A Speed-Adjusted Vertical Handover Algorithm Based on Fuzzy Logic

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Abstract. The development of wireless communication technology promotes the inevitability of network integration. In order to solve the problems in the process of heterogeneous wireless networks handover, this paper proposes a speed-adjusted vertical handover algorithm based on fuzzy logic. The algorithm periodically acquires motion information of the terminal in the heterogeneous network environment. By using a threshold function based on the simple weighting method and adjusting the threshold value in combination with the speed, the information that is not suitable for handover will be filtered out. Then, the received signal strength (RSS), network available bandwidth, and battery power are normalized and put into a fuzzy logic controller to obtain a comprehensive network performance value (NCPV). Finally, the handover decision is performed according to NCPV. The simulation results show that this algorithm can reduce unnecessary handover with the increase of speed and suppress the generation of ping-pong effect, compared with the traditional algorithm. In addition, this algorithm also considers factors such as network delay, service cost, etc. Those improve the quality of service (QoS) and user satisfaction.

Keywords: Vertical handover · Speed-adjusted · Fuzzy logic

1 Introduction

With the development of wireless mobile communication technology, the future mobile communication network will be a heterogeneous and converged network in which multiple access technologies coexist, cooperate and complement each other. It is clear that various wireless technologies need to be integrated to achieve smooth and seamless handover across technologies to ensure better user experience.

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The handover process generally consists of three phases generally, which are divided into network discovery phase, handover decision phase and handover execution phase [1]. Paper [2] proposes an adaptive weight vertical handover algorithm, which can select a suitable network as target handover network according to the type of working application and the adaptive calculating weight vector to user's preference. However, it does not consider the impact of terminal movement on handover. Paper [3] proposes a novel vertical handoff decision algorithm, Self-Adaptive VHO Algorithm which considers the long term movement region and short term movement trend of mobile hosts, achieves a good integrative handoff performance. But this paper does not take into account an important factor: RSS. Paper [4] filtered unsuitable information according to MN's movement trend and received signal strength of WLAN to reduce unnecessary data volume and system overhead. Then put the RSS, network available bandwidth and cost into the fuzzy logic controller, obtain the final comprehensive performance value (VCPN) of the network through normalization, and finally make a decision based on VCPN and dwell time. In article [5], fuzzy logic is applied to the start-up phase of handover, and a multi-objective decision method (MODM) using fuzzy logic is used to select the optimal network in the decision phase, But the impact of speed on the handover performance is still a problem worth considering.

According to the current research situation, this paper designs a algorithm in heterogeneous network environment. The terminal periodically obtains motion information and filters out unsuitable handover information through a preliminary screening of the threshold function based on a simple weighting method, thereby reducing unnecessary system overhead. Then, the RSS, and other factors are normalized and put into a fuzzy logic controller to obtain the NCPV. Finally the terminal perform handover decision based on this value.

The rest of this paper is organized as follows. Section 2 presents related work and a proposed vertical handover decision algorithm is described in Sect. 3. The simulation and analysis is in Sect. 4. Section 5 concludes this paper.

2 System Model

We consider an overlay wireless network composed of WLAN and LTE, as shown in Fig. 1. Suppose that LTE covers the entire service area providing lower data rate and WLAN only covers some portions of the service area providing higher data rate. The vertical handover decision phase is triggered when any of the following events occurs: (a) the MN detects a new wireless link; (b) there is severe signal degradation of the current wireless link; (c) a new service request is made.

3 Proposed Algorithm

In the traditional handover algorithm, due to the large difference between heterogeneous networks, the algorithm cannot improve the user's QoS completely. The speed-adjusted vertical handover algorithm based on fuzzy logic proposed

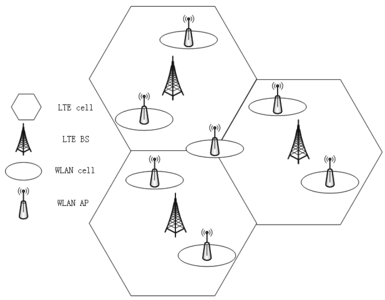


Fig. 1. System model

in this paper can be divided into two phases: initial screening and final decision. The algorithm is shown in Fig. 2.

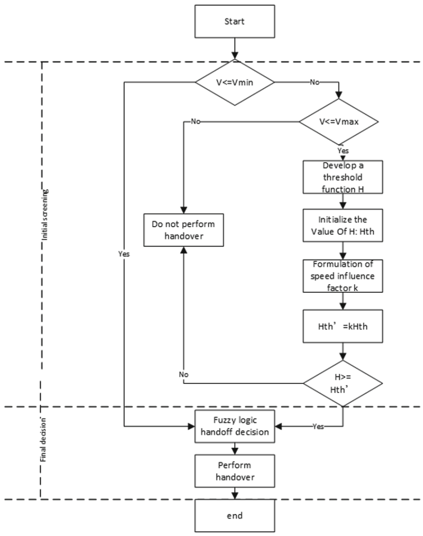


Fig. 2. Flow chart of speed-adjusted vertical handover algorithm based on fuzzy logic

3.1 Initial Screening

The first phase of the algorithm uses the simple weighting method to initially screen the network based on the network delay *delay_n*, network service fee *cost_n*, and the distance from the terminal's direction of movement from the BS or AP *d_n* (*n* represents the network type) as a multi-attribute parameter. The reason for the initial screening is that if all the parameters are input into the fuzzy logic module, the requirements for the user's mobile device are very high and the processing speed becomes very slow.

Calculation Method of *d_n*. First of all, we take the distance of the terminal from the Wlan AP as an example in Fig. 3. The center of the circle is the position of the AP. The line connecting the terminal and the AP is the x-axis, and the angle between the x-axis and the extension line of the direction of movement of the terminal is θ. The length of the vertical line extending from the center of the circle to the direction of the terminal is d_n. If the distance from the terminal to the AP is d, then

$$d\_n = d \sin\theta \tag{1}$$

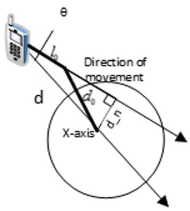


Fig. 3. Schematic diagram of the calculation of d_n

It can be seen from Fig. 3 that the shorter the d_n is, the less appropriate the handover is at this time. The distance d from the AP to the terminal can be calculated by the GPS positioning system of the smart terminal. If the coordinates of the terminal are (x1, y1) and AP coordinates are (x2, y2), then

$$d = \sqrt{(x1 - x2)^2 + (y1 - y2)^2} \tag{2}$$

Assume that the terminal travels a distance of l_0, at this time, the distance from the AP is d_0, which can still be measured by GPS. The value of $cos\theta$ can be given by:

$$cos\theta = \frac{l_0^2 + d^2 - d_0^2}{2dl_0} \tag{3}$$

From this, d_n can be expressed as:

$$d\_n = d\sin\theta = d\sqrt{1 - \frac{(l_0^2 + d^2 - d_0^2)^2}{4d^2l_0^2}} = \frac{\sqrt{4d^2l_0^2 - (l_0^2 + d^2 - d_0^2)^2}}{2l_0} \tag{4}$$

Threshold Function and Its Initial Threshold. The selected parameters can effectively prevent some target networks from having better network performance, but the mobile terminal only appears a short time within the coverage area of the network and still perform a handover. It also makes a rough assessment of other network performance, filters out information that is not suitable for handover. This not only reduces the number of unnecessary handovers, but also takes into account the user preference for handover decisions.

Parameter Normalization. Since different network performance parameters need to be compared, and different networks have large differences in performance, the foregoing parameters need to be normalized first. Paper [6] gives the normalized formula of delay,

$$delayi\_n = \begin{cases} 1, & delay\_n \leq D_{\min} \\ \frac{D_{\max} - delay\_n}{D_{\max} - D_{\min}}, & D_{\min} \leq delay\_n \leq D_{\max} \\ 0, & delay\_n \geq D_{\max} \end{cases} \tag{5}$$

Where $delay\_n$ is the connection delay of the target network n, D_{max} and D_{min} are the minimum and maximum delays allowed for user connections, respectively, and $delayi\_n$ is the delay after normalization. The normalized formula of the network service fee $cost\_n$ and the distance d_n of the terminal movement direction from the BS or AP can be expressed as

$$ai = \frac{a_c - a_{\min}}{a_{\max} - a_{\min}} \tag{6}$$

Where ai refers to $costi\_n$ and di_n, and a_{max} and a_{min} refer to their maximum and minimum values, respectively.

Initial Threshold Function and Its Threshold. According to the normalized result of the previous, it is simply weighted to get the expression of the threshold function:

$$H = w_1 * 1/delayi\_n + w_2 * 1/\cos ti\_n + w_3 * 1/di\_n \tag{7}$$

Where w_1, w_2 and w_3 are the weight factors of normalized $delayi\_n$, $costi\_n$ and di_n respectively, and $w_1 + w_2 + w_3 = 1$. In the process of terminal movement, if the new function value of the network is greater than the existing threshold function value, the network can enter the fuzzy logic decision stage, but at the same time it also creates a new problem. In Fig. 3, when the direction of movement of the terminal is constant, that is, d_n remains unchanged, the terminal's moving speed v also affects the staying time of the terminal in the current network coverage. If v is too large and the handover conditions are satisfied at the same time, the handover will also affect the user experience. Therefore, the speed influence factor is needed to balance the influence of the speed on the handover. Since k changes with v, set k to

$$k = \arctan(v/\alpha) + \beta(\beta \in (0, 1]) \tag{8}$$

where α and β are the coefficients of v and adjustable constants, respectively. Derivative of k, we can get

$$k' = \frac{1}{\alpha}({}^{1}/{}_{1+(\alpha)^2}) \tag{9}$$

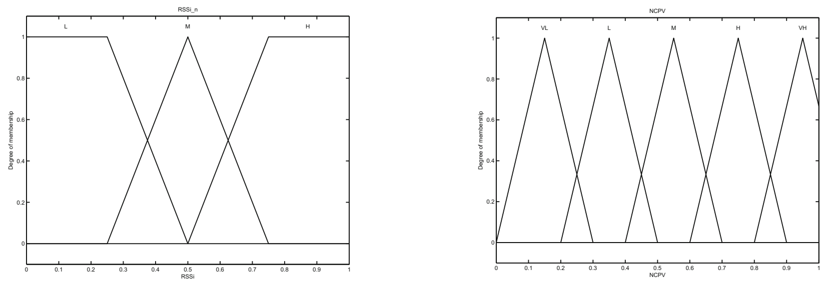
When v remains unchanged, the larger α is, the larger the derivative value is, and the steeper the function k is, which means that the function is more sensitive to changes in velocity. But when v is constant, increasing α causes the corresponding k value to decrease. The initial threshold will also be reduced, so proper setting of the initial threshold is crucial. The value of β can be adjusted according to the actual needs of the user. When the other values are constant, the larger the value of β, the larger the value of the initial threshold. When α and β are constant, in the range of vmin<v<=vmax,

$$Hth' = (1 + k)Hth \tag{10}$$

It means that as the speed v increases, the value of the threshold function also increases, eliminating unnecessary handovers and suppressing the handover of the terminal when there is a high speed. After repeated experiments, this paper takes $\alpha = 5$, $\beta = 0.5$ and the initial value of Hth is set here as the value of H when $delayi\_n$, $costi\_n$, and di_n take the maximum value.

3.2 Final Decision Based on Fuzzy Logic

After the initial screening by the simple weighting method, other parameters of the network should be put into the fuzzy logic module to enter the final decision phase based on the fuzzy logic. Here, the normalized $RSSi\_n$, the normalized $Bi\_$, and the normalized $batteryi\_n$ are selected as fuzzy inputs, and then the handover decision is made according to the output NCPV.



(a) membership functions of RSSi_n (b) membership functions of NCPV

Fig. 4. Input and output membership functions

First, RSS_n, B_n, and $battery\_n$ should be normalized. The normalization procedure is similar to the previous one, and the normalized formula is shown in formula (6), where ai denotes $RSSi\_n$, Bi_n, and $batteryi\_n$. Then the normalized parameters are fuzzified and then correspond to low (L), medium (M), and high (H) linguistic variables. It is denoted as three fuzzy sets: U(RSSi_n) = U(L, M, H), U(Bi_n) = U(L, M, H) and U(batteryi_n) = (L, M, H). At the same time establish the NCPV language variables and their fuzzy set: U (NCPV) = (VL, L, M, H, VH). The membership functions corresponding to input (take $RSSi\_n$ as an example) and output (NCPV) are shown in Fig. 4 respectively [7].

Some fuzzy rules thus established are shown in the Table 1.

Table 1. Fuzzy rules

RSSi_n	Bi_n	batteryi_n	Output
Low	Low	Low	Very low
Low	Low	Medium	Very low
...	...	...	...
High	High	Medium	Very high
High	High	High	Very high

4 Simulation Analysis

In order to verify the correctness of the above-mentioned algorithm, the LTE and WLAN heterogeneous networks are used as an example to establish a simulation model with MATLAB as shown in Fig. 5. As shown in this figure, the BS of the LTE is located at the origin, its coverage radius is 1500 m, and the carrier frequency is 2000 MHz. The coordinates of the mobile terminal are (40, 0). Wlan1's AP coordinates are (500, 0) and Wlan2's AP coordinates are (980, 360). Wlan's coverage radius is 300 m, carrier frequency is 3400 MHz. The transmission power of LTE and Wlan is 33 dBm and 23 dBm, respectively. Assume that the direction of movement of a terminal at the start of simulation is equal to the angle θ of Wlan1's AP, and its initial value is $\theta = 0.2\pi$ (inside the tangent line). Afterwards, the terminal will move at a constant speed v. At the moment of touching the edge of LTE coverage, another same terminal repeats the above motion with the movement direction of $=(0.2-0.02\text{i})\pi$ (0<i<=10). Then we change the speed of terminals and repeat the above movement. Since there is no time difference between the previous terminal and the next terminal, it can be regarded as the same terminal. LTE uses the cost231-hata model. The received signal strength is expressed as [8]:

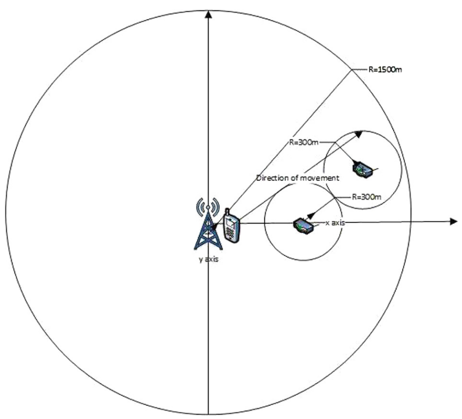


Fig. 5. Simulation model

$$RSS_L = P_{tL} - 127.5 - 35.2 \lg d_L \tag{11}$$

Where P_{tL} is the transmit power of LTE and d_L is the distance of the terminal from the LTE base station BS. The received signal strength of Wlan is expressed as [9]:

$$RSS_W = P_{tW} - 32.5 - 20 \lg f_W - 20 \lg d_W \tag{12}$$

Similarly, P_{tW} denotes the transmit power of Wlan in dBm, f_W is the carrier frequency of Wlan in MHz, and d_W is the distance of the terminal from the AP in km. According to the relevant literature, other parameters used in the simulation are shown in the Table 2:

Table 2. Simulation parameters

Parameter	LTE	Wlan1	Wlan2
delay_n	120 ms	80 ms	100 ms
costi_n	0.2	0.05	0.05
B_n	8 Mbps	12 Mbps	10 Mbps
battery_n	6 h *(The maximum power is 24 h)*	6 h	6 h

In the initial screening stage, when vmin<v<=vmax, the weighting factors $w1$, $w2$, $w3$ take 0.6, 0.1, and 0.3, respectively. The simulation results of this algorithm will be compared with RSS-based handover algorithms, handover algorithms based on simple weighting (RSS, network bandwidth, terminal's speed, and battery power) and fuzzy logic-based handover algorithms.

Figure 6 shows comparison of four algorithm handoff times as the speed increases. As can be seen from the figure, compared with other typical handover

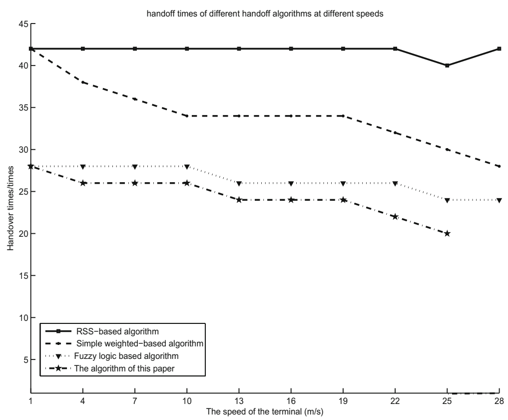
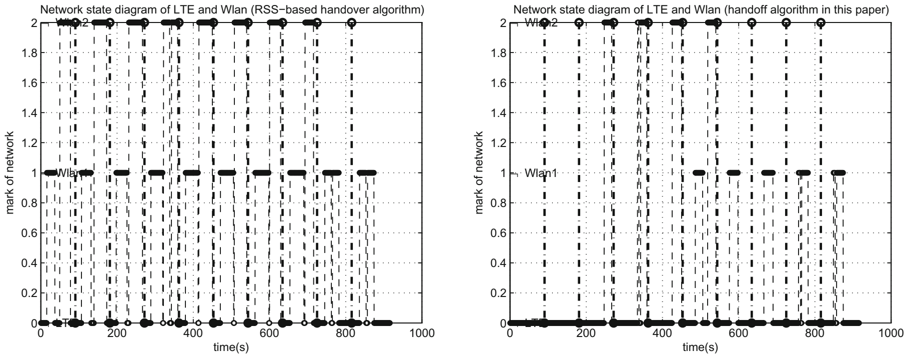


Fig. 6. Comparison of different algorithm handover times



(a) Net state of RSS-based algorithm

(b) Net state of this algorithm

Fig. 7. Network state of two algorithms

algorithms, the number of handovers based on this algorithm is significantly reduced. This algorithm can reduce unnecessary handover with the increase of speed and suppress the generation of ping-pong effect. Especially when the speed is 4–19 m/s, the handoff frequency is stable. As the speed continues to increase, the number of handovers decreases, indicating that the algorithm has an effect on the suppression of higher speed handovers.

Figure 7 shows the network state based on the RSS algorithm and the algorithm in this paper. (2 stands for Wlan2, 1 stands for Wlan1, 0 stands for LTE, and the dash dot line shows the complete movement of the terminal at the same angle). As can be seen from this figure, when the direction of the movement of the terminal and the angle between the APs is large, the algorithm of this paper didn't perform handover, because the larger the angle, the shorter the dwell time of the terminal in the network. In addition, it can better reflect the improvement of the user service quality in the handover decision, because this algorithm also considers the delay, cost and other factors.

5 Conclusion

In this paper, we design a algorithm that based on the speed of the terminal and fuzzy logic decision method. The terminal periodically obtains motion information, and initially filters through a threshold function based on a simple weighting method to filter out information that is not suitable for handover. Then we get the network comprehensive performance value (NCPV) from the fuzzy logic module, and finally perform the handover decision based on this value. Compared with the traditional algorithms, unnecessary handovers are reduced and the complexity of the system is reduced. The user's preference for the network is taken into account, which improves the user service quality and user satisfaction to some extent.

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