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Decision-making models for group vertical handover in vehicular communications

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Abstract In vehicular communications across composite radio environments, the one prominent feature is network heterogeneity, which means that diverse radio access networks co-exist with each other. And another particular feature is group mobility, because multiple mobile equipments in the vehicle are moving at the same time. Therefore, with movement of vehicle, many mobile terminals (MTs) in a train or bus may operate vertical handover actions almost at the same time, which is regarded as the group vertical handover (GVHO). However, the current literatures on vertical handover (VHO) mainly focus on when to trigger handover and how to select the best target network for single user, if these VHO schemes were applied in vehicular communication scenario, it may lead to system performance degradation or network congestion, because the MTs with these VHO decision-making methods selfishly select the best networks regardless of the influences from other concurrent VHO users. Therefore, in order to provide reliable QoS guarantee and keep service connectivity for group mobility in vehicular communications across heterogeneous networks, three models are proposed in this paper to deal with the decision-making problems of incomplete and inaccurate information in GVHO scenario. Two of them adopt MT controlled VHO, while another adopts network assisted VHO. The performances of these schemes are studied with regard to the average transmission delay and average packet losses rate.

Keywords Vehicular communications · Heterogeneous networks · Group mobility · Group vertical handover · Decision-making model

1 Introduction

In vehicular communications, one of the major requirements is that the subscribers' session or data transmission should be handed over seamlessly during vehicle movement [1]. Moreover, the heterogeneity has become the most prominent feature of the next generation wireless communication systems. For heterogeneous radio environment, it consists of diverse radio access networks (RANs) [2]. Therefore, one problem emerges as how to provide continued connectivity as users roam across diverse RANs with reliable QoS guarantee. It will be beneficial if the various capabilities of existing heterogeneous networks could be utilized to support handover [3]. Hence, the vertical handover is expected as one of the most effective mechanisms to support seamless roam in vehicular communications across heterogeneous networks [4, 5].

Vertical handover enables the users to seamlessly roam over different RANs [6, 7]. The methods of VHO can be generally classified into four categories according to its control methodology: MT controlled handover, Network

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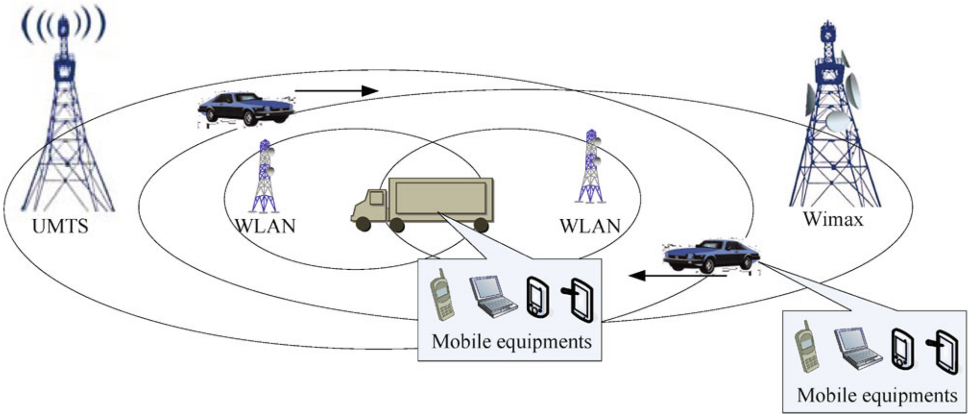


Fig. 1 Group vertical handover in vehicular communications

controlled handover, MT assisted handover (Network controlled) and Network assisted handover (MT controlled) [8]. Currently, many literatures about VHO decision strategies have been proposed with advanced tools and proven concepts, which will be briefly introduced in Sect. 2. Most current literatures for VHO adopt the MT controlled mechanism, and these schemes can select the best target network based on the individual information in MT side, because it has known the decisions of previous users and instant network statuses, which implies that individual information for decision-making in MT side is complete and accurate.

In order to deal with the group mobility in vehicular communications, the concept of group vertical handover is proposed. For GVHO, it is defined that a group of multi-mode terminals connecting to different RANs operate vertical handover at the same time or nearly simultaneously [9]. Nowadays, the GVHO may occur commonly especially in vehicular communication scenario. As indicated in Fig. 1, in the hot-spot area covered by multiple RANs, it is supposed that all the terminals are multi-mode one, when a bus or train is crossing this hot-spot area, the mobility of device leads to the variation of both network coverage and link qualities, so the terminals belonging to different passengers in the bus or train may trigger handover almost simultaneously to achieve always best connected.

In the proposed GVHO scenarios, the VHO schemes for single user may lead to system performance degradation such as inefficient resource utilization, larger transmission delay and high handover reject rate, because those schemes make decision for current user without the knowledge of other users' decision, so the information for VHO decision is totally incomplete. For example, most VHO schemes make handover decision based on QoS parameters such as RSS or available resources. In this situation, the GVHO users will selfishly select the network that can provide the best QoS guarantee, but ignore the influences from other concurrent VHO requests. As a result, most users may handover to the same target network because of the fragmentary individual information, then the available resources of target network will decrease dramatically, which further lead to network congestion and performance degradation. Therefore, an efficient decision-making model for GVHO is quit necessary to make better coordination among VHO requests and multiple networks to avoid inaccurate vertical handover.

Based on the problems discussed above, three decision-making schemes for GVHO will be presented in this paper, which aim to optimize the system performance and keep service connectivity in group mobility scenario of vehicular communications. The first and second ones are MT controlled handover. In the scenario of GVHO, the decision-making for MT controlled handover is similar as the distributed decision system, and the key to successful solution is to reduce uncertainty of information for decision-making. The first proposed scheme is inspired by the idea of separating massive VHO requests in time sequence, while the second one is trying to distribute concurrent VHO requests into available networks according to the predefined probability distribution. Different with previous two schemes, the third decision-making scheme is network assisted (MT controlled) handover. MT side triggers the handover, but the network side makes decision, because the network side can collect more information and nearly eliminate uncertainty of information. The function model of common radio resource management (CRRM) in network side collects VHO requests and information of available networks in current hot spot area, then it makes coordination among VHO requests and multiple networks to achieve optimized decision results that can improve whole system performance.

The rest paper is organized as follows: Sect. 2 briefly presents the previous works on vertical handover. Section 3 formulates the problem and objective in group vertical handover. Section 4 presents the proposed GVHO schemes in detail. And then the simulation results and analysis are given in Sect. 5. Finally, Sect. 6 concludes this paper.

2 Overview of previous works on VHO

Handover management is one of the most important solutions supporting user mobility [8]. Unlike traditional horizontal handover, the vertical handover allows the mobile equipments to roam over different radio access networks. Hence, how to utilize diverse characteristics of diverse networks to provide continued service connection as users roam over different areas and radio networks emerges as a topic of intense interest.

For vertical handover, it mainly cares about two aspects: (a) when to trigger the handover; (b) which network to hand over in heterogeneous radio environments. Currently, the literatures about VHO mainly pay attentions on the second aspects. In the procedure of handover decision, many criterions, such as radio signal strength, packet loss rate, latency, available resources and user preferences, should be considered.

In [10], a policy based VHO scheme is proposed, a cost function is defined and makes network selection in the most appropriate way to maximize user throughput of activated service. Although this method is sample for operation, it cannot get the accurate decision result especially the multiple criterions need to be considered simultaneously and the relationships of these criterions are complex.

Fuzzy logic is also used for vertical handover because it has capability to map the relationships among multiple criterions into mathematics expression and allow simultaneous evaluation of several handover criteria [11]. In [12–14], the fuzzy logic is used as follows. The decision factor dependent membership functions are applied on the values of decision factors. The degree of truth for each rule premise is then obtained. The truth value for the premise of each rule is computed, and applied to the conclusion part of each rule. All of the fuzzy subsets assigned to each output variable are combined together to form a single fuzzy subset for each output variable. Finally the fuzzy output set is transferred to a real number for each network and the best network is then selected.

Furthermore, multiple attribute decision making (MADM) methods are also well studied for vertical handover because it can quantify the importance weights of each criterion to the objective and rank the candidate networks according to importance weights and network characteristics. In [15], analytic hierarchy process (AHP) and the grey relational analysis (GRA) are adopted. AHP is used to calculate the weights of various service parameters and the GRA is applied to rank the candidate networks according to QoS score function. In [16], the proposed scheme defines the vector norms as satisfaction function to revise the weighting factors of metrics given by AHP. Moreover, the vertical trigger and control method is also considered in this literature. In [17], simple additive weighting (SAW) is used to order preference by similarity to ideal solution (TOPSIS).

Those vertical handover algorithms discussed above have a common assumption that the users are coming one by one, and those schemes are proposed to select the best network for each user. However, a prominent feature of vehicular communications is group mobility, because there are many passengers with mobile equipments in the bus or train, they may operate handover nearly at the same time due to the fact of vehicle movement. Once those schemes discussed above were applied to the handover in vehicular communications, it will lead to inefficient system performance, the reason is that some decision factors cannot be measured or the measurements are not accurate enough for the decision-making in group mobility scenario. Unfortunately, there are few literatures paying attentions on the problems of group mobility in vehicular communications, especially on how to support group vertical handover across heterogeneous networks in vehicular communications.

In [9], it discussed the problem in group handover and proposed three network selection algorithms with the concept of social cost introduced in game theory. In this literature, the social cost is the function of transfer latency. The first algorithm assumed that each mobile node knows the traffic load of other nodes, and the selection result is achieved with Nash Equilibrium in polynomial time. However, the consumption of this algorithm is unavailable in real network environment, so the other two algorithms are proposed based on the random delay, and the difference between the second algorithm and the third one are: (a) the second algorithm firstly broadcasts the selection result, and then operate handover procedure; (b) the third one firstly operate handover action based on the decision result, and then broadcast the selection result after the handover has been operated successfully. Although the mobile modes can avoid making decision simultaneously, the proposed algorithms do not take the service characteristics into consideration, and cannot provide differential QoS guarantee for various services in the integrated service environment.

In order to deal with the problems discussed above, three decision-making models are proposed, which not only aim to effectively support vertical handover for group mobility, but also provide reliable QoS guarantees for both real-time and non-real-time services.

3 Problem formulation

It is supposed that the set $\mathcal{N}$ denotes the available networks in current hot spot area. For each network $i \in \mathcal{N}$ ($i = 1, 2, \dots, n$), the available resources are AR_i Mbps and the round trip time is RTT_i ms, both of which are various with time. Let the set $\mathcal{U}$ denote users operating handover at a given time. For each user $j \in \mathcal{U}$ ($j = 1, 2, \dots, m$), the required service bit rate is R_j Mbps, and it is assumed that

$R_j \in \mathcal{R}$, where $\mathcal{R}$ is the discrete set of allowable bit rate. Let set $\mathcal{U}_{RT}, \mathcal{U}_{NRT} \subseteq \mathcal{U}$ be the set of handover users with real-time (RT) service and non-real-time (NRT) service, respectively.

Various services have their special characteristics. The real-time service is delay-sensitive, while the non-real-time service is sensitive to packet losses. Therefore, for decision-making models of GVHO scenario, the goals for RT service and NRT service are also different. For real-time service, its objective is to minimize the average transmission delay of whole system, while the objective of NRT service is to minimize the average packet losses rate (PLR).

If the allocated rate approaches the available resources, the transmission delay will increase due to network congestion. Therefore, a simple fraction function is given to approximate the non-linear increase of transmission delay with the allocated rate to user j and the available resources of network i [18], as

$$T_{ij} = \frac{R_j \cdot RTT_i}{2 \cdot AR_i^*} \tag{1}$$

where AR_i^* is the available resources of network after the vertical handover.

For non-real-time service, its packet losses rate is estimated as an exponential function of packet delay distribution [18]. Meanwhile, the unbalanced load distribution among multiple networks also has influences on PLR. As a result, the PLR is given as follows.

$$PLR_{ij} = \eta_i \exp\left(-\frac{T_o}{T_{ij}}\right) \tag{2}$$

where T_o is maximal tolerable delay of non-real-time service, T_{ij} also can be calculated as same as (1), and η_i is factor of load balancing, which is defined as

$$\eta_i = \frac{\sum_{i \in \mathcal{N}} AR_i^* - AR_i^*}{\sum_{i \in \mathcal{N}} AR_i^*} \tag{3}$$

4 Decision-making models for GVHO

4.1 Scheme 1: algorithm based on time window

The traditional VHO schemes for single user are inefficient in the GVHO scenario, because the current handover MT makes decision without the knowledge of other MTs' decisions and network statuses, which lead to the dilemma that each MT just selfishly selects the "best" network regardless of the influences from other concurrent handover MTs. Therefore, the natural idea is to separate simultaneous arrived VHO requests in time sequence. This method is first proposed in [9], but it does not consider the QoS guarantee for different services.

Based on this idea, the handover user $j \in \mathcal{U}$ sends VHO request after a random delay, and then the users awaiting for handover could receive the decision results of previous users, so the simultaneous decision-making for multiple VHO users can be proportionally be avoided. Moreover, different time windows are defined for RT and NRT services respectively due to the various service characteristics.

The detailed decision-making algorithm based on time window is explained as follows.

Step 1: if handover user $j \in \mathcal{U}_{RT}$, the random delay t_j is generated within the time window $[0, T]$; otherwise, if user $j \in \mathcal{U}_{NRT}$, t_j is generated within the time window $[T, T_1]$.

Step 2: the handover user sends the VHO request to the target network when t_j is expired. The methods to select the most appropriate target network for RT service and NRT service are explained as follows respectively. For RT user $j \in \mathcal{U}_{RT}$, the target network is selected as

$$N_{select} = \arg\min_{i \in \mathcal{N}} T_{ij} \tag{4}$$

For NRT user $j \in \mathcal{U}_{NRT}$, the selection principle is formulated as

$$N_{select} = \arg\min_{i \in \mathcal{N}} PLR_{ij} \tag{5}$$

It should be note that $(AR_i - R_j) > 0$ should be satisfied for both RT and NRT users.

Step 3: the current user j handover to the selected network, and then the selected network updates the available resources as $AR_i^* = AR_i - R_j$. Meanwhile, the network broadcasts this VHO result to other active users with unexpired time window.

Although the time window is introduced to avoid simultaneous decision-making for mass handover users, it is probable that more than one users generate the same random delay. The probability that a handover user makes decision without collision of other users will be analyzed in the following parts. It should point out that the following analysis are presented for real time users, and the deduced method also can be applied for non-real-time users.

Generally, the frame structures of the most RANs are divided into slot in time domain, and the user selects a available basic resource block in one slot according to the random delay to send handover request. Because the lengths of slot are different for various RANs, it is assumed that Δ is the common divisor of various slot lengths. Hence, for RT user, the time window is divided into s time intervals,

$$s = \left\lfloor \frac{T}{\Delta} \right\rfloor \tag{6}$$

And the handover user i select one time interval, $\lfloor t_i/\Delta \rfloor$, to make decision according to the generated random delay t_i.

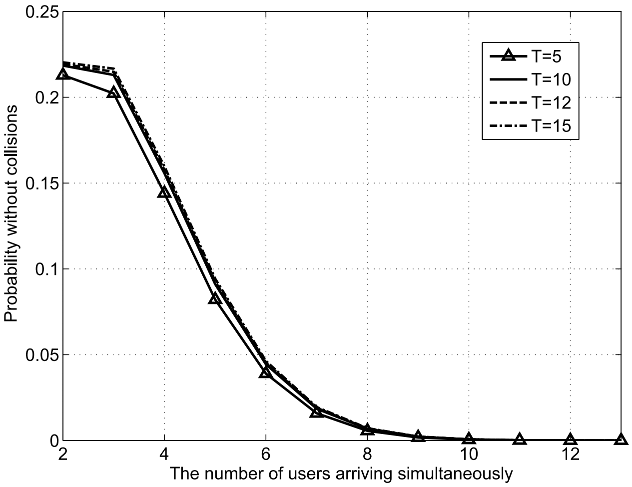


Fig. 2 The probability comparison with different time windows

Suppose that there are m_0 RT users attempting to send handover request simultaneously, which obeys Poisson distribution with rate of λ. Let P_s be the probability that a handover user makes decision without collision of others. Let ε be the event that the current user is free from collision. So $P(\varepsilon|m_0)$ is given as

$$P(\varepsilon|m_0) = 1 - P(\varepsilon_1|m_0) \tag{7}$$

where ε_1 represents the event that the selected time interval is also used by other handover users simultaneously. Then, $P(\varepsilon_1|m_0)$ can be calculated as

$$P(\varepsilon_1|m_0) = \sum_{i=1}^{m_0-1} \binom{m_0-1}{i} \left(\frac{1}{s}\right)^i \left(1-\frac{1}{s}\right)^{m_0-1-i} \tag{8}$$

Finally, we can get

$$P_s = (1 - P(\varepsilon_1|m_0)) \cdot P(m_0) \tag{9}$$

where

$$P(m_0) = \frac{\lambda^{m_0}}{m_0!} \cdot \exp(-\lambda) \tag{10}$$

As indicated in Fig. 2, it is assumed that the common divisor Δ is 0.25 ms and the user arrival rate λ is 3. It can be observed that the probability is very smaller when several users make decision simultaneously. Therefore, the proposed scheme with time window still has ability to avoid simultaneous decision-making, though the users may select the same random delay occasionally.

4.2 Scheme 2: algorithm with probability distribution

Handover latency is an important criterion to evaluate the VHO handover efficiency. Although the algorithm based on the time window could avoid simultaneous decision-making in GVHO scenario, it also brings about unnecessary delay during handover. Therefore, for decision-making with incomplete information, another natural idea is inspired as distribute multiple handover users into different networks with a predefined probability. However, this method is a tradeoff between optimal and the worst system performance. This scheme can efficiently avoid the network congestion, but it cannot get the optimal decision results because the predefined probability to some extent is a little subjective and inaccurate. For predefined probability distribution, there are three types [19, 20]:

1. *Conservative type*;
2. *Risk-preferred type*;
3. *Trade-off between conservative and risk.*

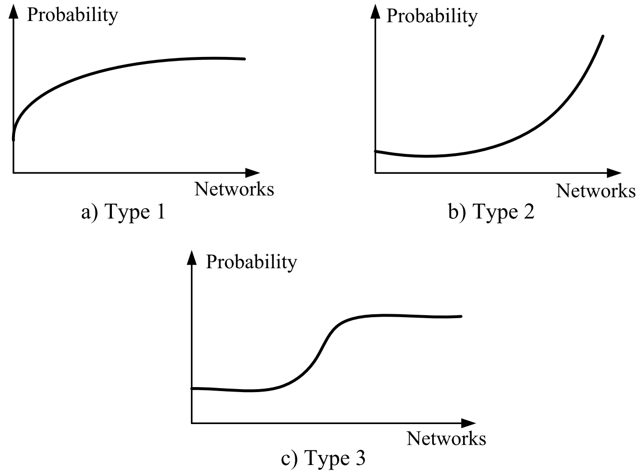


Fig. 3 Illustration for diverse types of probability distribution

For the first one, the values of probabilities for each network change progressively with regard to network performance, while for the risk-preferred type, the user aims to achieve more benefits, so the network with better system performance has much higher probability to be selected. But more benefits also mean more risks, because a lot of VHO users may select this network as target network. The third one makes tradeoff between the previous two types, the risk-preferred type is adopted for the networks whose delay or PLR performance is worse than a threshold, and conservative type is used for the networks with better performance, because these networks are likely to be selected at the same time. The illustrations for the three probability distribution types are given in Fig. 3. The networks in the right position of x-label have better system performance.

The detailed procedure of this scheme is presented as follows.

Step 1: MT collects information of all available networks. If the user j is RT user, the MT calculates the transmission delay T_{ij} according to (1). Let the set $\mathcal{N}_c^{rt}$ denote the candidate network for current RT user, and the elements in $\mathcal{N}_c^{rt}$

are those networks that can provide sufficient available resources. Furthermore, the networks in $\mathcal{N}_c^{rt}$ are sorted by T_{ij} in descending order. Supposing the number of networks in $\mathcal{N}_c^{rt}$ is l, so the network with larger index number has the better system performance (average transmission delay or PLR).

Step 2: in order to avoid select the same network with the best system performance in the set $\mathcal{N}_c^{rt}$, the predefined probability distribution is given as the probability vector as

$$\mathbf{P} = \{P_1, P_2, \ldots, P_l\} \tag{11}$$

where $0 < P_1 < P_2 < \cdots < P_l < 1$, $\sum_{i=1}^{l} P_i = 1$, and the probability distribution functions of each type are described as

$$P_{type1}(i) = \frac{\ln(i+1)}{\sum_{k\in\mathcal{N}_c^{rt}} \ln(k+1)} \quad (i = 1, 2, 3, \ldots, l) \tag{12}$$

$$P_{type2}(i) = \frac{\exp(i+1)}{\sum_{k\in\mathcal{N}_c^{rt}} \exp(k+1)} \quad (i = 1, 2, 3, \ldots, l) \tag{13}$$

$$P_{type3}(i) = \begin{cases} \frac{P_{type2}(i)}{\sum_{k=1}^{l_0} P_{type2}(k)+\sum_{k=l_0+1}^{l} P_{type1}(k)} \\ \quad (i = 1, 2, \ldots, l_0) \\ \frac{P_{type1}(i)}{\sum_{k=1}^{l_0} P_{type2}(k)+\sum_{k=l_0+1}^{l} P_{type1}(k)} \\ \quad (i = l_0+1, \ldots, l) \end{cases} \tag{14}$$

In (14), l_0 means the number of networks whose transmission delay or PLR performance is worse than a threshold. In order to provide with different QoS guarantee according to various service characteristics, the third type of probability distribution is adopted for RT users, while the conservative type is given for NRT users.

Step 3: the MT generates a random probability $P \in (0, 1)$, and compares it with the given probability distribution, if $\sum_{k=1}^{i-1} P_k \le P < \sum_{k=1}^{i+1} P_k$, the network $i \in \mathcal{N}_c^{rt}$ is selected as target network. Then MT sends VHO request to the selected network, if this network has enough resources, the current VHO user is permitted to access; otherwise, the VHO request is rejected.

Step 4: the current user j handover to selected network, and then the selected network updates the available resources as $AR_i^* = AR_i - R_j$.

The GVHO decision-making procedure for non-real-time service is similar with those of real time service described above, and the difference is that the principle for sorting in the set $\mathcal{N}_c^{nrt}$ is based on the packet losses rate.

4.3 Scheme 3: network assisted GVHO decision-making

The decision-making scheme proposed in the above part can proportionally avoid network congestion due to the fact that it distributes massive VHO requests into different networks according to a probability distribution, but it cannot optimize the whole system performance. Therefore, the network assisted mechanism for GVHO is proposed in this sub-section. The network assisted method can collect more information than MT controlled mechanism, so it is expected to make decisions from the global view of the whole system. The detailed algorithm description is presented as follows.

Step 1: CRRM function model in network side collects the network status and VHO users' information .

Step 2: the CRRM makes coordination among VHO requests and multiple networks. In order to guarantee the Qos requirements of real time service, the decision-making for RT service is operated firstly, then for NRT service. Furthermore, matrix **D** denotes the decision results, which is given as

$$\mathbf{D} = \begin{pmatrix} d_{11} & \ldots & d_{1m} \\ \vdots & \ddots & \vdots \\ d_{n1} & \ldots & d_{nm} \end{pmatrix} \tag{15}$$

where d_{ij} indicates whether the user $j \in \mathcal{U}_{RT}$ selects the network $i \in \mathcal{N}$ as the target network or not. It is defined that $d_{ij} \in \{0, 1\}$, if "$d_{ij} = 1$", it means that the select result is positive; otherwise, the select result is negative.

The objective of decision-making for RT users is to minimize the average transmission of the whole system, which is described as

$$\min_{\mathbf{D}} \frac{1}{m} \sum_{i\in\mathcal{N}} \sum_{j\in\mathcal{U}_{RT}} T_{ij} \tag{16}$$

Based on this objective, the decision-making procedure for RT service is formulated as

$$\min_{\mathbf{D}} \frac{1}{m} \sum_{i\in\mathcal{N}} \frac{(\mathbf{D}_i \cdot \mathbf{R}^{\mathrm{T}}) \cdot RTT_i}{2 \cdot AR_i^*} \tag{17}$$

s.t.

$$\begin{aligned} & AR_i^* = AR_i - \mathbf{D}_i \cdot \mathbf{R}^{\mathrm{T}} = AR_i - \sum_{j\in\mathcal{N}_{RT}} d_{ij} R_j \\ & AR_i^* > 0 \\ & d_{ij} \in \{0, 1\} \\ & \sum_i d_{ij} = 1 \end{aligned} \tag{18}$$

where $\mathbf{D}_i$ means the decision results of network i, and **R** means the data rate requirements of handover users. The constraints of optimized problem (17) are formulated in (18). The first and the second formula in (18) indicate the admission principle of the proposed handover scheme: the target network should have sufficient available resources for admitted users. The third formula indicates the alternatives of decision result.

As indicated in (17) and (18), the network assisted GVHO decision-making procedure is formulated as the problem of integer programming with non-linear objective, which is regarded as NP-hard problem. In this paper, the enumeration method is adopted to search for global solution.

Step 3: the CRRM gives the decision results to the corresponding networks and then each network update the available resources and inform the corresponding VHO users for connection initiation.

For NRT user, the decision-making procedure is similar with above steps, the difference is that the objective for NRT user is

$$\min_{\mathbf{D}} \frac{1}{m} \sum_{i\in\mathcal{N}} \sum_{j\in\mathcal{U}_{NRT}} PLR_{ij} \tag{19}$$

5 Simulation results and analysis

The system performances are evaluated in this section. Besides the three proposed algorithms in Sect. 4, the traditional VHO decision-making scheme for single user is also given as comparison. For this compared traditional VHO scheme, it selects the network providing the minimal transmission delay (packet losses rate) for real time service (non-real-time service), and the selection principle for RT and NRT users are formulated in (4) and (5), respectively. To facilitate description, the traditional VHO scheme is named as "compared scheme", and the three proposed algorithms in Sect. 4 are named as "scheme 1", "scheme 2" and "scheme 3" orderly.

For the simulation parameters, it is supposed that there are four available radio access networks in current area, the available resources of each network are denoted by vector $\mathbf{AR} = \{2, 1.5, 2, 3\}$ (Mbps), and the round trip time vector $\mathbf{RTT} = \{180, 190, 200, 200\}$ (ms) describes the corresponding parameters of all available networks. For real-time service, the set of allowable rate is $\mathcal{R} = \{0.1, 0.2, 0.3, 0.4, 0.5\}$ (Mbps) with probability of $\{0.3, 0.25, 0.2, 0.15, 0.1\}$, while the same probability distribution is given for the bit rate of non-real-time service as $\mathcal{R} = \{0.5, 0.6, 0.7, 0.8, 0.9\}$ (Mbps).

Figures 4 and 5 give the performance comparison of average transmission delay for real-time users and packet losses rate for non-real-time users, respectively. As indicated from curves, the scheme 3 achieves the best performance, while the compared scheme has the worst performance, and even leads to network congestion, which is shown as the unchanged value in Figs. 4 and 5 when the number of VHO requests reaches certain value. The reason of this dilemma is that almost all users select the same network as target network, and then the available resources of the target network decrease rapidly. When the number of VHO requests is still small such as smaller than 8 VHO requests for RT service and smaller than 6 VHO requests for NRT service, the scheme 2 has better performance than that of scheme 1, because the scheme 1 introduces additional random delay to avoid simultaneous arriving of VHO requests, and the scheme 2 can efficiently distribute mass VHO requests into different available networks according to pre-defined probability distribution. However, with increasing of VHO requests, the scheme 1 achieves better performance than that of scheme 2. The probabilities given in scheme 2 are a little subjective, and meanwhile, the users with the same service type have the same probability distribution, which may lead to inaccurate decision results when there are mass VHO requests, that is to say, more than one users select the same time interval and make decision simultaneously.

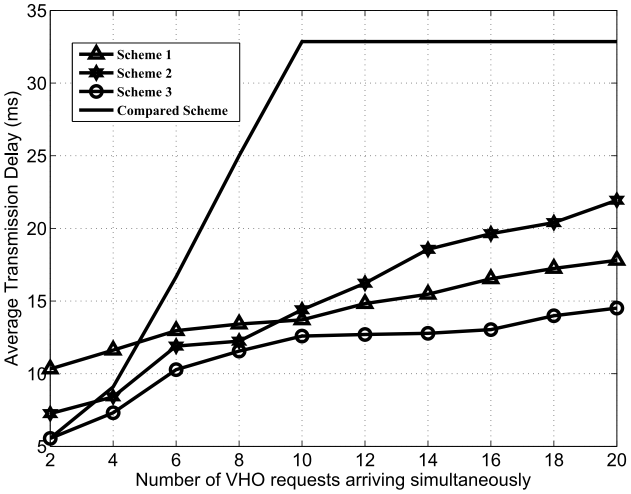


Fig. 4 Transmission delay comparison

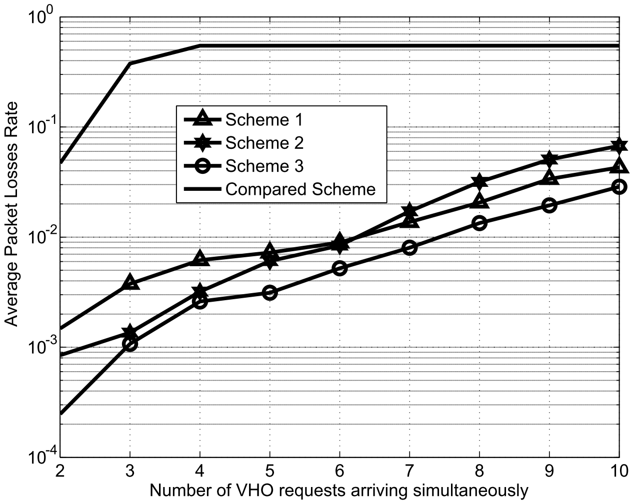


Fig. 5 Packet losses rate comparison

Figure 6 indicates the performance comparison of VHO reject rate. For each network, if it has enough resources for

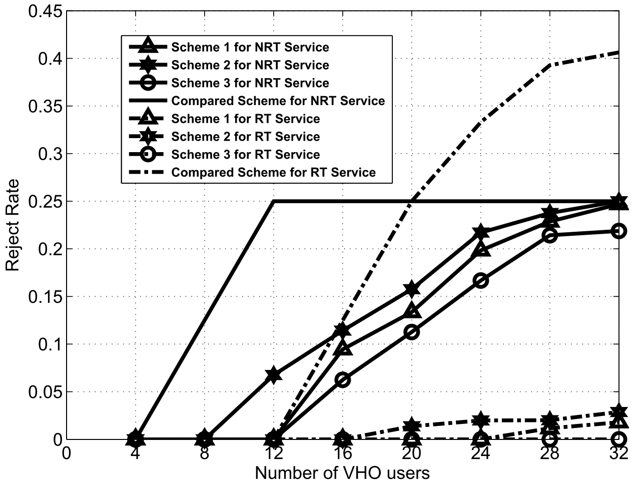


Fig. 6 Reject rate comparison in integrated service environments

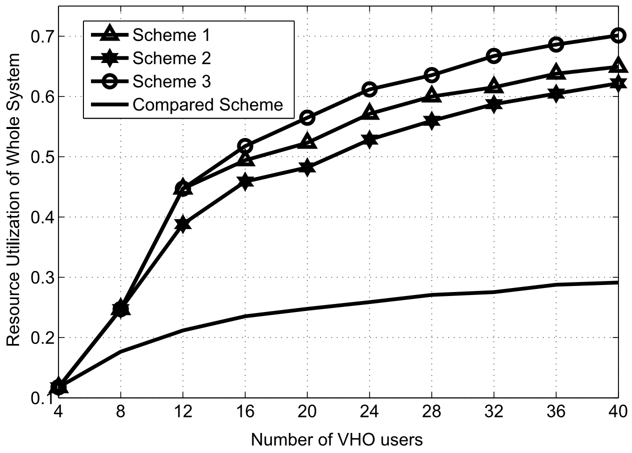


Fig. 7 Resource utilization of different schemes

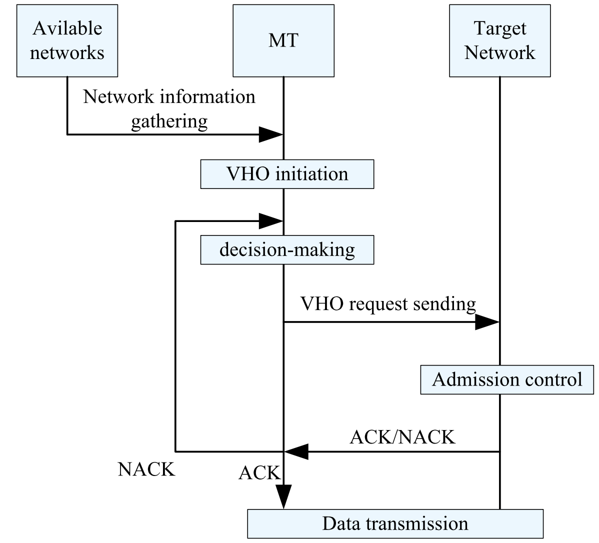
new user, the VHO request is permitted; otherwise, the VHO request is denied. The simulation is operated in the integrated service environments, and the ratio of real-time service to non-real-time service is 3:1. As shown from curves, the VHO reject rate for real time service is distinctly lower than that of non-real-time service, because the three proposed schemes provide solid QoS guarantee for real-time service. Furthermore, scheme 3 has the best performance, because it makes better coordination among multiple VHO requests and networks. Scheme 1 has the better performance than that of scheme 2 due to the fact that the scheme 1 makes decisions with complete information of previous users' results. Although scheme 2 has ability to disperse VHO requests into several networks timely, the information for decision making is random and inaccurate, which has vital influence on the accuracy of decision result especially when there are mass VHO requests making decision simultaneously. However, scheme 1 is less efficient than scheme 3, the reason is that the scheme 1 just considers the relationship of current VHO request and multiple networks, but ignores the coordination among multiple VHO requests and multiple networks. Obviously, the compared scheme has the worst performance, because the MTs under this decision-making scheme just selfishly consider itself to select the network with best performance, which leads to unbalanced network loads even network congestion.

The radio resource utilizations of whole system with different schemes are shown in Fig. 7, which is operated in integrated service environments. As indicated in Fig. 7, the compared scheme has less efficient utilization, because multiple users select the same target network, but ignore the resource of other networks, which leads to unbalance load across heterogeneous networks. It also can be observed that the resource utilization improves slowly with increasing of VHO users, the reason is that some VHO users especially NRT users will be denied when there are too many VHO users. Furthermore, it is worth noting that the scheme 3 has the best performance, because it has capability to collect more information about both MTs and users, and make good coordination among multiple VHO requests and multiple networks, so this scheme can make full user of heterogeneous networks to support group mobility in vehicular communications.

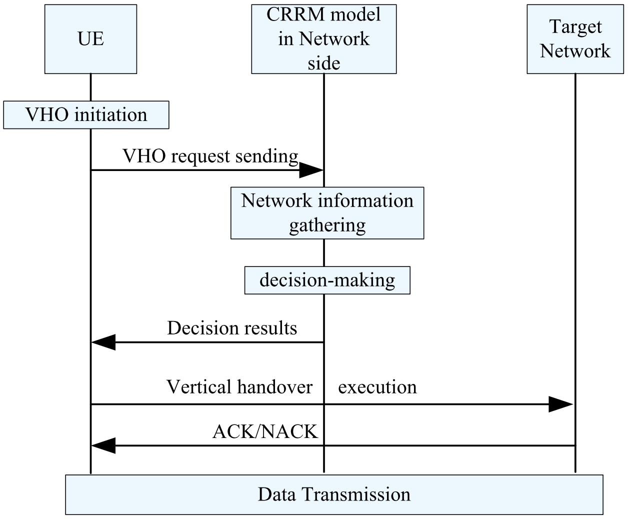
To analyze further reasons of performance differences among multiple schemes indicated in above figures, that's because MT controlled vertical handover can be regarded as distributed decision-making system, which is sensitive to the collected information. The incomplete information has vital influence on accuracy of decision results. The Network assisted vertical handover has the knowledge of multiple VHO requests and network status to get the global optimized decision results. Although the scheme 1 and scheme 2 proportionally decrease the uncertainty of incomplete information in the distributed decision-making system, the performance gains are achieved by the sacrifice of other system performances such as additional delay.

As discussed above, the scheme 1 and scheme 2 adopt the MT controlled vertical handover, while scheme 3 adopts the Network assisted vertical handover. Figure 8 gives illustrations for procedure of MT controlled VHO and Network assisted VHO, respectively. It is supposed that 3 bits for VHO request, 3 bits for network information, 2 bits for decision results and 3 bits for ACK/NACK. For vertical handover schemes, the signaling overhead is an important criterion to evaluate efficiency of VHO. Therefore, Fig. 9 gives the signaling overheads comparison of the three proposed schemes.

As indicated in Fig. 9, the MT controlled vertical handover is more efficient without GVHO scenario, but the network assisted vertical handover costs less signaling overheads in GVHO scenario, because each MT should collects information from all available networks for decision-making



a) MT controlled VHO



b) Network assisted VHO

Fig. 8 Illustration of different VHO control methods

when MT controlled method is adopted, which increase signaling overheads in GVHO scenario.

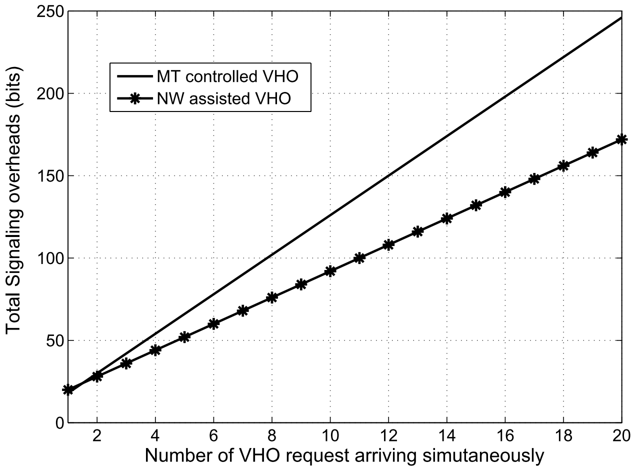


Fig. 9 Signalling overheads of different VHO control methods

6 Conclusions and further works

Group mobility is a prominent feature of vehicular communications, and the efficient handover management is quit needed to keep service connectivity and provide solid QoS guarantees for diverse services during vehicle movement. However, the current VHO schemes mainly focus on the single user scenario and may cause chaos in group mobility scenario due to the incomplete and inaccurate information for decision-making. In this paper, three decision-making models are proposed to deal with the problems of group mobility in vehicular communications across heterogeneous wireless networks, as well as to optimize the whole system performance.

The schemes based on the time window and probability distribution both adopt MT controlled VHO mechanism, and both schemes try to eliminate uncertainty and inaccuracy of collected incomplete information to make the appropriate decision in distributed decision-making system. The third scheme adopts the network assisted VHO mechanism, and it makes coordination among multiple VHO requests and multiple networks to get the global optimal decision results. Numerical simulation results indicate that the three proposed schemes can provide solid QoS guarantee especially for real-time service, and the third scheme has the best performance in several simulation scenarios. When the number of VHO requests arriving simultaneously is small, the second scheme has the better performance than that of the first one; however, the first scheme is more efficient under the situation of mass VHO requests arriving simultaneously due to the fact that the information for decision-making in the second scheme is a little subjective and inaccurate. For the decision-making scheme for GVHO based on the probability distribution, it could be improved if the probability distribution for each user can be changed adaptively on the basis of any predictive information, so this work will be further researched in the future studies.

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