A Vertical Handoff Method via Self-Selection Decision Tree for Internet of Vehicles

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***Abstract*—Vehicles often communicate among different networks in Internet of Vehicles (IoVs). However, existing unstable network statuses and different user preferences result in vehicle frequent vertical handoffs (VHOs). In this paper, we propose a novel VHO method based on a self-selection decision tree for IoVs. We first establish the respective handoff probability distribution of vehicles according to network attributes and movement trend. Then, based on handoff probability distributions and defined user preferences, we propose a novel handoff method by the self-selection decision tree for IoVs. Finally, we also present a feedback decision method according to the feedback of vehicle handoff, to improve next handoff quality when vehicle movement trend and vehicle service status change. Simulation results show that the proposed method not only supports the VHO among Wireless Access in Vehicular Environments, Worldwide Interoperability for Microwave Access, and third-generation cellular but also reduces switching times and ensures the network update rate and the vehicles' service quality.**

***Index Terms*—Decision tree, feedback decision, Internet of Vehicles (IoVs), self-selection, vertical handoff (VHO).**

I. Introduction

INTERNET of Vehicles (IoVs) allows a vehicle to be equipped with Internet access and, usually, also a wireless local area network (WLAN). IoV allows the vehicle to share Internet access to other devices both inside and outside the vehicle. Often, in IoVs, the vehicle is outfitted with special technologies that tap into the Internet access or the WLAN and provide extra benefits to the driver.

As well known, IoV shows its greatest degree of strength to meet the needs of vehicles. In particular, with wireless access technologies becoming popular, many vehicles can access IoVs with high speed. Nevertheless, high-speed moving vehicles will result in network frequent handoffs among Wireless Access in Vehicular Environments (WAVE), Worldwide Interoperability for Microwave Access (WiMAX), third-generation (3G) cellular, and so on. Generally, handoff contains horizontal handoff (HHO) and vertical handoff (VHO). HHO refers to a mobile terminal (*called vehicle in this paper*) switch between the same kinds of access networks. VHO also refers to a mobile terminal switch among different kinds of access networks. High-speed moving vehicles can access to the Internet through 3G or 4G networks, but it is more expensive in cost than the poor quality of service (QoS). In recent years, with the large-scale deployment of roadside access points, 802.11p (WAVE) or WiMAX technology has been often used to exchange data or information by accessing to the surrounding infrastructures (access points or base stations) [1].

However, existing unstable network statuses and different user preferences result in vehicle frequent VHOs. In order to solve the issue, in this paper, we introduce a VHO method based on a self-selection decision tree for IoVs. First, according to the signal strength, transmission rate, bit error rate (BER), blocking probability, and movement trend, we establish the respective handoff probability distribution. Second, we use the self-selection decision tree to make handoff decisions. Finally, according to the feedback of services and movements, a feedback decision method is proposed and is used to calculate and trigger the next handoff in IoVs.

Compared with existing efforts, our main contributions can be summarized as follows: 1) we introduce terminal states of motion in the handoff decision; 2) we propose the handoff method based on a self-selection decision tree for VHO among WAVE, WiMAX, and 3G cellular; 3) we propose a feedback decision method, which makes the next handoff timely and accurate for IoVs; and 4) we construct a simulation to evaluate our proposed method, and results show that our method can outperform vehicle VHO effectively in IoVs.

The remainder of this paper is organized as follows. Section II introduces the related work of VHO methods. Section III gives the parameters of network attributes that affect the VHO in IoVs. It contains received signal strength (RSS), transmission rate, BER, and blocking probability. Our proposed VHO method is shown in Section IV. Section V introduces our proposed feedback decision method based on terminal states. Evaluation of the proposed method using simulations is explained in Section VI. This paper concludes with the ending remarks in Section VII.

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II. Related Work

During VHO, if the RSS of two or more networks has only a small difference, vehicles will handoff frequently among base stations. This is called the ping-pong effect. In order to solve the problem, many researchers proposed some state-of-the-art studies such as handoff decision methods [2], [3]. A fixed "dwell timer" [4] was maintained, and the handoff is executed only if the condition prevails for longer than the dwell time period. These two types of methods avoid the ping-pong effect. However, the RSS fluctuations are often severe, and the thresholds are fixed, so that even a moving average filter cannot smooth out the signal sufficiently. This results in false handoff triggers or late (unsuccessful) handoff attempts.

Liu *et al.* [5] proposed a VHO decision algorithm, which is called the self-adaptive VHO algorithm, that synthetically considers the long-term movement region and the short-term movement trend of mobile hosts. In [6], a performance comparison between four VHO decision algorithms, namely, multiplicative exponent weighting (MEW), simple additive weighting (SAW), technique for order preference by similarity to ideal solution (TOPSIS), and gray relational analysis (GRA), was proposed. All these four algorithms allow different attributes (e.g., bandwidth, delay, packet loss rate, and cost) to be included for VHO decision. Comparative results show that MEW, SAW, and TOPSIS provide similar performance to the four traffic classes. GRA provides a slightly higher bandwidth and a lower delay for interactive and background traffic classes. Tawil *et al.* [7] introduced a distributed VHO decision scheme that combined the multiple-attribute decision-making method and SAW in a distributed manner. The method considered the dropping probability, the bandwidth, and the cost when triggering the handoff.

Moreover, in [8] and [9], based on the Markov decision process formulation with the objective of maximizing the expected total reward of a connection, a handoff method was proposed. The network resources that are utilized by the connection are captured by a link reward function. A signaling cost is used to model the signaling and processing load incurred on the network when VHO is performed. The value iteration algorithm is used to compute a stationary deterministic policy. Gambini *et al.* [10] focused on the optimization of a channel access strategy for a cognitive multistandard radio node. The node has the capability to switch between two orthogonal uplink radio interfaces. The radio interfaces are different in coverage and QoS requirements of primary users. The proposed strategy prescribed a cross-layer selection of physical layer (transmitting powers) and medium access to control layer (handover probability) parameters. These parameters are designed to maximize secondary throughput while guaranteeing the primary QoS constraints. Yang *et al.* [11] proposed a handover scheme with geographic mobility awareness (HGMA), which took the historical handover patterns of mobile devices into consideration. HGMA conserves the energy of handoff devices in three ways. It prevents mobile devices from triggering unnecessary handovers that are based on the signal strength. It also contains a handover candidate selection method for mobile devices to select a subset of WiFi access points or WiMAX relay stations to be scanned intelligently. In [12], Qing defined a fuzzy logic based on VHO decision algorithm in heterogeneous networks, which provided a generalized VHO decision procedure to reduce redundant handoffs. The algorithm considered the RSS, available network bandwidth, monetary cost, and user preference as the VHO decision criteria.

Recently, Sharna and Murshed [13] have proposed a weight estimation technique, which could control the span of the weights in response to user preference adaptively. Abdelmalek *et al.* [14] proposed a VHO decision algorithm based on scalar Kalman filtering. Criteria such as the probability of a false handoff, the number of handoffs, and the position of handoffs are used to evaluate and compare our work with the existing handoff algorithms that are based on filtering techniques. Ma and Ma [15], [16] proposed a QoS-based VHO scheme for WLAN and WiMAX interworking networks with the aim of providing the best service to users. They also proposed a simple yet efficient method to estimate the available bandwidth in WLAN and WiMAX networks, evaluate the real-time status of the overlay networks, and make a handoff decision based on that information.

Although the studies have achieved good results, the handoff selections of the target networks do not truly reflect the terminal user demands for the network, as shown in Table I. For example, some users want to access low-cost network, some users want to access high-speed networks, and so on. Hence, in this paper, we propose a VHO method based on a self-selection decision tree and feedback decision in IoVs. The RSS, transmission rate, BER, blocking probability, and movement trend are taken into consideration in the self-selection decision tree. We make handoff decisions through the self-selection decision tree. Then, both the current statuses and the handoff statuses of networks are considered in feedback decision. According to the feedback of services and movements, a feedback decision method is proposed for IoVs.

III. Handoff Selections Based on Attributes

Because the parameters of network attributes often affect the VHO in IoVs, we first introduce these parameters before explaining our proposed method. The main parameters include RSS, transmission rate, BER, and blocking probability.

A. Network Attributes and Handoff Selections

1) RSS: RSS is a basic condition to trigger a VHO. Signal strength reflects the current quality of the channel, and then, RSS can be calculated by the following:

$$\mathrm{RSS}(d_k) = K_1 - K_2 \lg(d_k) + u(x) \; (k = 1, 2, \ldots) \qquad (1)$$

where d_k represents the kth distance between a vehicle and a base station, K_1 is the transmission power of the network, K_2 is the path loss factor, and $u(x)$ is the Gaussian distribution function following $(0, \sigma_1)$. Based on RSS, handoff probability can be obtained by the following:

$$P_{h1} = P\left(\mathrm{RSS}_B(d_k) > \eta\right) \qquad (2)$$

where $\mathrm{RSS}_B(d_k)$ is the RSS of the target network, and η is the minimum required signal strength threshold to access to the network. For an illustration of our proposed method, we present all parameters of handoff probability in Table II.

TABLE I
SUMMARY OF PREVIOUS WORK

Previous works \ Attributes	RSS	Transmission rate	BER	Blocking probability	Movement trend	User preferences
M. Ylianttila et al. [2]	√	√	–	–	–	–
Buddhikot M et al. [4]	√	√	√	–	–	–
M. Liu et al. [5]	√	√	√	–	√	–
R. Tawil et al.[7]	√	√	√	√	–	–
E. Stevens et al. [8,9]	√	√	√	√	–	–
Gambini et al. [10]	√	√	√	√	–	–
Yang et al. [11]	√	√	√	√	√	–
Qing et al. [12]	√	√	√	√	–	√
S.A. Sharna et al. [13]	√	√	√	√	–	√
Abdelmalek S et al. [14]	√	√	√	√	–	–
Dong Ma et al. [15,16]	√	√	√	√	–	–

TABLE II
PARAMETERS OF HANDOFF PROBABILITY

Parameters	***Illustraion***
P_{h1}	The handoff probability based on RSS
P_{h2}	The handoff probability based on transmission rate
P_{h3}	The handoff probability based on BER
P_{h4}	The handoff probability based on blocking probability
P_{h5}	The handoff probability based on movement trend
P_{th}	The handoff probability in continuous network priority
P_{bh}	The handoff probability in network bandwidth priority
P_{ch}	The handoff probability in network cost priority
P_{sh}	The handoff probability when services contain session services
P_{eh}	The handoff probability when services don’t contain session services

2) Transmission Rate: The transmission rate is an important indicator in the network selection process that affects the QoS within vehicles directly. According to Shannon’s theorem, we get the maximum transmission rate of the channel (denoted by C) by the following:

$$C = W \log_2(1 + s/n) \tag{3}$$

where W is the frequency bandwidth, and s/n is the signal-to-noise ratio (SNR). Handoff probability based on transmission rate can be calculated by the following:

$$P_{h2} = P(C_B > C_A) \tag{4}$$

where C_B is the maximum transmission rate of the target network, and C_A is the maximum transmission rate of the current network.

3) BER: When the BER of the network is higher than a certain threshold value, it indicates that the network cannot meet some demands of the vehicle services. To calculate the BER, we employ Gaussian random distribution in general case as the noise distribution. The BER is the function of SNR. Hence, the function of SNR can be calculated by the following:

$$\text{SNR}(k) = \frac{\text{RSS}(k)}{I(k)} (k = 1, 2, \ldots) \tag{5}$$

where $I(k)$ is the interfering signal strength. The function of BER can be obtained by the following:

$$\text{BER}(k) = Q\left(\sqrt{\text{SNR}(k)}\right) \tag{6}$$

where $Q(x) = (1/\sqrt{2\pi}) \int_x^\infty \exp(-t^2/2) dt$. Handoff probability based on BER can be calculated by the following:

$$P_{h3} = P\left(\text{BER}(k) < \tau\right) \tag{7}$$

where $\text{BER}(k)$ is the BER of the destination network, and τ is the maximum BER in order to support the vehicle services.

4) Network Blocking Probability: When network channels of one area have been occupied, the new terminal service calls would be rejected by the system [17]. The probability of l channels can be calculated by the following:

$$p_l = \frac{\frac{(-\lambda \mathbf{A}\mathbf{X}^{-1}\mathbf{e})^l}{l!}}{\sum_{n=0}^{m} \frac{(-\lambda \mathbf{A}\mathbf{X}^{-1}\mathbf{e})^n}{n!}}, \quad l = 0, 1, \ldots, m \tag{8}$$

where m is the total number of available channels in the coverage area. Because the network blocking probability p_B is equal to p_m, we can get that the handoff probability P_{h4} is equal to $1 - p_B$.

Hence, handoff probability based on blocking probability is as follows:

$$P_{h4} = 1 - \frac{\frac{(-\lambda \mathbf{A}\mathbf{X}^{-1}\mathbf{e})^m}{m!}}{\sum_{n=0}^{m} \frac{(-\lambda \mathbf{A}\mathbf{X}^{-1}\mathbf{e})^n}{n!}} \tag{9}$$

where $\mathbf{A}$ is the matrix of incoming vehicle, $\mathbf{A} = (a_1, a_2, \ldots, a_n)$, $\mathbf{e}$ is an $(n \times 1)$-order matrix, and $\mathbf{X}$ is the distribution of system services, i.e.,

$$\mathbf{X} = \begin{bmatrix} -u_1 & h_{12} & \cdots & h_{1n} \\ h_{21} & -u_2 & \cdots & h_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ h_{n1} & h_{n2} & \cdots & -u_n \end{bmatrix}$$

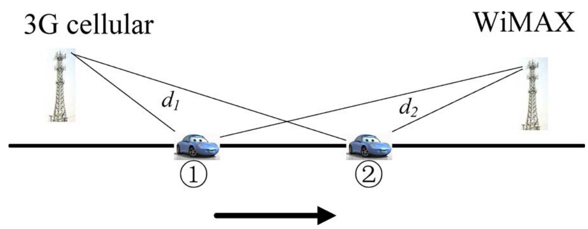

Fig. 1. Vehicle movement model.

where h_{ij} is the state transferring probability, and u_i is the exit rate of service of the vehicle.

B. Vehicle Attributes and Handoff Selections

The vehicle movement trends and the service statuses also have a close relationship with VHOs.

1) Vehicle Movement Trend: The relationship between vehicle movement trend and access points is shown in Fig. 1. The distance between vehicles and access points can be calculated by the RSS. Vehicles can obtain M sample values of RSS within a set period of time T_d. The cumulative change value is expressed as follows:

$$\Delta D_d = \sum_{i=1}^{M-1} \left[10^{\frac{K_1+u(x)-\mathrm{RSS}_{i+1}}{K_2}} - 10^{\frac{K_1+u(x)-\mathrm{RSS}_i}{K_2}} \right], \quad i = 1, 2, \ldots, M-1 \tag{10}$$

where, if $\Delta D_d < 0$, the vehicle is close to the access point. Hence, the duration of the network that is accessed to will be increased to reduce the switching frequency. Handoff probability based on movement trend can be calculated by the following:

$$P_{h5} = P(\Delta D_d < 0) \tag{11}$$

where D_d is the distance cumulative change value of the destination network during time T_d.

2) Vehicle Service Statuses: At present, 3GPP defines four categories for service flows, which are conversational services, streaming services, interactive services, and background services [6], as follows.

1) Conversational services are typical real-time services that require small delay and jitter of end to end, such as voice session, multimedia conference, and Voice over Internet Protocol.
2) Streaming services are real-time services that transmit data with unipolarity and more relaxed delay, such as video in demand and live video.
3) Interactive services are request–response modes that admit the higher delay, such as Web browsing.
4) Background services usually are services that have no limit on the transmission delay, such as e-mail and background file transfer protocol download.

Based on their characteristics, the four categories of services have different requirements to networks. Conversational services focus on session quality, and their real-time property requires network handoff to impact on the session as little as possible. Third-generation cellular technology can be a good way to ensure the quality of the session. When vehicle services include conversational services, the priority of networks is "3G cellular>WiMAX>WLAN." The data of streaming services are larger, which require the network to have enough bandwidth and low cost. The priority of networks is "WLAN>WiMAX>3G cellular." Interactivity and background services admit the higher delay and have fewer data transmission; thus, the corresponding priority changes as "WLAN>WiMAX>3G cellular."

IV. Proposed VHO Method

Having introduced the parameters of network attributes, this section will present our proposed VHO method based on self-selection decision tree. Here, we first define four types of user preferences in Section IV-A. Then, according to the corresponding handoff probability and user preferences, we propose a novel vertical vehicle method by a self-selection decision tree in Section IV-B.

A. Users' Network Preferences

We first introduce four types of user preferences, which are defined in this paper as follows.

1) Continuous network priority: the users hope vehicles access to a network with longer duration to avoid excessive switching, which guarantees that the duration is as long as possible.
2) Network bandwidth priority: the users hope vehicles access to a network with a high transmission rate.
3) Network cost priority: because of different communication costs required by each network, the vehicles want to access to the network with a relative low cost.
4) Service orientation priority: vehicles want to access to the network as much as possible to meet the requirements of the vehicle services.

B. Our Method Based on Self-Selection Decision Tree

In Section III, we have introduced the handoff probability based on the maximum transmission rate and the handoff probability based on the vehicle movement trend. When the handoff probability based on the maximum transmission rate is the condition subsequent of judgment, which can be used in the decision making when the user selects network bandwidth priority. When the handoff probability based on the vehicle movement trend is the condition subsequent of judgment, which can be used in the decision making when the user selects continuous network priority. However, network cost priority and service orientation priority do not have corresponding handoff probability distributions. Hence, in this paper, we introduce the normalization method to calculate the priority coefficient of the network cost and service orientation.

1) Network Cost Normalization: Each network has a fixed fee model. In general, we consider that the standards of network cost in the short term do not change. Each network cost corresponds to a normalization $\alpha_i (0 < \alpha_i < 1,\ i = 1, 2, \ldots)$ when the normalization of 3G cellular is α_m and the normalization

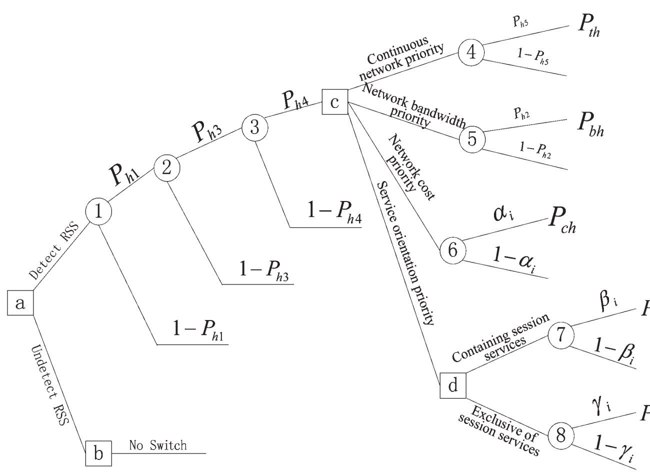

Fig. 2. Self-selection decision tree.

of WiMAX is α_n ($\alpha_n > \alpha_m$) since the cost of 3G cellular is higher than WiMAX.

2) Service Orientation Normalization: Network selections are affected by session services. Hence, in this paper, vehicle services are divided into two categories, i.e., containing session services and exclusive of session services. The priority of containing session services is "3G cellular>WiMAX> WLAN." The priority of exclusive of session services is "WLAN>WiMAX>3G cellular." When vehicle services contain session services, each priority of networks corresponds to a normalization $\beta_i (0 < \beta_i < 1,\ i = 1, 2, \ldots)$. The normalization β_m of 3G cellular is greater than the normalization $\beta\beta_n$ of WiMAX by this time. When vehicle services do not contain session services, each priority of networks corresponds to a normalization γ_i $(0 < \gamma_i < 1,\ i = 1, 2, \ldots)$. The normalization γ_n of WiMAX is greater than the normalization γ_m of 3G cellular by this time. The self-selection decision tree structure is based on the aforementioned analysis, as shown in Fig. 2.

In Fig. 2, squares represent decision nodes in the self-selection decision tree structure. Decision nodes in the decision-making process need to select decisions. Circles represent event nodes, which mean random events in the decision-making process. Decision nodes in the self-selection decision tree are as follows: a, b, c, and d. Event nodes in the self-selection decision tree are as follows: 1, 2, 3, 4, 5, 6, 7, and 8.

Decision node a means the selection of whether the received signal should be detected or not. Decision node b means that the vehicle does not switch the network when the received signal is not detected. Decision node c means the user selection of priority modes. Decision node d means the selection of whether vehicle services include session services.

Event node 1 signifies the random event of whether vehicles switch the network after the received signal is detected. Event node 2 signifies the random event of whether the target network's BER satisfies network switch. Event node 3 signifies the random event of whether target network's blocking probability satisfies network switch. Event node 4 signifies that the random event based on vehicle movement trend is in continuous network priority mode. Event node 5 signifies that the random event based on maximum transmission rate is in network bandwidth priority mode. Event node 6 signifies that the random event based on the normalization of network cost is in network cost priority mode. Event nodes 7 and 8 signify the random event of containing session services and exclusive of session services is in service orientation priority mode, respectively. P_{h1}, P_{h2}, P_{h3}, P_{h4}, and P_{h5} represent events h_1, h_2, h_3, h_4, and h_5, respectively. According to the self-selection decision tree, corresponding handoff probabilities can be calculated by the following:

$$P_{th} = P(h_1)P(h_3|h_1)P(h_4|h_1h_3)P(h_5|h_1h_3h_4) \quad (12)$$

$$P_{bh} = P(h_1)P(h_3|h_1)P(h_4|h_1h_3)P(h_2|h_1h_3h_4) \quad (13)$$

$$P_{ch} = P(h_1)P(h_3|h_1)P(h_4|h_1h_3)\alpha_i \quad (14)$$

$$P_{sh} = P(h_1)P(h_3|h_1)P(h_4|h_1h_3)\beta_i \quad (15)$$

$$P_{eh} = P(h_1)P(h_3|h_1)P(h_4|h_1h_3)\gamma_i \quad (16)$$

with

$$P(h_1)P(h_3|h_1)P(h_4|h_1h_3) = P(h_1h_3h_4).$$

When the vehicle selects the continuous network priority, where existing $P_{thi} = \max(P_{th1}, P_{th2}, \ldots, P_{thn})$, i signifies the sequence number of the target network, and n is the sum of target networks. If $P_{thi} > P_{th0}$, where P_{th0} is the reference value of current network after self-selection decision, our method will select the target network i as switching network. If $P_{thi} \leq P_{th0}$, our method will stop the network handoff and maintain the current network connection.

When the vehicle selects the network bandwidth priority, if $P_{bhi} > P_{bh0}$, where $P_{bhi} = \max(P_{bh1}, P_{bh2}, \ldots, P_{bhn})$, our method will select the target network i as switching network. If $P_{bhi} \leq P_{bh0}$, our method will stop the network handoff and maintain the current network connection.

When the vehicle selects the network cost priority, if $P_{chi} > P_{ch0}$, where $P_{chi} = \max(P_{ch1}, P_{ch2}, \ldots, P_{chn})$, our method will select the target network i as switching network. If $P_{chi} \leq P_{ch0}$, our method will stop the network handoff and maintain the current network connection.

When the vehicle selects the service orientation priority, if vehicle current services contain session services and $P_{shi} > P_{sh0}$, where $P_{shi} = \max(P_{sh1}, P_{sh2}, \ldots, P_{shn})$, our method will select the target network i as switching network. If $P_{shi} \leq P_{sh0}$, our method will stop the network handoff and maintain the current network connection. If vehicle current services do not contain session services and $P_{ehi} > P_{eh0}$, where $P_{ehi} = \max(P_{eh1}, P_{eh2}, \ldots, P_{ehn})$, our method will select the target network i as switching network. If $P_{ehi} \leq P_{eh0}$, our method will stop the network handoff and maintain the current network connection.

V. Feedback Decision Based on Vehicle States

After network switch through self-selection decision tree, the vehicle movement trend changes. The vehicle service status changes may affect the judgment of the next handoff.

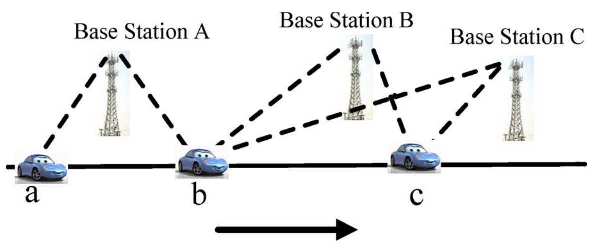

Fig. 3. Diagram of vehicle motion state.

A. *Vehicle State Feedback After Handoff*

When the user selects the service orientation priority, service changes in the vehicle may affect the quality of the other services in the vehicle. When the user selects continuous network priority, the vehicle movement changes may affect the duration of the accessed network.

1) Feedback of Vehicle Service State: When the user selects the service orientation priority, the major impact on the handoff decision is the changes of conversational class. There are two kinds of changes. In the first change, the services including conversational class change to the services that do not contain conversational class. When the vehicle contains conversational class, after networks switched by self-selection decision tree, the vehicle disconnects the session services at a certain time. Followed by the next selection decision, the decision point d in the decision tree selects the exclusive of session service's branch to make decision.

Thus, these vehicle service changes will lead to a new network decision-making choice, but do not affect the QoS on the vehicle. In the second change, the services that do not contain conversational class change to the services including conversational class. When the vehicle does not contain conversational class, after networks switched by self-selection decision tree, the vehicle connects the session services at a certain time. Followed by the next selection decision, this will cause the network being switched again. It is likely to interrupt sessions. Therefore, in this case, we need to make decisions according to the feedback of service changes to improve the quality of the new session services.

2) Feedback of Vehicle Motion State: When the user selects the continuous network priority, vehicles' priority access to networks is becoming close in the same network parameters case. After the handoff, the vehicle state of motion changes will affect the next handoff.

As shown in Fig. 3, the vehicle access to base station A at location a. If the vehicle makes a handoff decision according to the self-selection decision tree at location b, the vehicle should access to the wireless network covered by base station B. Then, the vehicle will switch to the network covered by base station C at location c. Therefore, based on the aforementioned analysis, we can know that the number of switching that occurs will increase in the case of a relatively dense base station distribution. If the network covered by base station C can meet the requirements of the vehicle services and the vehicle access to network C at location b, the vehicle does not need to switch at location c. It reduces the handoff times and increases the stabilization time of the network. Vehicle speed changes will impact the duration of the networks. In addition, the direction changes of the vehicle may increase or decrease the duration of the networks.

B. *Feedback Decision Based on the Vehicle State*

Based on the specific changes of the vehicle state, we can achieve the feedback decision method through the feedback of vehicle handoff.

1) Feedback Decision Based on Vehicle Service State

Algorithm 1: Feedback Decision Based on Vehicle Service

```
SessionRequest = INVITE;
SessionTermination = BYE;
CancelCall = CANCEL;
IF ReceiveMessage (ReceiveMessage = INVITE) THEN
    The branch of containing session services should be
    chosen at the decision point d;
END
IF ReceiveMessage (ReceiveMessage = BYE) THEN
    The exclusive of session service's branch will be chosen
    at the decision point d;
END
IF ReceiveMessage (ReceiveMessage = CANCEL) THEN
    The exclusive of session service's branch will be chosen
    at the decision point d;
END
IF ReceiveMessage (ReceiveMessage = NULL) THEN
    Do not make handoff decisions;
END
```

In service orientation priority, the changes of session services will lead to the occurrence of the network switch. The network switch occurs after the change of service, with a certain lag. When the services that do not contain conversational class change to the services including conversational class, network switching is likely to cause interruption of the session. In this case, the network handoffs should be timely. We propose a decision method of services' feedback. Session initiator initiates a call request. In other words, when the vehicle transmits or receives a call request signaling INVITE, it will immediately trigger the self-selection decision tree to select networks. The branch of containing session services should be chosen at the decision point d. When the vehicle transmits or receives the signaling BYE or CANCEL, the exclusive of session service's branch will be chosen at the decision point d, as shown in Algorithm 1.

2) Feedback Decision Based on Vehicle Motion State: In continuous network priority, if the base stations are very densely distributed, the network handoff will create too much handoff times according to the self-selection decision tree. It will reduce the duration of the network. In order to improve the duration of the network, we predict the network an approximate duration for the feedback decision. The estimation method of vehicle average velocity is given before analyzing the feedback decision.

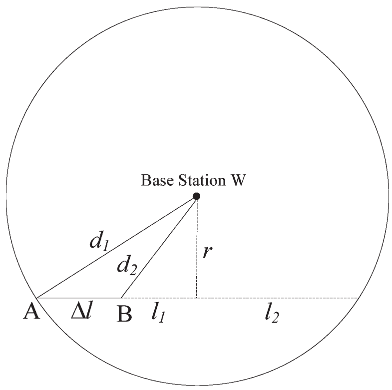

Fig. 4. Duration prediction model

In general case, vehicles are in variable motion. Thus, studies in vehicle velocity generally introduce the average velocity over a certain cycle time T_V. The tachometer function of the vehicles may sample N instantaneous speed values in a certain cycle time T_V. T_V may be chosen based on the practical application. In a certain cycle time T_V, the average velocity of the vehicle should be as follows:

$$\overline{V} = \frac{1}{N}\sum_{j=0}^{N-1} V_j, \quad j = 0, 1, \ldots, N-1 \tag{17}$$

where V_j is the jth sample value of the vehicle velocity.

The predicted model of network duration is shown in Fig. 4. Point A is a position of the vehicle access to new network W, and point B is a position reached by the vehicle after a short time Δt. The predicted duration of network is as follows:

$$\begin{cases} d_1^2 = r^2 + (\Delta l + l_1)^2 \\ d_2^2 = r^2 + l_1^2 \end{cases} \tag{18}$$

with

$$l_1 = \frac{d_1^2 - d_2^2 - \Delta l^2}{2\Delta l}(\Delta l = \overline{V}\Delta t).$$

Because of $l_2 = l_1 + \Delta l$, the predicted duration of network can be given by the following:

$$t_c = \frac{2l_2}{\overline{V}} = \frac{d_1^2 - d_2^2 + \overline{V}^2\Delta t^2}{\overline{V}^2\Delta t}. \tag{19}$$

When there are m networks that satisfy $P_{thj} > 0.5$, $j = 1, 2, \ldots, m$, there will be $P_{thj}t_{cj} = \max(P_{th1}t_{c1}, P_{th2}t_{c2}, \ldots, P_{thm}t_{cm})$. The jth network will be chosen as the target handoff network. In order to avoid too much handoff times created by changes of vehicle movement direction, we analyze the trigger of the next handoff through the signal strength of the network edge and the vehicle movement trends.

Because the predicted duration cannot completely reflect the duration of network, it may increase or decrease the duration of network when the vehicle changes its movement direction. If the last handoff time is t_1, we have $P_{h1}(t_1)$ and $P_{h2}(t_1)$. When $P_{h1}(t_1) > P_{h1}(t_1)$, the network update and the handoff decision do not need to be proceeded. When the vehicle leaves from the current network $(P_{h1}(t_n) = P_{h1}(t_1))$ and this network will not guarantee the QoS $(P_{h2}(t_n) = 1 - P_{h2}(t_1))$, the next handoff decision should be triggered through the self-selection decision tree.

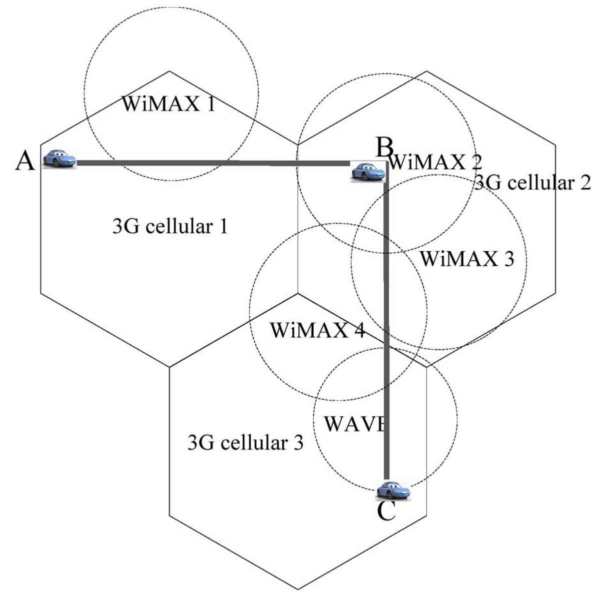

Fig. 5. Simulation scenario.

VI. SIMULATION

Here, as shown in Fig. 3, we construct a simulation scenario to evaluate our proposed method in terms of four priority modes, namely, switching position, switching type, target network, and maximum throughput rate.

A. Simulation Setup

The simulation scenario is shown in Fig. 5. Simulation motion scenario parameters are as follows. The coordinates of point A are [10, 200], the coordinates of point B are [210, 200], and the coordinates of point C are [210, 0]. The distance between A and B is 20 km. The distance between B and C is 20 km. The coordinates of WiMAX1, WiMAX2, WiMAX3, and WiMAX4 base stations are [110, 245], [210, 200], [110, 245], and [185, 115], respectively. Third-generation cellular covers the whole scenario, and the coordinates of 3G cellular1, 3G cellular2, and 3G cellular3 are [60, 160], [210, 160], and [135, 30], respectively. We assume that the vehicle is moving at a uniform speed of 60 km/h from point A to point C. There is a video session in the vehicle from 540 to 660 s after departure. From [210, 85] to [210, 0], the strength is stable as vehicles are crowded in the scenario. The vehicles can be composed of ad hoc network through WAVE.

Network simulation parameters are as follows. The signal intensity is the stability in the coverage area of WAVE, which is about −95 dBm. We adopt −95 dBm as the fixed strength value, and the access bandwidth is 27 Mb/s. The coverage radius of WiMAX is 10 km, the access bandwidth is 45 Mb/s, the transmission power is 25 dBm, the path loss is 35 dBm, and σ_1 is 8 dBm. The coverage radius of 3G cellular is full area, the access bandwidth is 2 Mb/s, the transmission power is 30 dBm,

TABLE III
SPECIFIC CIRCUMSTANCES OF NETWORK SWITCHING

Mode / Times	Continuous priority	Bandwidth priority	Cost priority	Service priority
1	Switch to WiMAX1 (7600m, VHO)	Switch to WiMAX1 (7600m, VHO)	Switch to WiMAX1 (7600m, VHO)	Switch to WiMAX1 (7600m, VHO)
2	Switch to 3G cellular1 (12425m, VHO)	Switch to 3G cellular1 (12400m, VHO)	Switch to 3G cellular1 (12400m, VHO)	Switch to 3G cellular1 (9025m, VHO)
3	Switch to WiMAX2 (15100m, VHO)	Switch to WiMAX2 (15100m, VHO)	Switch to WiMAX2 (15100m, VHO)	Switch to WiMAX1 (11100m, VHO)
4	Switch to WiMAX4 (24800m, HHO)	Switch to WiMAX3 (24400m, HHO)	Switch to WiMAX3 (24200m, HHO)	Switch to 3G cellular1 (12300m, VHO)
5	Switch to WAVE (31900m, VHO)	Switch to WiMAX4 (26700m, HHO)	Switch to WiMAX4 (26700m, HHO)	Switch to WiMAX2 (15100m, VHO)
6	—	Switch to WAVE (31600m, VHO)	Switch to WAVE (31600m, VHO)	Switch to WiMAX3 (24200m, HHO)
7	—	—	—	Switch to WiMAX4 (26800m, HHO)
8	—	—	—	Switch to WAVE (31600m, VHO)

the path loss is 33 dBm, and σ_1 is 6 dBm. The maximum BER threshold τ is 0.006. The minimum RSS threshold η is -110 dBm, the interference signal strength is -130 dBm $+ u(x)$, where $u(x)$ is the Gaussian distribution function following $(0, \sigma_2)$, and σ_2 is 10 dBm.

B. Simulation Results

The value i of 1, 2, and 3 corresponds to 3G cellular, WiMAX, and WAVE, respectively, where $\alpha_1 = 0.2$, $\alpha_2 = 0.4$, and $\alpha_3 = 1$; $\beta_1 = 1$, $\beta_2 = 0.6$, and $\beta_3 = 0.4$; and $\gamma_1 = 0.35$, $\gamma_2 = 0.7$, and $\gamma_3 = 1$. Comparative probabilities are as follows: $P_{th0} = 0.6$, $P_{bh0} = 0.6$, $P_{ch0} = 0.5$, $P_{sh0} = 0.5$, and $P_{eh0} = 0.5$. The vehicle does a switching decision calculation every 6 s.

1) Specific Circumstances of Handoff: As shown in Table III, specific circumstances of network switching in four priority modes have been depicted. VHO and HHO exist throughout the simulation process, and the total handoff times in four priority modes are as shown in Fig. 6.

In continuous network priority mode, the total handoff times is 5, where the VHO time is 4, and the HHO time is 1. In network bandwidth priority mode, the total handoff times is 6, where the VHO time is 4, and the HHO time is 2. In network cost priority mode, the total handoff times is 6, where the VHO time is 4, and the HHO time is 2. In service orientation priority mode, the total handoff times is 8, where the VHO time is 6, and the HHO time is 2. VHO method based on self-selection decision tree reduces the switching times, compared with the method of SNR difference trigger (11 times) and the RSS fuzzy logic method (15 times). This is because the calculation adopts the handoff probability of multicondition, which reduces the redundant handoff times between approximate networks. The vehicle does a switching decision calculation every 6 s, and each calculation of time is spent within 200 ms, as shown in Fig. 7. It is timely compared with the fixed RSS threshold method and the dwell time method.

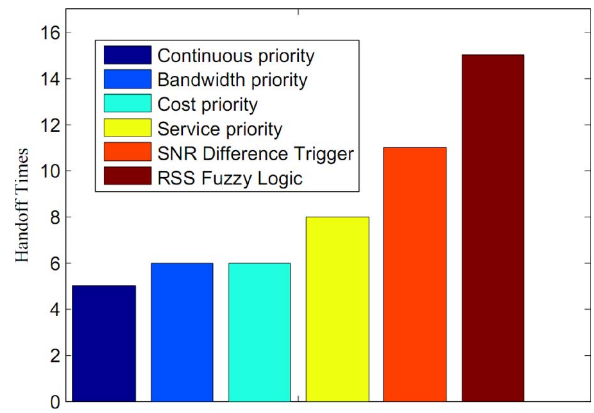

Fig. 6. Handoff times.

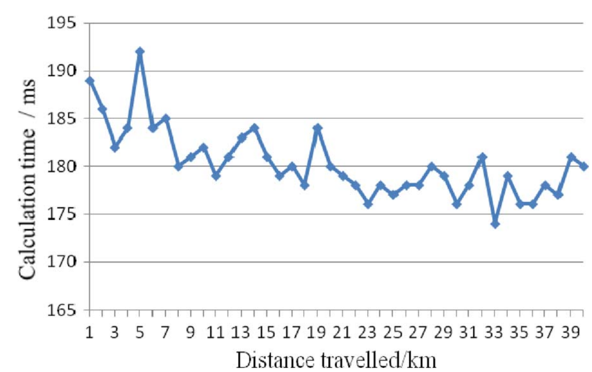

Fig. 7. Calculation time.

2) Maximum Throughput Rate: In the experiment, Table IV shows the maximum throughput rates of the vehicle in four priority modes. Since qualities of target network are considered in the decision tree method, the network throughput rates obtain a good guarantee. By comparing the simulation scenario, the maximum throughput rates reflect that the switching destination network is the optimal network that can be accessed to at the time.

VII. CONCLUSION

This paper has introduced a VHO method based on a self-selection decision tree, which can support the VHO among WAVE, WiMAX, and 3G cellular. The decision tree makes decision according to user preferences, and the feedback decision method in line with the feedback of services and movements on vehicles can avoid the negative impact of service changes and movement changes.

TABLE IV
MAXIMUM THROUGHPUT RATE

Distance moved/km	**Maximum throughput rate MB/s**			
	Service priority	*Cost priority*	*Bandwidth priority*	*Continuous priority*
1	0.16	0.17	0.18	0.16
2	0.18	0.15	0.19	0.18
3	0.17	0.18	0.21	0.22
4	0.16	0.20	0.18	0.19
5	0.18	0.19	0.19	0.17
6	0.21	0.22	0.20	0.21
7	0.19	0.20	0.22	0.23
8	3.52	3.62	3.68	3.71
9	3.51	3.59	3.71	3.68
10	0.17	3.74	3.96	3.87
11	0.19	3.80	3.88	3.98
12	3.76	3.64	3.76	3.66
13	0.22	0.21	0.23	0.19
14	0.21	0.22	0.24	0.22
15	0.22	0.19	0.21	0.23
16	3.51	3.54	3.70	3.71
17	3.53	3.61	3.75	3.71
18	3.89	3.89	3.86	3.92
19	3.92	4.21	3.97	3.99
20	4.18	4.27	4.22	4.12
21	4.19	4.19	4.27	4.18
22	3.92	3.97	4.12	4.03
23	3.92	3.89	3.96	3.98
24	3.74	3.81	3.92	3.86
25	3.82	3.94	3.97	3.92
26	3.85	3.90	3.90	3.97
27	3.88	3.89	3.92	4.06
28	3.98	4.14	3.98	4.16
29	4.01	4.04	4.08	4.02
30	4.12	3.93	3.99	3.97
31	3.93	3.96	4.02	3.98
32	3.12	3.02	3.16	3.79
33	3.20	3.11	2.97	3.12
34	3.02	3.17	3.17	2.97
35	3.11	3.05	3.16	3.17
36	3.24	2.96	3.02	3.12
37	2.98	2.98	3.07	3.01
38	3.01	3.02	2.95	2.97
39	2.91	2.98	2.98	2.94
40	2.88	2.92	3.01	2.95

The distinguishing features of the method include the following: 1) vehicle and network statuses are considered; 2) the four types of preference are defined for vehicles; and 3) the method is verified through simulation in four priority modes. The method reflects the specific needs of vehicle to the network. Moreover, there may be some other network attributes and user preferences that were not taken into account. In addition, the proposed decision tree method can be further optimized. Hence, the future work focuses on how to optimize our proposed method by improving user preferences.

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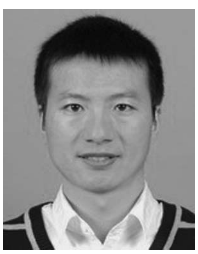

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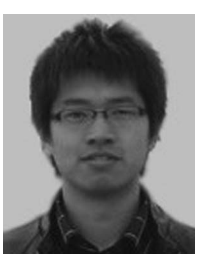

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