Handover algorithm for multiple networks based on Bayesian decision

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Abstract: An improved vertical handover algorithm for multiple networks based on Bayesian decision is proposed. Firstly, the handover probability distribution is established considering multiple conditions including signal strength, bit error rate, blocking probability and user demands, and accordingly the prior handover probability is calculated. Secondly, the posterior probability based on Bayesian decision algorithm is got. Finally, the optimal access network is selected according to the decision strategy based on posterior probability. Simulation results indicate that the proposed algorithm not only effectively achieves vertical handover among WLAN, WiMAX and LTE with the least number of handovers, but also keeps high average network load, which can provide the users with good service quality.

Key words: multiple networks; blocking probability; Bayesian decision; vertical handover

CLD number: TN911.5 **Document code**: A

Article ID: 1674-8042(2015)04-0347-07 **doi**: 10.3969/j.issn.1674-8042.2015.04.008

With the rapid development of wireless communication technology, more and more wireless access technologies have emerged. Integration of heterogeneous wireless networks, can simultaneously support many different types of business. Vertical handover can be used to ensure that mobile terminals have the continuity of high-quality communications and roaming services in multi-network session anytime, any place, any when. Thus, the research on vertical handover algorithm in heterogeneous networks has a high theoretical and practical significance.

Currently, there have been many wireless access technologies which can be applied to terminal nodes, but different access technologies have their own characteristics. For vertical handover technology in heterogeneous wireless networks a lot of related research has been made, including vertical handover algorithm based on signal strength[1], gray relational analysis (GRA)[2] and vertical handover algorithm based on signal to interference plus noise ratio (SINR)[3]. But most of the vertical handover algorithms take a single network attribute factor as the indicator of handover decision regardless of actual demand preference of the business for network. TAO Yang, et al.[4] proposed adaptive speed vertical handover algorithm based on business needs for better heterogeneous network handover in business. Ref.[5] proposed a vertical handover algorithm in heterogeneous wireless network environment based on car networks to select the existing optimal access network as target network for handover.

Although some research achievements have been obtained, due to uniqueness of a heterogeneous network environment and different preferences and service needs from different users, only considering the network state and terminal-related stat is not sufficient. But some simple weighted strategies do not reflect the actual demands of network terminals, and the research on verification of heterogeneous network environment is deficient.

To solve these problems, the terminals in wireless local area nework (WLAN), world interoperability for microwave access (WiMAX) and long term evolution (LTE)[6] heterogeneous network environments

Received date: 2015-09-15

Foundation items: National 863 Project of China (2014AA01A703); Natural Science Foundation of Education Department of Shaanxi Province (2013JK1045); ZTE Forum Foundation of ZTE Corporation

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are taken as the research objects. By fully considering the actual demands of different applications, the weights of netowork attribute factors are adaptively adjusted to make effective handover decision.

1 Vertical handover algorithm based on Bayesian decision

The block diagram of the improved vertical handover algorithm based on Bayesian decision[6] is shown in Fig. 1. The weights of network attribute factors are determined according to different applications and then network handover decision is made according to the weights. Afterwards, the Bayesian decision algorithm is used to calculate posterior probability. Finally, by comparing the handover probabilities, the optimal target network can be selected for network handover.

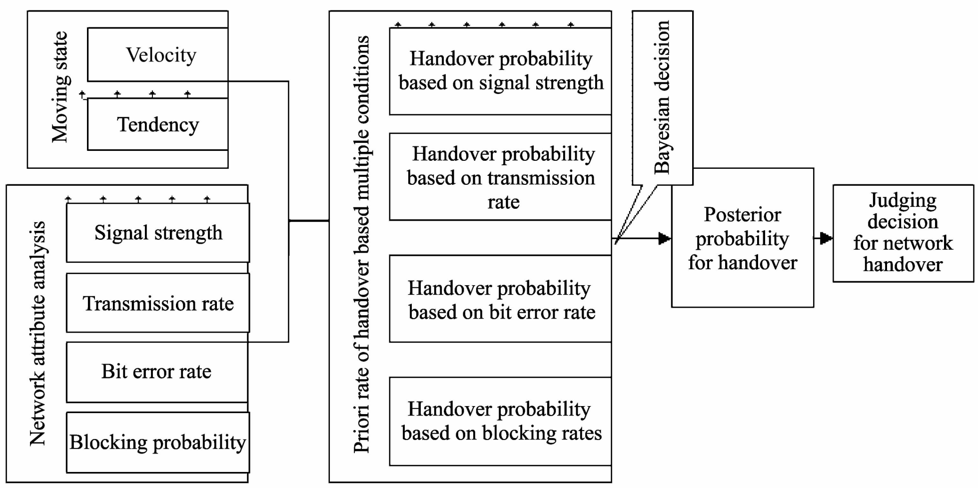

Fig. 1 Vertical handover algorithm based on Bayesian decision

1.1 Network attribute factors based on business demands

To provide the users with the best service in complex heterogeneous networks, namely, vertical handover algorithm should choose optimal network to meet different user requirements. Therefore, the multi-attribute vertical decision algorithm based on business demands analyzes first the quality of service (QoS) to selecte network attributes for business evaluation and sets the threshold for the candidate networks. Then analytic hierarchy process (AHP)[7] is used to determine the weight of each network attribute factor. Finally, by means of Bayesian criteria, the optimal handover network is got.

Since different preferences and business demands lead to a variety types of business[8], to meet user requirements, the business is divided into four classes: conversational class, interactive class, streaming class and background class, as listed in Table 1.

Table 1 Requirements of network QoS

Service type	Typical service	Requirements of network QoS
Conversational class	Voice service Video phone	Real-time service requires low delay Symmetric uplink and downlink data rates
Interactive class	Web browsing Location service	Error rate has certain requirements Asymmetric uplink and downlink data rates
Streaming class	Video stream, audio stream FTP download	High bit error rate Minimum requirements for delay
Background class	E-mail MS/MMS/FAX	High bit error rate Minimum requirements for delay

1.2 Network attribute factors definition and analysis

Network attribute factors affecting vertical handover of heterogeneous wireless networks include signal strength, transmission rate, bit error rate and network blocking probability. The detailed analysis is as follows:

1) Signal strength

Signal strength is a basic trigger condition of vertical handover and reflects the quality of signal strength of the current channel. It can be expressed as

$$Y_{\mathrm{RSS}}(d) = K_1 - K_2 \lg(d) + u(x), \quad (1)$$

where K_1 is network transmission power, K_2 is network path loss factor, d denotes the distance between the terminal and access point and $u(x)$ is Gaussian random distribution function that obeys $(0, \sigma)$.

2) Maximum transmission rate

Transmission rate is an important indicator for network selection, which directly affects business quality of the terminal. According to Shannon's theorem, the maximum transmission rate of the channel is

$$V_C = W \log_2\left(1 + \frac{s}{n}\right), \quad (2)$$

where W is bandwidth, s is average signal power and n is average noise power.

3) Bit error rate (BER)

When bit error rate of network is higher than a certain threshold, the network will not meet the current needs of the business. To calculate the bit error rate, assuming that there exists the Gaussian noise obeying random distribution, and the distance from the terminal to the base station is $d_k (k = 1, 2, \cdots)$, BER is a function of signal to noise ratio (SNR) and can be expressed as

$$R_{\mathrm{SNR}}(k) = \frac{R_{\mathrm{RSS}}(k)}{I(k)}, \quad (3)$$

$$R_{\mathrm{BER}}(k) = Q(\sqrt{R_{\mathrm{SNR}}(k)}), \quad (4)$$

where $I(k)$ is interference signal strength, $Q(x)$ obeys Gaussian distribution with parameter $(0, 1)$, namely,

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} \exp\left(\frac{-t^2}{2}\right) \mathrm{d}t.$$

4) Network blocking probability (P_{bk})

This paper uses a mathematical model of network blocking probability proposed in Ref.[10], which studies the effects of two algorithms on network blocking probality in vertical handover, and it is expressed as

$$P_{\mathrm{bk}} = \frac{\rho_n^{N_n}(1 - \rho_n)}{1 - \rho_n^{N_{n+1}}}, \quad (5)$$

where $\rho_n = \frac{\theta_n \lambda}{\mu}$ is the effective handover business load; θ_n is the percentage that the user is switched to network n; λ is the arrival rate of handover business, μ is the departure rate of handover business, λ/μ is the current handover load that obeys Poisson distribution; $N_n = \frac{B_n}{D}$, B_n is network load, D is the average transmission rate for user business. According to Eq. (5), the blocking probability can be calculated by

$$P_{\mathrm{bk}} = \frac{\left(1 - \frac{\lambda}{\mu}\right)}{1 - \left(\frac{\lambda}{\mu}\right)^{N_i + 1}} \left(\frac{\lambda}{\mu}\right)^{N_i}. \quad (6)$$

1.3 Multi-condition handover probability distribution

The current network handover is based on single or multiple network attribute factors, accordingly, the corresponding threshold values are set. The handover probabilities based on single network attribute factor are as follows:

1) Handover probability based on signal strength

$$P_1 = P(Y_{\mathrm{RSS}}(d) \geqslant \eta),$$

where $Y_{\mathrm{RSS}}(d)$ is the signal strength of target network for handover and λ is the minimum signal strength threshold required when the terminal has access to network.

2) Handover probability based on bit error rate

$$P_2 = P(R_{\mathrm{BER}}(k)) < \tau,$$

where $R_{\mathrm{BER}}(k)$ is the BER of target network for handover and τ is the maximum BER which can meet terminal business needs.

3) Handover probability based on transmission rate

$$P_3 = P(V_{C_B} > V_{C_\phi}),$$

where V_{C_B} is the maximum transmission rate of target network for handover, and V_{C_ϕ} is the minimum transmission rate which only meets current business needs.

4) Handover probability based on blocking probability (network load)

$$P_4 = P(P_{bk} < \varepsilon),$$

where P_{bk} is the network load of target network for handover, and ε is the maximum blocing probability which meets the business needs.

For the above conditions, there is a correlation between each other, where the signal strength is a comparative reference condition. Based on the above analysis, a prior probability for handover can be given by

$$P_{th} = P(Y_{RSS}(d) > \eta,\ R_{BER}(k) < \tau,\ V_{C_B} > V_{C_\phi},\ P_{bk} < \varepsilon). \tag{7}$$

2 Vertical handover algorithm based on Bayesian decision

When making a decision for network handover, the two states for network handover are taken as random variables, ϕ_1 and ϕ_2, and the prior probabilities of two states are expressed by P_{th} and P_{fh}, where P_{th} indicates the probability that handover occurs, P_{fh} indicates the probability that handover does not occur, $P_{th}+P_{fh}=1$. In general, if $P_{th}>P_{fh}$, making the decision for network handover.

If only according to the prior probability for handover decision, all the networks are classified into a state, ϕ_1 and ϕ_2. Therefore it is necessary to introduce network priority to make common decision for handover[9-10].

2.1 Selection of target network based on Bayesian decision

In order to distinguish the multi-target networks in covered areas accurately, the rule of multi-target networks based on Bayesian decision for handover are given as follows:

Let x_1, x_2 and x_3 denote the handover states of three access networks C_1, C_2 and C_3, respectively. Set network priority: $C_1 > C_2 > C_3$, there is $P(x_1)>P(x_2)>P(x_3)$. Assuming that $P(x_1|\phi_1)$ is the conditional probability that the terminal has access to network x_1 in case of network handover and $P(x_1|\phi_2)$ is the conditional probability that the therminal has access to network x_1 in case of no network handover, using Bayesian theorem, there is

$$P(\phi_1 \mid x_1) = \frac{P(x_1 \mid \phi_1)P(\phi_1)}{\sum_{i=1}^{2} P(x_1 \mid \phi_1)P(\phi_i)}, \tag{8}$$

where $P(\phi_i|x_1)$ is the posterior probabilities of handover states. Based on the posterior probability, the decisions are made as follows:

1) If $P(\phi_1|x_1)>P(\phi_2|x_1)$, the state of network x_1 is classified as ϕ_1 and the terminal is switched to network C_1;

2) If $P(\phi_1|x_1)<P(\phi_2|x_1)$, the state of network x_1 classified as ϕ_2 and the terminal is not switched to network C_1.

Therefore, according to the above analysis, it can be inferred as follows:

1) If $P(x_1|\phi_1)P(\phi_1)>P(x_1|\phi_2)P(\phi_2)$, the state of network x_1 is classified as ϕ_1 and the target network is considered to be switched to network C_1;

2) If $P(x_1|\phi_1)P(\phi_1)<P(x_1|\phi_2)P(\phi_2)$, the state of network x_1 is classified as ϕ_2 and the target network can not be switched to network C_1.

2.2 Selection of target network for handover based on Bayesian decision

Assuming there are several candidate handover target networks, an optimal selection strategy based on Bayesian decision is as follows:

1) If $P(x_1|\phi_1)P(\phi_1)>P(x_2|\phi_1)P(\phi_1)$ as well as $P(x_1|\phi_1)P(\phi_1)>P(x_3|\phi_1)P(\phi_1)$, network C_1 is selected as a candidate for handover;

2) If $P(x_2|\phi_1)P(\phi_1)>P(x_1|\phi_1)P(\phi_1)$ as well as $P(x_2|\phi_1)P(\phi_1)>P(x_3|\phi_1)P(\phi_1)$, network C_2 is selected as a candidate for handover;

3) If $P(x_3|\phi_1)P(\phi_1)>P(x_1|\phi_1)P(\phi_1)$ as well as $P(x_3|\phi_1)P(\phi_1)>P(x_2|\phi_1)P(\phi_1)$, network C_3 is se-

lected as a candidate for handover.

In practical applications, this algorithm can be extended for the selection of the best candidate target network among four or more candidate networks.

3 Simulation and analysis

In order to verify the proposed algorithm, simulation scenarios must be combined with the actual network application. In this paper, the simulation movement scene is constructed to verify vertical handover algorithm for mobile terminal by using Matlab.

3.1 Experimental parameters

This paper gives a simulation scenario, as shown in Fig. 2.

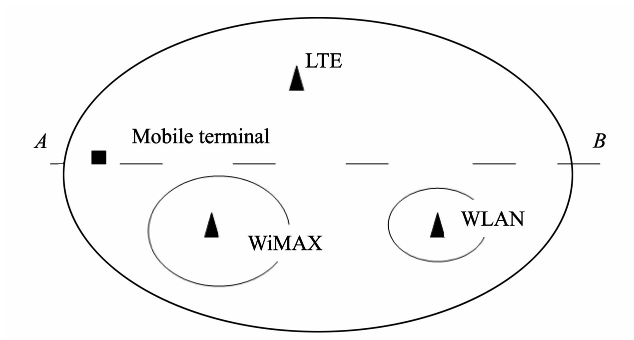

Fig. 2 Terminal movement scene

To facilitate data acquisition and analysis, the mobile terminal moves from point A to point B in a straight line at the speed of 1 m/s. The network simulation properties are set, as shown in Table 2.

Table 2 Network property settings

Network attribute	Property values		
Simulation model	LTE	WiMAX	WLAN
Locations	(50,300)	(−350,−100)	(350,100)
Coverage (m)	500	200	100
Access bandwidth (Mbit/s)	27	45	2
Transmit power (MHz)	20	25	30
Path loss (dBm)	L=35.3+34(d), d is the distance between the trminal and base station		
Maximum bit error rate	0.006		
Signal strength threshold η (dBm)	The minimum value is −110 dBm, the interference signal intensity is −130+$u(x)$, where $u(x)$ obeys normal random distribution with parameters (0, σ_2), σ_2 is 10 dBm.		
Minimum transmission rate C_ϕ	Support for the current business needs to be 120 kbit/s		

3.2 Experimental results and analysis

In the simulation experiments, the handover probability of each network is calculated at the interval of one second in the mobile terminal for a terminal handover decision, where $P(x_1 | \phi_1) = 0.4$, $P(x_2 | \phi_1) = 0.32$ and $P(x_3 | \phi_1) = 0.28$.

This paper focuses on the design of multi-network attributes vertical judgment algorithm, which has different performance in many aspects and are combined with the different wireless networks of LTE, WiMAX and WLAN. For the current business types in the same network environment, there are three different algorithms for comparative analysis of the handover Network. The following simulation diagram gives the specific circumstances of simulation experiments based on the current interaction class services of network handover.

Fig. 3 shows the number of terminal handovers based on different decision strategies in heterogeneous networks. It can be seen that not only the number of terminal handovers based on Bayesian decision significantly decreases, but also the residence time of the terminal in the network with good properties are the longest. This not only effectively reduces "ping-pong" effect and system overhead, but also provides the user with the best network experience.

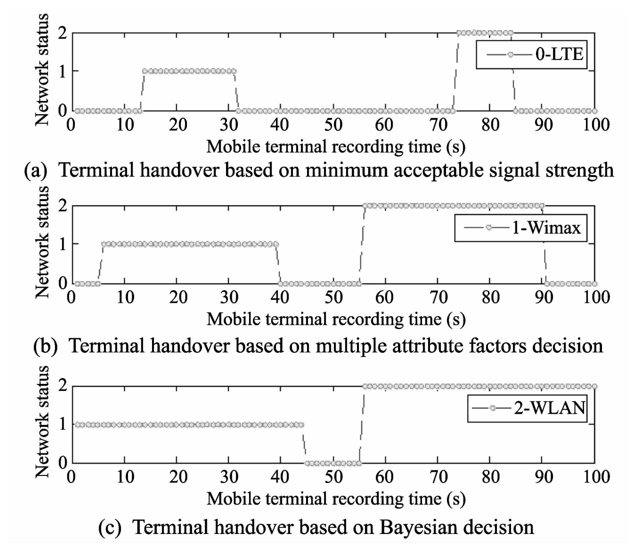

Fig. 3 Terminal handover according to different decision strategies in a heterogeneous network

Fig. 4 shows the relationship between average network load and blocking probability. It can be seen that the handover based on Bayesian decision makes the terminal have access to the network in good load condition as far as possible, which reduces the network blocking of hot-spot cells.

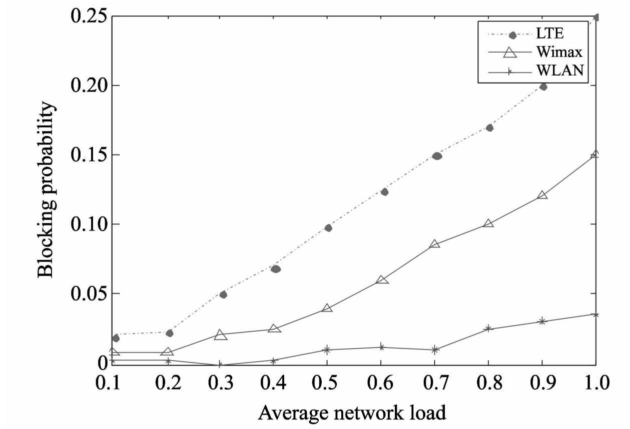

Fig. 4 Relationship between average network load and blocking probability in a heterogeneous network

Fig. 5 shows the handover probabilities of the mobile terminal based on different handover decision strategies when it moves at different speeds in a heterogeneous network. It can be seen that the improved algorithm can reduce the number of handovers, which ensures better network performance and provides the users with better service quality and effects.

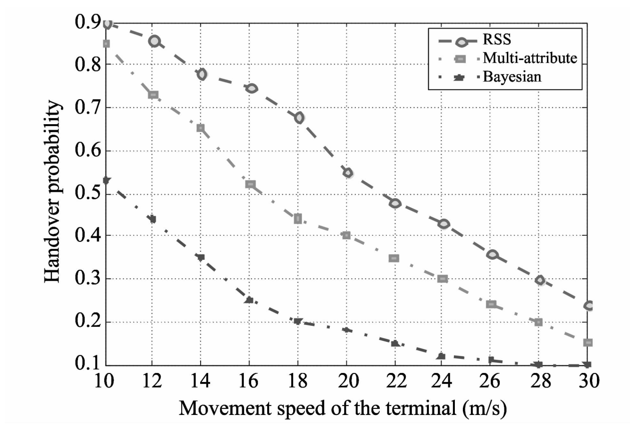

Fig. 5 Terminal handover probability with different decision strategies at different movement speeds

4 Conclusion

This paper presents a vertical handover algorithm for multiple networks based on Bayesian decision. When the terminal moves in different networks such as WLAN, WiMAX and LTE, full considering the weights of network attribute factors in different applications, the optimal access network can be selected by the proposed Bayesian decision algorithm. Simulation results show that this algorithm not only can be used for any vertical handover in heterogeneous networks, which can reduce the number of handovers, but also ensure that the target network is the current optimal network for handover. The further work will focus on how to introduce the user's access preference into the vertical handover algorithm to improve the terminal handover performance in a heterogeneous network.

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基于贝叶斯决策的多网络切换算法

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摘　要： 现有的垂直切换技术通常不支持多网络下切换。为此，提出了基于贝叶斯决策的改进算法。首先根据接入用户终端的信号强度、网络阻塞率和误码率以及不同用户业务对网络的实际需求建立多条件相关的切换概率分布，得出先验切换概率；然后利用贝叶斯垂直切换决策算法计算出后验概率；最后，根据后验概率的决策规则选出最优接入网络。仿真结果表明，该算法不仅有效地实现异构无线接入网之间的垂直切换，避免了不必要的切换，而且还能保持较高的网络平均负载，使用户获得更好的服务。

关键词： 网络；网络阻塞率；贝叶斯决策；垂直切换

引用格式： KONG Ling-bin, WANG Jun-xuan. Handover algorithm for multiple networks based on Bayesian decision. Journal of Measurement Science and Instrumentation, 2015, 6(4): 347-353. [doi: 10.3969/j. issn. 1674-8042. 2015. 04. 008]