Foundation of China under grant No. 60973114, 61170249, 61271259, by the Science & Technology Research Program of the Municipal Education Commission of Chongqing under Grant No. KJ120529,KJ130536, and the Foundation of Chongqing Key Laboratory of Computer Network and Communication Technology of China under Grant No. CY-CNCL-2010-02.

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doi:10.4304/jsw.8.11.2936-2942

- A novel multi-parameters vertical handoff decision algorithm is proposed, based on interval type-2 fuzzy logic and adaptive network fuzzy inference system. The adaptive network fuzzy inference system has the ability to adapt according to the network conditions and user requirements.
- The adaptive network fuzzy inference system and type-2 fuzzy logic modules of the vertical handoff algorithms are implemented using Matlab and the heterogeneous network scenario is implemented in NS-2.

II. Related Work

In the network discovery phase, almost all previous studies adopted to measure the received signal strength (RSS) of networks by uniform sampling in a fixed sampling time. When the RSS sampling result of a network subjected to certain conditions, the network would become the target candidate network. In [1], a fixed threshold RSS algorithm was proposed. However, the high-speed mobile users have entered a new network that failed to join the candidate network set in time because of fixed RSS sampling time, this algorithm leaded to the delay of network discovery time and the decrease of handoff efficiency.

In handoff decision phase, two main categories of handoff algorithms are proposed in the research literature[9] based on 1) the threshold comparison of one or more metrics[1-3,13-15] and 2) artificial intelligent techniques applied to improve the QoS of the handoff procedure[4-12,16-17].

The first category is the traditional algorithms widely used in cellular networks, which employs a threshold comparison of one or several specific metrics to decision a handoff. The most common metrics are RSS, carrier-to-interference ratio (CIR), signal-to-interference ratio (SIR), and bit error rate (BER)[13]. However, this study did not describe in enough detail how to define each characteristic property. In addition, it did not provide a detailed example to validate the decision function. The second categories of VHO algorithms use artificial intelligence (AI) techniques such as pattern recognition, neural networks [17], or fuzzy logic [10,11,13,17] to improve the accuracy and effectiveness of the handoff.

To sum up, Fuzzy logic (FL) concepts are applied to choose when and over which network to handoff among different available access networks.

A fuzzy logic system (FLS) that employs the type-2 fuzzy sets and/or type-2 fuzzy logic and inference is called a type-2 fuzzy system. In contrast, a fuzzy logic system using ordinary (i.e., type-1) fuzzy sets, logic and inference is called type-1 fuzzy system[18,19]. Accordingly, there are two kinds of adaptive fuzzy control: type-1 adaptive fuzzy control and type-2 adaptive fuzzy contro1.

Type-2 fuzzy set is all extension of type-1 fuzzy set. It is a three-dimensional system and includes a spatial uncertainty band, so the type-2 fuzzy set is supposed to have a better capability of modeling uncertainties[20]. Literatures show that the fuzzy contro1 using type-2 fuzzy sets can outperform the type-1 fuzzy control[21-23]. From the viewpoint of application, all existing vertical handoff algorithms employ type-1 fuzzy sets to build a type-1 fuzzy control system. It limits introducing uncertain factors from linguistic rules through predefined membership functions. To overcome the weakness, type-2 fuzzy sets have recently been proposed with their more general fuzzy membership functions and potential ability to solve real-world uncertain scenarios.

The concept of the type-2 fuzzy set was originally introduced by Zadeh [24] as an extension of the ordinary fuzzy set. Then, it has significantly been developed from theoretical research to applications in the past decade. A fuzzy logic system consisting of at least one type-2 fuzzy set is called a type-2 FLS[20]. In comparison with the type-1 FLS, a type-2 FLS has twofold advantages as follows: First, it has the capability of directly handling the uncertain factors of fuzzy rules caused by expert experience or linguistic description. Second, it is efficient to employ a type-2 FLS to cope with scenarios in which it is difficult or impossible to determine an exact membership function and related measurement of uncertainties. These strengths have made researchers consider type-2 FLS as the preference for real-world applications.

III. Assumption And Decision Parameters

A. Assumption

We assume that the terminal-controlled cooperated with network-assisted in the handoff decision problems. And the network environment and terminal satisfies the following conditions [2]:

- Neither the RSS of the WiMAX nor the RSS of the TD-SCDMA or CDMA network will change as time passes. In other words, the signal coverage area is stable.
- We assume that there is no height difference between the AP in a WiMAX and the BS in a TD-SCDMA or CDMA network. This means that the AP and BS are located in the same 2D space, and the M-ST only moves in this 2D space.
- There is no restriction on M-ST's movement, which means that the M-ST can move in any direction with any speed.
- We assume that the terminal was deployed by the multi-mode technology, which are able to be aware of, learn about, and adapt to the changing conditions for heterogeneous networks. This means that the AP and BS are sensed in the surrounding of M-ST.

B. Decision Parameters for VHO Algorithm

Several parameters have been proposed in our algorithm. We briefly explain each of them below.

- RSS: is the most widely used parameter because it is easy to measure and is directly related to the satisfaction of user. There is a close relationship between the RSS readings and the distance from the mobile terminal to its access point of attachment. Majority of existing horizontal and vertical handoff algorithms use RSS as the main decision parameter. And so, RSS is an important parameter for our algorithms as well. To achieve fair and effective comparison of RSS, it is necessary to normalize the RSS according to the threshold of received power and maximum transmit power of the different networks.
- Bandwidth: System available bandwidth is the major decision factor when terminal choose handoff network. In heterogeneous networks, the maximum available bandwidth and user's available bandwidth are

different, for the purpose of handoff fairness and effectiveness, the normalized bandwidth is used as the bandwidth indicator for handoff decision.

- Delay: For user, there would be different performance parameter value in different wireless access networks; therefore, in some situations the delay quality of a network service should be taken into consideration in making handoff decisions.
- Charge: For different wireless access networks, there would be different charging policies, therefore, in some situations the cost of a network service should be taken into consideration in making handoff decisions.
- Power: In different networks, the terminal device power consumption differs. The users prefer to choose the lower power consumption network.

IV. Candidate Network Adaptive Updating Policy

A. Compute Updating Time based on Speed Measurement

The GPS positioning technology is widely used in the smart terminal of heterogeneous network. Through uninterrupted receiving and calculating of satellite signals, smart terminal can obtain the actual speed at a specific time. On the whole, the terminal's movement is a variable motion. Therefore, the key is to calculate the radial average speed of smart terminal in a fixed sampling cycle.

The calculation principle of the radial average speed of smart terminal is to get N samples of instantaneous speed of terminal within T_S duration and to calculate the average value of the N samples. The result is just the radial average speed of mobile terminal. Assuming that the sampling period is T_S, the radial average speed of terminal is $\overline{V}_r$.

$$\overline{V}_r = \frac{1}{N}\sum_{i=0}^{N-1} V_i^r \qquad (i = 0 \cdots N-1) \tag{4}$$

Where V_i^r represents the radial speed of i'th sample relative to BS or AP.

In the process of handoff, the strategy function of update time of the target candidate network set makes adjustment according to terminal's radial average velocity. The strategy function is given as

$$\Delta T = T_{\min} + (T_{\max} - T_{\min})(1-r)^n \tag{5}$$

Where $T_{\min}$ and $T_{\max}$ are the minimum and maximum time of vertical handoff respectively, $V_{\max}$ is the maximum available speed of terminals in the current service network, r is the adaptive factor, $r = \overline{V}_r / V_{\max} \quad (0 \le r \le 1)$. $\overline{V}_r$ is the radial average speed of terminals in the sampling period T_S. Its value is given by (4). n is the exponential factor depending on the actual application. In mobile environment, the $\overline{V}_r$ is bigger, the r is bigger, so ΔT is smaller. Therefore, the candidate target network set can be updated more quickly.

B. Adaptive Updating Strategy

In this paper, we quantify the network capacity using amounts of channel. We assume that the total amounts of channel for i'th network is C_i^t and the number of the channel that has been occupied is C_i^o. When terminals access the network, the number of the required channel is C^r. R is the channel occupancy rate and given by $R = (C^r + C_i^o)/C_i^t$.

We also assume that M is the maximum channel occupancy rate, RSS from i'th network is RSS_i, the signal strength threshold from i'th network is RSS_i^{th}, the allowable delay of signal strength is ΔH_{dB}, N^t is the capacity of candidate network set, and the number of existing network in candidate network set is N^o.

1) Insert

In the i'th network, if $RSS_i \ge RSS_i^{th} + \Delta H_{dB}$ and $N^o < N^t$, Then, there are two cases.

Case 1: $R < M$ .This means that some unoccupied channel is existed in the i'th network and the i'th network can provide services for terminals. Therefore, i'th network is allowed to insert the candidate network set.

Case 2: $R \ge M$ .This means that no unoccupied channel is existed in the i'th network and the network can not provide services for terminals. Therefore, i'th network is refused to insert the candidate network set.

2) Remove

In the i'th network, if $RSS_i \le RSS_i^{th} + \Delta H_{dB}$ or $R > M$ (i'th network is overloaded), i'th network is removed from the candidate network set.

3) Replace

In the i'th network, if $RSS_i \ge RSS_i^{th} + \Delta H_{dB}$ and $RSS_i > RSS_j^{\min}$ (j'th network is a candidate network), $RSS_j^{\min}$ is the smallest received signal strength in the candidate network set, but the candidate network set can not accept new network, then, i'th network will replace j'th network.

V. Vertical Handoff Decision Algorithm based on Type-2 Fuzzy Logic

A. Multi-mode Smart Terminal

The proposed multi-mode smart terminal process model has a component of *wireless access network*, and it includes three modules: (1) a WiMAX module to handle Wireless Metropolitan Area Network (WMAN) operations, (2) a CDMA module to handle Wireless Wide Area Networks (WWAN) operations, (3) and a TD-SCDMA module to handle other Wireless Wide Area Network (WWAN) operations. Besides, it has a type-2 fuzzy logic-based smart handoff decision unit which is in charge of managing all of the handoff operations.

During the handoff network updating phase, M-ST listens to wireless medium for any handoff broadcast packet which might be sent by potential APs or BSs for a specified time span. During the listening period, the M-ST changes its working parameters such as frequency, modulation, quality, and bandwidth in order to adapt to any possible AP or BS.

When any AP is available, M-ST receives the handoff broadcast packet and extracts the network working parameters. It then invokes type-2 fuzzy logic-based handoff decision algorithm which takes these parameters as inputs; processes them; and produces an output called AP satisfaction value (APSV). APSV is generally defined by qualitative concept in order to quantify the strength of the satisfaction value of the candidate AP. The output concept values of APSV are *better, good, neutral, bad, and worse*. This transformation is based type-2 fuzzy membership function (Fig. 3). For instance, APSV can be designed to vary between weakest satisfaction degree and strongest satisfaction degree. Subsequently, all the aforementioned network parameters along with APSV are stored in the handoff decision table (HDT) for further usage.

All of these steps are repeated until the handoff detection process is terminated. In each turn, M-ST listens to the environment for potential APs, receives the handoff broadcast packet of the AP found, calculates the APSV using its adaptive type-2 fuzzy logic inference system, and stores all of the pieces of information required in the HDT. The sequence diagram of the proposed handoff decision algorithm is outlined in Fig. 1.

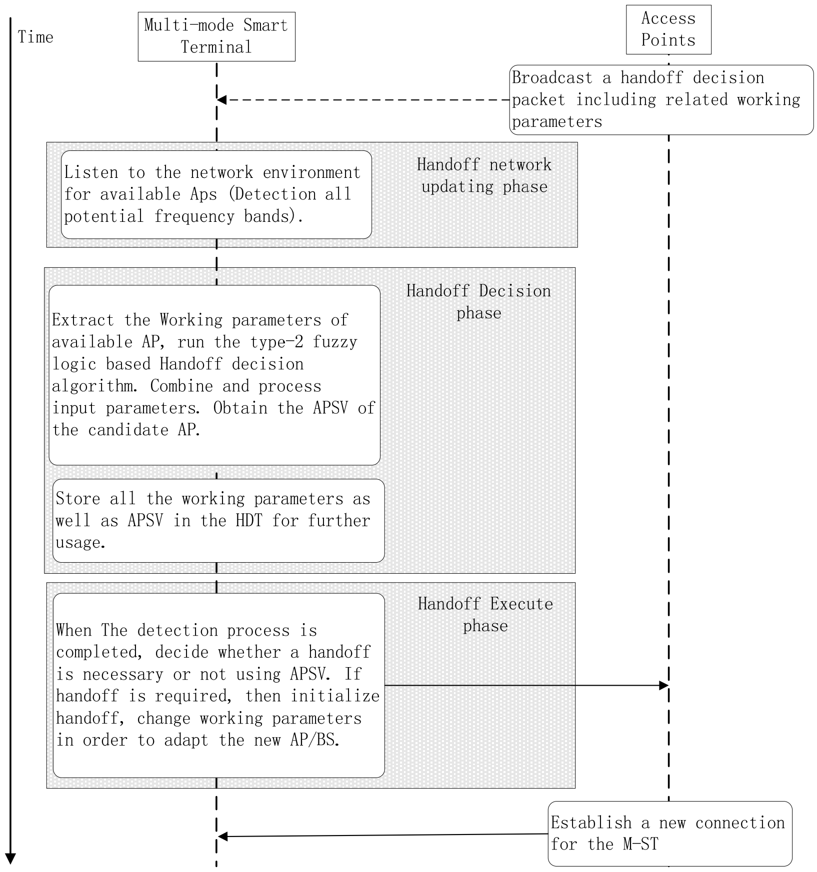

Fig. 1 Diagram of the proposed handoff decision algorithm

B. Proposed vertical Handoff Algorithm

Artificial intelligence-based systems such as fuzzy logic and artificial neural networks are good candidates for pattern classifiers due to their non-linearity and generalization capability [8-11]. Therefore, in the proposed handoff decision algorithm an interval type-2 fuzzy logic based approach has been adopted.

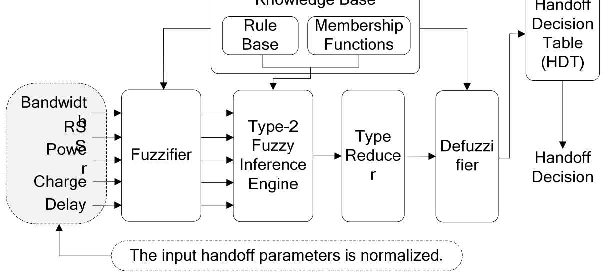

Fig. 2 Block diagram of the proposed interval type-2 fuzzy logic based vertical handoff decision system

Vertical handoff decision algorithm should initialize handoff process considering available network interfaces (bandwidth capacity, power consumption, link cost, and so on), system information, and application requirements (charge, delay, and so on). The block diagram of the proposed interval type-2 fuzzy logic based vertical handoff decision system is given in Fig. 2.

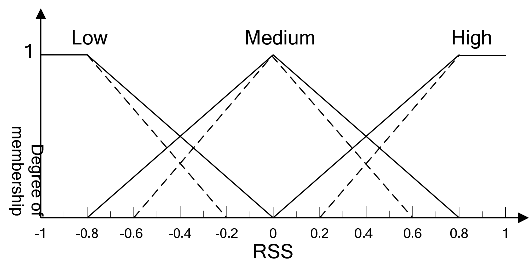

Fig. 3 interval type-2 membership function of normalized RSS

The algorithm combines the application requirements and network capabilities, and produces an output which is utilized to make handoff decision and to choose the best candidate AP from candidate network set. In the proposed handoff decision system, there are five input parameters for type-2 fuzzy inference engine. Membership functions of normalized RSS input are given in Fig. 3. In the figure, the horizontal axis indicates the crisp values of the aforementioned normalized RSS parameters, whereas the vertical axis (i.e. 1 values) stands for the membership value of RSS parameter. And membership functions of other input parameters are utilized by the same method. The crisp inputs are converted into the type-2 fuzzy variable by means of these membership functions. Trim and trapezoid shapes are chosen as type-2 fuzzy membership functions due to their capability of achieving better performance especially in real time applications.

As stated earlier, according to the input parameters of available networks the fuzzy inference engine produces an output fuzzy variable which describes the candidacy level of related candidate network. Any handoff initialization process is decided upon this value. One of the most crucial parts of this study is the new fuzzy inference system which is developed in order to make handoff decision. A fuzzy control system consists of four main parts: Fuzzifier, Fuzzy Inference Engine, Type Reducer and Defuzzifier. Fuzzifier converts a quantitative input into a type-2 fuzzy variable where physical quantities are represented by linguistic variables with appropriate membership functions. These linguistic variables are then used in rule base of fuzzy inference engine. Since there are five input variables each has three levels (i.e., low, medium, and high), there are 243 rules used for producing a new set of fuzzy output variables. Interval type-2 fuzzy system rule base and type-1 fuzzy system rule base are the same, which used in the form of (6).

$$Rule^n: \text{IF } x_1 \text{ is } \widetilde{X}_1^n \text{ and} \dots \text{and } x_l \text{ is } \widetilde{X}_l^n, \quad \text{THEN } y \text{ is } Y^n.\ n = 1, \cdots, N \tag{6}$$

$\widetilde{X}_i^n (i = 1, \cdots N)$ is interval type-2 fuzzy sets, $Y^n = [\underline{y}^n, \bar{y}^n]$ is an interval, which can be understood for the conclusion of the centroid of interval type-2 fuzzy sets. By (6) we can see that interval type-2 fuzzy rules and type-1 fuzzy rules are different: rule antecedent fuzzy sets of linguistic variables are the interval type-2 fuzzy sets rather than type-1 fuzzy set, rule consequent is centroid of interval type-2 fuzzy set, we can extend the membership function of rule consequent to interval type-2 fuzzy membership function, then calculate the centroid of interval type-2 fuzzy set.

Type reducer is responsible for converting type-2 fuzzy variable into type-1 fuzzy variable. There are many ways for type reduction, such as KM algorithm and EKM algorithm.

Defuzzifier is responsible for converting this type-1 fuzzy output variable into a number called AP satisfaction value (APSV). The output of the fuzzy control system, APSV, is then make handoff decision.

VI. PERFORMANCE SIMULATION

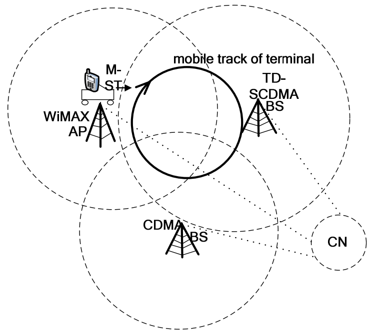

Fig. 4 The simulation model of heterogeneous network

In this paper, based on heterogeneous network model consisted of WiMAX, CDMA and TD-SCDMA network, we illustrate the performance of the vertical handoff by NS-2 simulation when the smart terminal move from the current WiMAX service network to CDMA or TD-SCDMA network with a variable speed. The network topology is given by Fig. 4. The simulation area is 2×2 kilometer square.

TD-SCDMA network's base station is full coverage and the coverage radius of the BS in CDMA or WiMAX is 700 meter. Between core network (CN) and smart terminal (MT) establish a UDP connection with constant bit rate data stream. The packet size is 800 Byte. Based on IEEE 802.16e,the system set the appropriate parameters $T_{\max}$, $T_{\min}$, $V_{\max}$, $D_{\max}$, $D_{\min}$ and set the parameters of the TD-SCDMA network superior to that of the CDMA and WiMAX network such as the bandwidth, the RSS, the delay, communication service charge, device power consumption , supportable user service, etc. To evaluate the performance of the proposed algorithm, simulation analyzes two indicators: the network set update rate and network block probability compared with the traditional vertical handoff based on type-1 fuzzy logic (FL-VHO) [10, 11] algorithm.

A. Candidate Network Set Update Rate Analysis

Since FL-VHO handoff algorithm apply the fixed scanning period to discover new network, its network set update rate is invariable with the change of terminal speed. However, in network discovery phase, the network set update rate of the proposed algorithm is adaptive to terminal speed, thus, it can discover new network more quickly. Fig.5 illustrates the relationships of network set update rate and handoff triggered time between terminal speed V and exponent n . The figure shows that the time adaptive factor r is increased along with the increase of user velocity, the network set update rate is faster and the handoff is triggered more timely. Furthermore, after the comparison of the three curves in Fig.5, we observe that when the terminal speed is constant, the network set update rate is increased along with the increase of exponent n and the handoff is triggered more timely. In Fig.5, exponent n corresponding to the three curves 1, 2, 3 are set to be 6, 3, and 2 respectively.

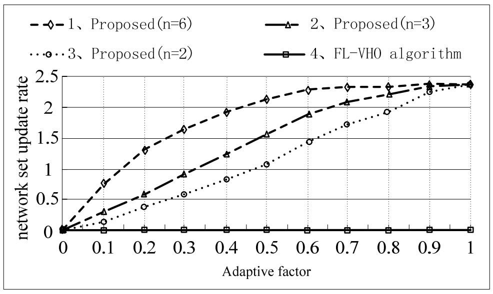

Fig. 5 The update rate of candidate network set

B. *Network Block probability Analysis*

As shown in Fig.6, since the traditional FL-VHO handoff algorithm triggers handoff frequently, the system load and the network block probability increased. While the proposed algorithm in this paper comprehensively considers many characteristics of access networks and terminals, the handoff effectiveness and fairness are better guaranteed, the Ping-Pong handoff effect is avoided effectively, thus, the network block probability decreased obviously.

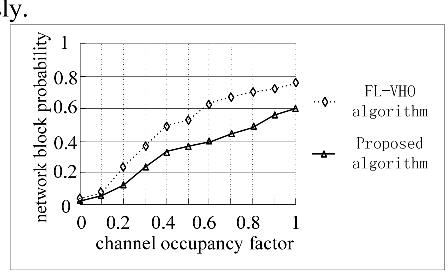

Fig. 6 The network block probability WiMAX handoff to TD-SCDMA or CDMA

VII. Conclusion

NGN network is an integrated network with multiple access network types, such as WWAN, WLAN and WMAN. In order to achieve seamless roam service, we proposed a vertical handoff decision algorithm based on type-2 fuzzy logic for heterogeneous networks based on the multi-mode smart terminal with velocity-measure capabilities of GPS technology. This algorithm adaptive updates the candidate network set and adjusts handoff opportunity according to the terminal speed. The best network is selected by type-2 fuzzy inference system. The simulations show that the proposed algorithm can increase the update rate of the network set and improve the performance of handoff, at the same time, assure the handoff fairness and effectiveness.

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