

Cross-Layer Design Vehicle-Aided Handover Scheme in VANETS

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Summary

The requirement for in-vehicle passengers to access Internet multimedia services has risen recently. As a consequence, Vehicle Ad hoc NETWORK (VANET) has gained much attention, and is regarded as a promising solution for providing in-vehicle Internet service through inter-vehicle and infrastructure communication. A new developed wireless network technique, termed WiMAX Mobile Multihop Relay (MMR), provides a good communication framework for a VANET formed from vehicles on high-speed freeways. Applying MMR WiMAX allows some public transportation vehicles to act as relay vehicles (RVs) to provide Internet access to passenger vehicles. However, the standard handover procedure of mobile or MMR WiMAX suffers long delay due to the lack of information about the next RV. This study presents a cross-layer fast handover scheme, called vehicular fast handover scheme (VFHS), where the physical layer information is shared with the MAC layer, to reduce the handover delay. The key idea of VFHS is to utilize oncoming side vehicles (OSVs) to accumulate physical and MAC layers information of passing through RVs and broadcast the information to vehicles that are temporarily disconnected, referred to as disconnected vehicles (DVs). A DV can thus perform a rapid handover when it enters the transmission range of one of approaching RVs. The effectiveness of VFHS is verified using ns2 simulations. Simulation results indicate that VFHS significantly decreases handover latency and packet loss. Copyright © 2009 John Wiley & Sons, Ltd.

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1. Introduction

To provide inter-vehicle and infrastructure communication services, an emerging new ad hoc network is Vehicle Ad hoc NETWORK (VANET) [1][2][3] which has received much attention recently. In a

VANET, a vehicle is a mobile node with high mobility in highways or streets. While a common wireless technique in VANET is the dedicated short-range communications (DSRC) which modifies the version of the IEEE 802.11a and upgrades transmission rate up to 3 Mbps, it is more suitable for short range transmission. Consequently, a vehicle driving on the highway needs to switch its wireless link connection to different roadside units frequently. However, vehicle on the freeways cannot feel free

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to stop or change direction, therefore, forming a short term group relationship for communication purpose among vehicles is more promising because all vehicles have sparial-temporal relation. Therefore, a new communication model is required for forming a VANET on the highway.

For a vehicle in this short term group, a good way to access the Internet is through the multirelay technique, e.g., IEEE 802.16j Mobile Multihop Relay (MMR) [4]. Special vehicles, such as public transportation buses, can be considered to serve as relay nodes [5]. Such vehicles are called relay vehicles (RVs), and have full power to support communication and mobility management for their neighboring vehicles. Hence, a RV and a set of neighboring vehicles form a cluster network in the group.

Indeed, there were 148,898 coaches and 1,302,747 sedans per day on the major freeway in 2007 in Taiwan [6]. Thus, a coach was surrounded by 8.7 sedans on average. Additionally, a coach passes through the Taichan toll booth every 5.3 seconds on average. In summary, a coach equipped with WiMAX relay which provides connectivity for 8-9 sedans in a promising solution for VANETs on freeways in Taiwan. Unfortunately, due to the dynamics of coach distribution on the freeway, a sedan still needs to face the disconnection problem when it is out of the transmission range of any coaches. A communication framework based on MMR was proposed in [5]. To support mobility functionality, an RV broadcasts a neighbor advertisement message (MOB_NBR-ADV) [4][7] to its cluster members at periodic intervals of up to 30 seconds. MOB_NBR-ADV identifies the network, and defines the characteristics of neighboring RV to potential vehicles seeking initial network entry or handover. However, a potential vehicle may not be able to receive any MOB_NBR-ADV message when it is entering a gap located between two RVs. In such a case, the vehicle is forced to perform the network entry procedure and the communication is interrupted until connectivity resumes. The entry procedure scans all channel frequencies allocated by RVs, and suffers from long handover latency. The vehicle that loses the connectivity is formally termed disconnected vehicle (DV).

This paper focuses on the problem of supporting a cross-layer fast handover scheme, called vehicular fast handover scheme (VFHS), for moving vehicles by taking advantage of relay, inter-vehicle communication and vehicular ad hoc networks in a high-speed freeway environment. The major contribution of this paper is to allow oncoming side vehicles (OSVs) to provide

network topology messages (NTMs) to DVs. An OSV is a vehicle traveling in opposite traffic direction, and can accumulate the physical layer information of an RV by receiving MOB_NBR-ADV messages or performing the entry procedure. The MOB_NBR-ADV message carries each neighboring RV physical layer information, e.g. Frequency Assignment (FA) index, once the value N_NEIGHBORS is more than zero. With NTMs, a DV is able to learn the information of neighboring RVs and perform fast handover procedure. By avoiding the entry procedure, the handover latency can be significantly reduced.

The proposed scheme is evaluated through ns-2 simulation with the NIST mobile WiMAX tool [8]. The traffic of the OSV is modeled with a Poisson process. Simulation results demonstrate that the proposed VFHS scheme has lower handover latency and packet loss than the standard WiMAX handover model.

The remainder of this article is structured as follows. Section 2 presents an overview of the related work. Section 3 describes the motivating scenario, characterizations of the VFHS scheme and cross-layer design. Section 4 illustrates the detailed algorithm of VFHS. The performance analysis is presented in Section 5. Finally, section 6 summarizes this work.

2. Related Work

Numerous improved handover schemes have been presented recently. All of them concentrate on pure, standard mobile WiMAX networks. This section describes and summarizes these improved schemes.

Several existing schemes for reducing handover latency in WiMAX are categorized to three categories: improving scanning latency [9][10][11], inter-cell handover limitation [12] and cross layer design [13]. A prediction-based pre-coordination mechanism (PCM) [9] has been presented to support fast handover in WiMAX network by improving the scanning latency. The PCM is practiced on mobile WiMAX, which adopts the position information of the MS, e.g. location, distance, and direction, to predict the target BS. The ACS [11] focuses on to selecting a minimum scanning period for MSs. During handover, the serving BS estimates the scanning time of each neighbor BS, and notifies this information to the MS. The MS chooses a BS with the shortest scanning period as its target BS. Boone *et al.* [10] studied two strategies, namely Most Recently Used Strategy (MRU) and Most Frequently Used Strategy (MFU), to decrease scanning times in MSs based on the historical channel

information of neighboring BSs. In inter-cell handover limitation, Park *et al.* [12] developed a cell-ID-based handover method in an MMR network to lower the handover overhead. The cell-ID scheme modifies the standard BSID format to support hierarchical BS/RS ID format. Finally, Chen *et al.* [13] proposed a cross layer design fast handover scheme to eliminate the handover latency by exchanging MAC messages. Unfortunately, previous studies do not consider the characteristics of the underlying VANETs, namely store-carry-forward routing, high-speed mobility, and continuous transition between RVs.

Some literatures discuss to develop an improved infrastructure or service framework. Yang *et al.* [14] proposed a cross-layer design WiMAX mesh network, called coordinated external peer communication (CEPEC), to provide Internet-access services in freeways environment. To support Internet-access services to a vehicle allocated outside of the coverage of the serving BS, CEPEC separates the road into multi-segment, and uses channel-sharing to relay packets. Each segment has a segment head (SH) to perform local-packet collecting and aggregated packet relaying. Mussabbir *et al.* [15] enhanced FMIPv6 method with IEEE 802.21 technology over VANET. The authors proposed an improved FMIPv6 mechanism to support network mobility (NEMO) in vehicular environments and utilized IEEE 802.21 protocol to advance the handover performance by using serval cache to store and maintain network information. Dikaiakos *et al.* [16] introduced an application level mechanism over VANET to push and pull traffic condition information. The mechanism adopted ad hoc model to disseminate data.

3. Preliminary

3.1. System Model

To illustrate the effectiveness of the proposed infrastructure for VANETs and the design of VFHS, this section introduces a simple animating scenario taking place on a freeway. Figure 1 depicts a snapshot of a small freeway district. The direction of the traffic is depicted with an arrow near the middle of the road. In this snapshot, a number of vehicles of various sizes are traveling on the road. Here, all vehicles are assumed to be equipped with a number of sensors to detect and gather information around the vehicle, a GPS adapter, an on-board diagnostic (OBD) and a WiMAX communication interface for inter-vehicle communication. The OBD is a on-broad unit, and

able to control engine functions and perform self-diagnostic [17]. Additionally, all vehicle subsystems, e.g. GPS, wireless communication interface, and sensors, connect to the OBD to store and retrieve data. This work also assumes that drivers or passengers can adopt a laptop or PDAs to access the Internet, and support navigation, traffic jam avoidance and alert report by the OBD.

The model considers three kinds of vehicles according to their capability:

- **Relay Vehicle (RV):** An RV is a large vehicle that can provide the capability of relay and mobile management of the MMR WiMAX network to its neighboring vehicles. A RV together with vehicles in its transmission range forms a cluster network. The transmission range is denoted in by circles.
- **Disconnected Vehicle (DV):** A DV is a small vehicle that is outside of the coverage of any RV, and needs to transmit packets.
- **Oncoming Side Vehicle (OSV):** An OSV is a small vehicle driving on the oncoming direction, and has no packets to transmit. The OSV can accumulate the physical layer information of the RV located in the opposite direction (oncoming RV), and provide this information to DVs with the cross-layer network topology message (NTM) for facilitating fast handover. The OSV uses a set of specific channels to broadcast NTM to DVs.

Besides vehicles on the road, a number of MR-BSs provide WiMAX multirelay transmission environment are deployed at the roadside, as shown in Figure 1. The MR-BS and the RV are configured in point-to-multipoint (PMP) mode, and the MR-BS can manage a number of RVs simultaneously. The MR-BS can operate as a serving MR-BS when an RV connects to it for transmitting and receiving packets from the Internet. Figure 1 represents the relay links using black, bolt, and shows some gaps between RVs on the road. A vehicle located in the gap becomes a DV.

The disconnection problem we anticipate to solve is shown in the following example. Vehicle A, as shown in the middle area of the Figure 1, travels from south to north. This vehicle A becomes a DV when it leaves the transmission coverage of the previous RV and thus losses its connectivity. Therefore, A attempts to handover to a nearby RV. According to the handover procedure of the standard WiMAX [7], the previously RV may not receive or measure the signals of neighbor RVs located on the front. Therefore,

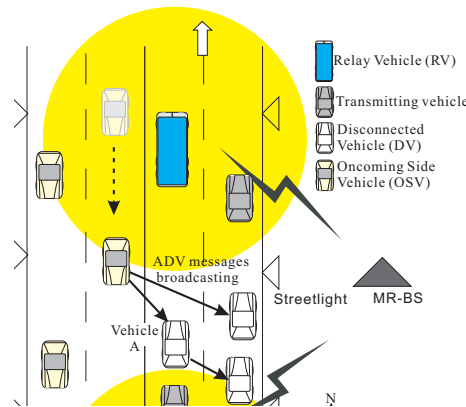


Fig. 1. System Model

the MOB_NBR-ADV message comprises 'empty' physical information about neighboring RVs. At this moment, *A* has to perform complete *entry* procedure, because *A* does not have any information of neighbor RVs. Figure 2 illustrates the entry procedure of the standard WiMAX. The entry procedure consists of scanning, synchronization, ranging and authorization. Among them, scanning incurs the longest delay, as all possible channels need to be scanned.

To solve this problem, this study proposes a novel methodology for reducing scanning latency. The proposed protocol allows an OSV to accumulate the physical layer information about RVs. The OSV can broadcast NTM to DVs using predefined broadcast channels upon acquiring the physical information of neighboring RVs. This NTM enables a DV to know which channel to listen to when it enters the transmission range of the target RV on the front. According to NTM, a DV can adjust its physical setting, such as the channel, on-the-fly when it receives NTM, rather than waiting and receiving the neighbor advertisement message from the target RV. Besides, by comparing blocks of recorded time and velocities, the DV can identify the nearest RV on the front.

3.2. Cross Layer Concept on VFHS

The interaction of the handover procedure at MAC layer with position and channel information at physical layer delivers an interesting and efficient solution. As mentioned in the Problem Description, the handover latency is affected by the number of

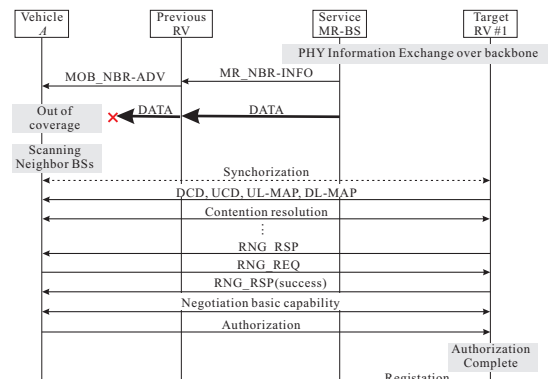


Fig. 2. Entry procedure in standard WiMAX

channels. Designing protocols with either optimizing scanning procedure or improving handover procedure may not provide the best performance. Therefore, the MAC and physical layers need to be optimized jointly across layers.

To support dynamic adaptation, VFHS adopts explicit cross-layer design [18][19] to provide signaling message to cross MAC and physical layers. Figure 3 illustrates the cross-layer structure of the system under consideration. NTM is a cross-layer message comprising information of the physical (position and channel) and MAC (WiMAX) layers. In VFHS, the position and channel information of the oncoming RV are accumulated, abstracted and managed by OSVs

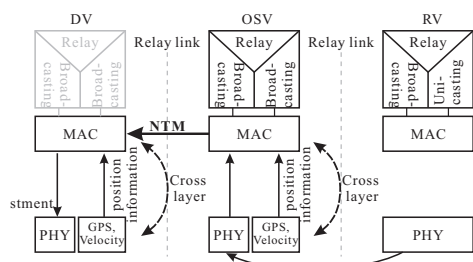


Fig. 3. Cross layer stack integration position information with WiMAX MAC layer

when acquires. In addition to the RV information, an OSV inserts its position information into NTM, and broadcasts to DVs. Upon receiving a NTM, DVs can adjust the setting of the channel frequency of the WiMAX adapter immediately by retrieving the channel and position information; instead of scanning all channel frequencies sequentially by the physical layer. Therefore, according to this cross-layer design, VFHS reduces the time of scanning procedure.

4. Vehicular Fast Handover Scheme (VFHS) for VANETS

4.1. Algorithm of VFHS

This section describes the VFHS algorithm in detail. The algorithm is split into three parts, namely scanning, entry and broadcast. The scanning is performed in both DVs and OSVs. The entry and broadcast are performed in DVs and OSVs, respectively.

Figure 4 illustrates the scanning algorithm, where T denotes a waiting interval to receive the signal of the RV, and nc be the next scanning channel. Let C be the amount of channel frequencies in the frequency assignment index. The objective of the scanning algorithm is to identify the signal of the RV during waiting interval. If the signal can be detected, and the channel information can be parsed successfully, then the function returns nc , otherwise, it returns false (-1).

Figure 5 illustrates the entry procedure in a DV. The procedure follows standard implementation except that the block of receiving NTM is added into the entry procedure to reduce the scanning latency. Let bc represent a set of channel frequencies for broadcasting NTMs, and $R_threshold$ represents a threshold value for guaranteeing the radio signal quality. When a vehicle is connected to an RV, the radio signal quality is considered good if the measured quality of the

Algorithm 1: Scanning Procedure for DVs

Input:

T , where T denotes idle time for receiving signal of target RV
 $nc \in C; C = \{nc_i | 0 \leq i \leq CN_{max}\}$,
 where CN_{max} denotes # of channel frequencies

Output:

$nc \in C; C = \{nc_i | 0 \leq i \leq CN_{max}\}$,

where CN_{max} denotes # of channel frequencies

```

1 IF DV receives signal of the target RV in  $nc$ 
2   | RETURN  $nc$ ;
3 ELSE THEN
4   | RETURN -1;
5 END IF

```

Fig. 4. Scanning procedure

radio signal is greater than $R_threshold$. Therefore, when the quality of the radio signal is lower than the threshold, as shown in lines 2-4, a vehicle becomes a disconnected vehicle (DV) and sends a sleep request to the serving RV before it becomes a DV to buffer packets destined to the DV temporarily. In addition, the DV also buffers packets to be sent. In the proposed algorithm, the sleep period is set to a maximum of 1024 frames, and can be terminated by force. Then, in lines 5-14, the DV calls scanning function to discover OSVs for acquiring the NTM. To reduce the scanning latency, receiving NTM has priority to be performed. Upon receiving the NTM, the DV parses the NTM, and extracts the channel information of the target RV. The DV then performs the scanning again to detect the target RV based on the extracted channel information, and tries to associate with target RV. The DV adds its system time to the NTM, and broadcasts to other DVs. Finally, this block (lines 6-18) repeats a default time (dtime) until a NTM is received currently. If DV does not receive NTM from OSVs, then the entry procedure enters the next block. Lines 16-20 present a pure scanning procedure. In this block, the DV detects all channel frequencies. When signal is detected from a channel frequency, the DV then executes the association function immediately. Otherwise, the block is repeated until it receives the signal from the target RV.

Figure 6 displays the broadcast NTM algorithm for OSVs. The broadcast NTM algorithm consists of two components. The first part, lines 2-8, parses physical information from MOB_NBR-ADV when the OSV has connected to an oncoming RV. The function on line 2, getADV, returns 'true' if a MOB_NBR-ADV message is acquired. The OSV then parses MOB_NBR-ADV, and stores physical information in p_info . To measure the location of the oncoming RV, the OSV sends a channel measurement request message to the oncoming RV for detecting parameters

Algorithm 2: Entry Procedure for DVs

Input:
 $nc \in C; C = \{nc_i | 0 \leq i \leq CN_{max}\}$,
 where CN_{max} denotes # of channel frequencies
 $bc \in C_{broadcast}; C_{broadcast} = \{c_i | 0 \leq i \leq CN_{max}\}$,
 where $CN_{broadcast_max}$ denotes # of broadcast
 channel frequencies

Output:
 None

```

1 IF radio signal quality is less than  $R_{threshold}$  THEN
2   sleep_period  $\leftarrow$  1024 frames;
3   send sleep request to serving RV;
4   buffer packets;
5   start dtime timer;
6   scan channel  $bc$ ;
7   IF connected to OSV THEN
8     receive NTM;
9      $nc \leftarrow$  channel information;
10    scan channel  $nc$ ;
11    IF associated with target RV THEN
12      broadcast NTM on channel  $bc$ 
13      with new system time;
14      EXIT;
15    ENDIF
16  ELSE THEN
17    scan all channels sequentially;
18    IF associated with target RV THEN
19      EXIT;

```

Fig. 5. Entry procedure on DVs

of RSSI and CINR by utilizing the c measure function. According to RSSI or CINR, the OSV can calculate further the position of the oncoming RV. After going through the above steps, the OSV combines the RV location, the OSV location, and RV's channel information into a NTM message, and broadcasts it to DVs.

The second part of Figure 6, lines 10-16, performs the entry procedure when the OSV is not able to connect to an oncoming RV. Like the DV entry procedure, the OSV scans all channel frequencies to detect the signal of RVs. Because the OSV can associate with an oncoming RV, it acquires the physical information simultaneously. The OSV then measures the location of the oncoming RV. Finally, the physical information is combined with the location information of the oncoming RV and the OSV to form a NTM, which is then broadcast to the DVs.

4.2. NTM Format

This sub-section defines the NTM format produced by OSVs. Figure 7 presents the format of NTM. Fields in the NTM format are described as follows.

Algorithm 3: Broadcast NTM Procedure for OSVs

Input:
 $nc \in C; C = \{nc_i | 0 \leq i \leq CN_{max}\}$,
 where CN_{max} denotes # of channel frequencies
 $bc \in C_{broadcast}; C_{broadcast} = \{c_i | 0 \leq i \leq CN_{max}\}$,
 where $CN_{broadcast_max}$ denotes # of broadcast
 channel frequencies

Output:
 None

```

1 IF connected to oncoming RV THEN
2   WHILE  $getADV$ 
3     parses MOB_NBR-ADV message;
4      $p\_info \leftarrow$  physical information;
5     measures oncoming Rv's position;
6     NTM  $\leftarrow$  Rv's location, OSV's location,
7      $p\_info$ ;
8     broadcasts NTM on channel  $bc$ ;
9   ENDWHILE
10 ELSE THEN
11   scans all channels sequentially;
12   IF associates with oncoming RV THEN
13      $p\_info \leftarrow$  physical information;
14     measures oncoming Rv's position;
15     NTM  $\leftarrow$  Rv's location, OSV's location,
16      $p\_info$ ;
17     broadcasts NTM on channel  $bc$ ;
18   ENDIF

```

Fig. 6. Broadcast NTM procedure on OSVs

1. An RV is identified by the first field, a 32-bit identifier composed of two components, a 24-bit MR-BS id (**MRBSID**) and an 8-bit RV id (**RVID**). The rationale for using a two-level hierarchical address is that each MR-BS is expected to serve several RVs located in its transmission range. Additionally, the direction information of an RV is also encoded in the (**RVID**).
2. The following two fields, **RV Speed** and **OSV Speed**, indicate the velocities of the RV and OSV, respectively. These fields can be estimated using GPS data, or measured by analyzing the REP-REQ/REP-RSP messages.
3. The field **Direction** (D) encodes the direction of the OSV, which can also be calculated from the GPS data. The field uses 3-bit to represent the direction. Table I given the mapping between the bit codes and the direction.
4. The **Hop Count** (HC) value records the number of vehicles (hops) that this topology message has been traversed.
5. The field **Time Stamp** (TS) represents the time when the message was generated. The clock of the OBU is synchronized by the GPS receiver.
6. The field **RV PHY Information** carries the

Table I. Mapping between Proceeding Direction and Codes

Bit	Direction
000	North
001	North East
010	East
011	South East
100	South
101	South West
110	West
111	North West

physical information of the RV, e.g. channel number, and FA index.

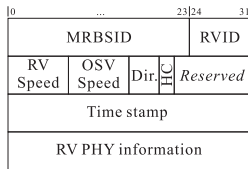


Fig. 7. NTM message format which carries cross-layer topology information

4.3. Message Lifetime

For providing the network topology status, the OSV retains the NTM message for a while. To avoid disseminating out-of-date NTM, the OBD of the OSV sets a message lifetime parameter. The OBD ensures that a NTM message is valid by computing parameters of the lifetime and TS. Every validated NTM is broadcasted to DVs periodically.

4.4. Feasibility

To demonstrate that the OSV has sufficient time to receive the physical information from an oncoming RV, Figure 8 shows the calculation result when an OSV crosses the coverage area of an oncoming RV. This example assumes that an RV broadcasts a neighbor advertisement message (MOB_NBR-ADV) every 30 seconds.

Figure 8 depicts a scenario where the maximum coverage area (l) of an RV is set to 2 kilometers, the OSV is traveling from north to south at 120 km/hour, and the RV is traveling from south to north at 110 km/hour. The shortest distance (s) between the OSV and RV is 0.01 kilometers. According to a trigonometric function, the value of T can be obtained,

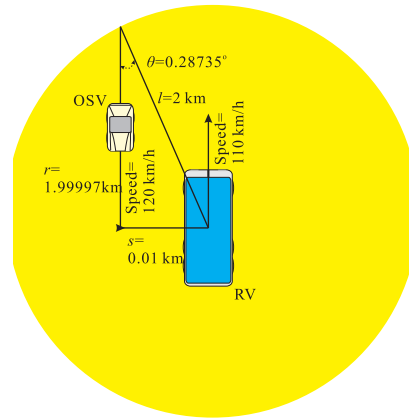


Fig. 8. Time to Pass Through Cell

$$\begin{aligned} \sin \theta &= \frac{s}{l} \\ &= \frac{0.01}{2} \\ \theta &= 0.28735 \end{aligned} \tag{1}$$

The leg (r) is computed as:

$$\begin{aligned} \cos \theta &= \frac{r}{l} \\ 0.999987 &= \frac{r}{2} \\ r &= 1.99997 \end{aligned} \tag{2}$$

Therefore, the time passing through the coverage of an oncoming RV is

$$\begin{aligned} T &= \text{Total_distance} / \text{average_velocity} \\ &= (1.99997 * 2) / (110 + 120) \\ &= 0.01739(\text{hrs}) \\ &= 62.60776(\text{sec.}) \end{aligned} \tag{3}$$

This calculation result demonstrates that the OSV passes through the RV in 62.6 seconds. The OSV may receive MOB_NBR-ADV more than 2 times when it is in the coverage area. Even if the OSV does not receive any MOB_NBR-ADV messages, it still has enough time to perform the entry procedure to connect to the RV and obtain its physical information. Hence, the OSV is able to provide NTM messages to DVs.

4.5. Example of VFHS

Figure 9 presents an example to illustrate the operation of VFHS. In the figure, two OSVs, namely OSV #1

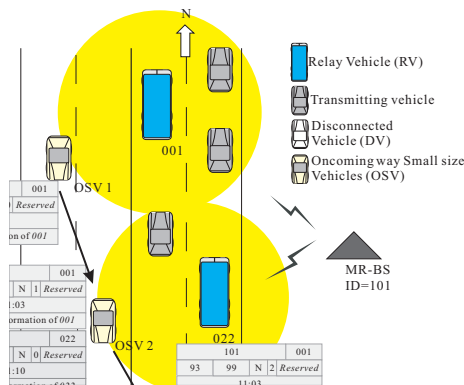


Fig. 9. Scenario: Carried Information from OSV

and OSV #2, are traveling from north to south on the freeway, and are passing through two coverage areas of RVs, i.e. 001 and 022, sequentially. When OSV #1 is in the coverage area of RV #001, it acquires location and physical information of RV #001 and broadcasts a NTM containing RV #001's information to OSV #2. As OSV #2 proceeds to the coverage area of RV #022, it acquires information of RV #022 and broadcasts two NTMs containing RV #001 and RV #022's information, respectively.

To reduce the message overhead, a DV can set a proper hop count (HC) value. A NTM message will be dropped when it is forwarded by HC hops (vehicles). For example, HC is set to 2 in Figure 9. Therefore, DV #1 can receive NTMs of RV #001 and RV #022, but DV #2 can only receive the NTM of RV #022. A DV can predict the next RV from the velocity and timestamp after processing NTM messages. Generally, in VANETs, vehicles travel at velocities near those of neighboring vehicles. Hence, the near recorded time corresponds to the near distance. Therefore, the DV #1 prepares and setup parameters of the physical layer to communicate with RV #022.

4.6. Unsuccessful Case

The above discussion focuses on the successful case, i.e. when the DV receives NTM successfully. This subsection investigates the unsuccessful case even it does not happen very often.

When a DV is located in the gap between two RVs and losses its connectivity, it monitors the broadcast

channel frequencies of the OSV continuously for acquiring NTM until connectivity is resumed. If it is not able to receive any NTM messages, it will perform the standard entry procedure to communicate with the target RV.

4.7. Security

This investigation does not address the security issue, because VFHS scheme focuses on improving layer 2 handover in VANETs. All vehicles are authenticated after the network entry procedure is completed. Therefore, the standard WiMAX mechanism can guarantee layer-2 or layer-3 security. Our future work will explore the security of the application layer.

5. Performance Analysis

This section presents simulation experiments with our VFHS, in which the handover latency and packet loss of standard WiMAX and the proposed VFHS scheme were investigated and compared.

5.1. Simulation Environment

To evaluate VFHS, simulations were performed using the network simulator NS-2.29 with NIST module [8]. Handover latency of VFHS and the standard mobile WiMAX were compared. Movement of vehicles was emulated using relative speed to RV's. To standing out the handover latency problem, the number of WiMAX channels was set to 30. The simulation time was set in seconds; the road length was set in meters; each road had two lanes; the average speed of the vehicle was measured in meters/sec, and the gap distance between RVs on the same lane was constant. The interval and duration times were measured in milliseconds, and the transmission range was measured in meters. Table II lists the parameter settings of the simulation in detail. The transmission coverage of each RV is 1000 meters. The other WiMAX parameters in the NIST module are set to default values. The simulation also assumes all vehicles transmits data by using constant bit rate (CBR) model. The duration of each simulation is 350 sec.

5.2. Simulation Scenario

Figure 10 depicts the simulation topology applied in experiments on handover efficiency. Two RVs were allocated at (500, 600) and (2550, 600). The WiMAX transmission coverage area of the RV was

Table II. System and scenario parameters

System parameters	
Modulation	OFDM_16QAM_3_4
RX Thresh	1.26562e-13
Packet size	250
Scan Duration	50
Interleaving interval	40
Nbr_adv_interval	30000
T21timer	0.5
DCD interval	0.2
UCD interval	0.2
contention size	5
Association level	0

approximately 1000 meters. The gap between RVs was set to 50 meters. Several OSVs moved in opposite directions. The simulator simulated a simplified but realistic traffic model where: (a) A DV moves at constant speed. (b) The arrival of OSVs is modeled as a Poisson process. The handover latency and packet loss were measured from the DV.

5.3. Metrics

The performance metrics of interest are:

- Handover latency: the time between the DV is disconnected from the previous RV until it resumes its connection with the target RV.
- Packet loss: the number of lost packets during handover.
- Throughput: the average rate of successful message delivery to destinations.

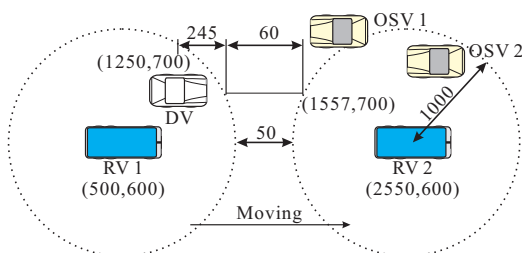


Fig. 10. Simulation Topology

5.4. Handoff Latency

Figure 11 presents the handover latency under various relative speeds of the DV to RV when the DV hands over from RV #1 to RV #2. The distance between RV #1 and RV #2 was set to 2050 meters. The arrival process of OSV on the oncoming direction

was assumed to be a Poisson process with arrival rate λ . According to Figure 11(a), the handover latency decreases quickly as the relative speed of DV increases from 2m/sec to 4m/sec, mainly because the time to pass through the disconnected area (gap) is reduced. The handover procedure in standard WiMAX takes about 11 seconds. Because the time for the DV to pass through the gap is less than 11 seconds, the handover latency is dominated by the handover procedure itself. Therefore, the increase in relative speed does not further reduce the handover latency. Conversely, VFHS can reduce the handover latency, since the DV can obtain the physical layer information of RV #2 earlier. Additionally, the time to pass through the gap is lowered as the speed of DV increases, thus further reducing the handover latency, as demonstrated in Figure 11(a). The arrival rate of OSV also influences the handover latency of VFHS, although not significantly. A higher arrival implies that the DV has a higher likelihood of receiving the physical layer information broadcasted by an OSV.

Figure 11(b) presents the handover latency excluding the time to pass through the gap. The handover latency of the standard WiMAX handover scheme is only about 2 seconds if the DV scans to the right channel immediately after it enters the transmission range of RV #2, which arises when the relative velocity is 6m/sec. However, the latency is variable with a maximum of 12 seconds. The latency excluding the time to pass through the gap is slightly less than 2 seconds in VFHS, irrespective of the relative speed. If the arrival rate of OSV is high, e.g., $\lambda = 0.7$, then the DV is quite likely to be able to receive NTM from an OSV, and the latency is quite stable (around 0.8 second). If the arrival rate is low, as shown in Figure 11(b), then the DV takes a longer time to receive NTM, and thus increasing the latency.

Figure 12 presents the impact of the OSV arrival rate on the handover latency excluding the time pass through the gap. A higher arrival rate leads to lower latency, as revealed in Figure 11, because the DV has better chance of receiving NTM. In particular, the latency fluctuates significantly when the arrival rate of OSV is low, as indicated in the case when $\lambda = 0.1$ in Figure 12. The additional delay is due to the late appearance of an OSV.

5.5. Packet Loss

Figure 13 presents the number of lost packets during handover when the DV is receiving a constant bit rate stream. The numbers of lost packets with and

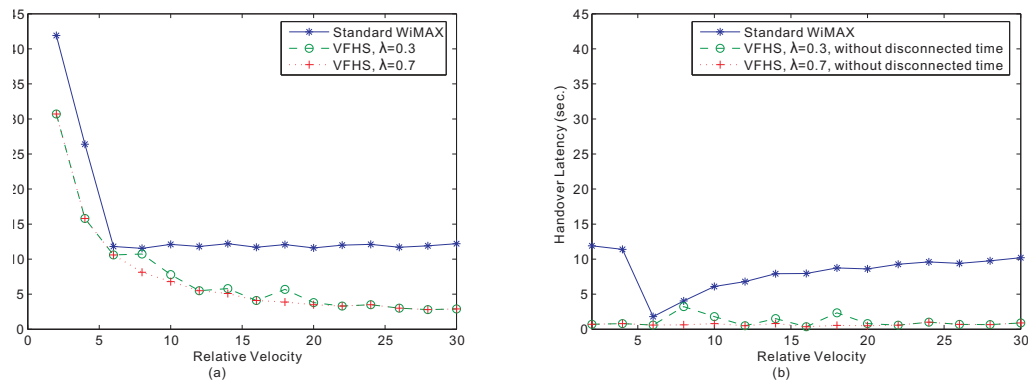


Fig. 11. Handover Latency under various relative speeds (a) handover latency (b) handover latency excluding the time to pass through the gap.

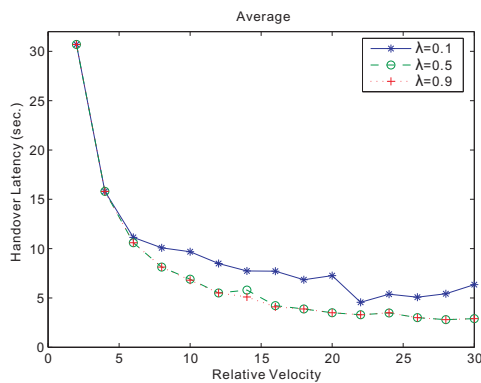


Fig. 12. Handover latency effect of OSV arrival rate on average.

without VFHS are compared at various relative speeds. Generally, the length of the disconnected period affects the number of lost packets. The VFHS resumes the connection faster than standard WiMAX handover. Additionally, if the arrival rate of OSV is higher, then the connection resumes more quickly. The downlink capability of the MR-BS is 72Mbps. Therefore, because the VFHS has shorter handover latency than standard WiMAX, it also has fewer of lost packets. The higher arrival rate of OSV also further decreases the number of lost packets.

5.6. Throughput

For simulating throughput, the simulation generates a set of nodes (vehicles) around the RV #1. The following four scenarios were simulated for representing such purpose: scenario 1: CBR packet size=500 bytes, scenario 2: CBR packet size=1000 bytes, scenario 3: CBR packet size=1500 bytes, scenario 4: CBR packet size=2460 bytes. Figure 14

shows the overall end-to-end downlink throughput for VFHS. For example in scenario 2, the throughput of the VFHS increases swiftly because the radio resource of the RV #1 can support approximate 40 vehicles to connect it. The upper bound of the throughput is approximate 2.4×10^4 packets because of the limitation of the packet scheduling. Then the curve increases in stable. Therefore the saturation point is 40. The results show that the VFHS can support a lot of vehicles connect to a RV simultaneously.

6. Conclusion

The increasing popularity of WiMAX mobile multirelay (MMR) network allows inter-vehicle communications to access the Internet via RV. A communication model for VANET based on MMR has been proposed where vehicles access the Internet through a nearby RV. However, vehicles may perform handover from time to time which could be very long in WiMAX networks.

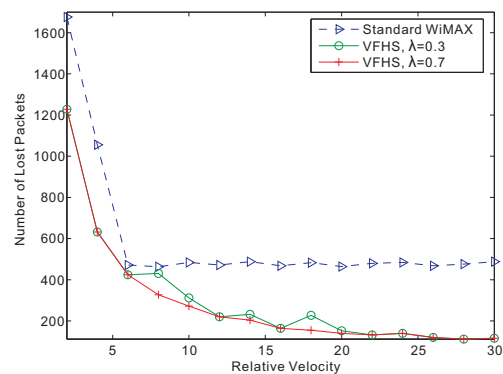


Fig. 13. Packet loss effect on relative velocity.

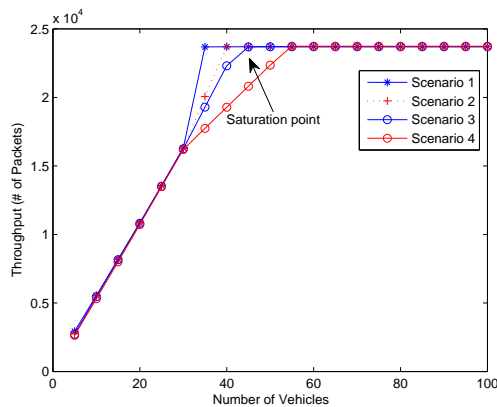


Fig. 14. Overall downlink throughput.

This study proposed a novel cross-layer fast handover method, called vehicular fast handover scheme (VFHS), to solve the long handover latency problem. In VFHS, NTM is broadcast to DV during a message lifetime interval by OSVs. NTM is a cross-layer message that includes both the physical and MAC information of the oncoming RVs and OSV. DV adjusts its parameters of physical layer of the WiMAX on-the-fly according to the received NTM. To verify the performance of the proposed scheme, simulations were performed on a multilane vehicular network which emulates realistic freeway conditions. Additionally, the efficiency of the protocol was verified by the simulation results. These results reveal that the proposed scheme decreases scanning time by up to 75%, while providing acceptable handover latency and packet loss for most real-time and non-real-time applications. This work also shown the throughput results. In practical, another handover case could be investigated. That is, the velocity of a vehicle is less than the serving RV. It consequently has to handover to the behind RV. Besides, the security problem is other important issue. Both of them will be studied in our future work.

7. Remark

This section compares related works with VFHS. Table III shows the comparisons of existing frameworks in vehicular environments. The major characteristics of each investigation are compared, and formal definitions are shown as following.

The "broadcast storm" is a problem which consumes sufficient network resource because each node received the message floods message to its

neighboring node, and the "push" is an actively broadcast or multicast method caused by a traffic condition. The "pull" is used to acquire specific information when a vehicle is willing to provide it. The "data transmission delay" is the amount of time required to transmit a packet from the source to the destination. The "header overhead" denotes that the packet is transmitted using tunneling or not. Finally, the "relay overhead" means that the packet is forwarded by a relay node (vehicle) or not.

For the broadcast storm problem, the VITP uses broadcast method to disseminate the traffic condition message. Consequently, it incurs a seriously broadcast storm problem. CEPEC utilizes the segment head (SH) to maintain the segment and relay message to its members. Therefore, the broadcasted message is limited in the same segment. For the push and pull, the optimized FMIPv6 and the CEPEC methods do not support because they do not consider the vehicular position and velocity. For the data transmission delay, the VITP and CEPEC need a number of vehicles to relay packets, and the optimized FMIPv6 method also needs a home agent to redirect packets. In VFHS, the packet is transmitted through the MR-BS and the RV. Hence, VFHS has lower data transmission latency. For header overhead, due to resulting from adding serval protocol header in each packet, the optimized FMIPv6 method leads to a serious overhead. For relay overhead, CEPEC, VITP and VFHS use SH, peer, and RV to relay packet respectively. The optimized FMIPv6 adopts IPv6 to address a vehicle without relay. However, the relay overhead is insufficient. Finally, for handover latency, CEPEC and VITP do not consider handover issues. Besides, although the optimized FMIPv6 and VFHS perform fast handover mechanism in vehicular environments, the optimized FMIPv6 improves fast binding update (FBU) message to redirect tunneled packets from oAR to nAR. The end point (vehicle) also needs to de-tunnel packets. Therefore, for application level, the handover latency in both of the optimized FMIPv6 and VFHS is the same in low velocity; however, the handover latency of the VFHS is much less than the optimized FMIPv6 in high velocity.

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Table III. Comparison of the Existing Vehicular Framework Protocols

Properties	Methods			
	Optimized FMIPv6 [15]	CEPEC [14]	VITP [16]	VFHS over WiMAX MMR [5]
Broadcast storm	No	Yes, but under control	Yes	No
Push	No	No	Yes	Yes
Pull	No	No	Yes	Yes
Data transmission delay	Medium	Medium/High	High	Low
Header overhead	Yes	No	No	No
Relay overhead	No	Yes	Yes	Yes
Handover latency	Low			Low

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