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An IP passing protocol for vehicular ad hoc networks with network fragmentation

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ABSTRACT

When a vehicle is moving fast in a highway, how to effectively reduce the handoff delay and maintain the connectivity of the vehicle to the Internet is an important issue. The existing IP passing protocol may be able to reduce the handoff delay and maintain the connectivity of the vehicle to the Internet when all the vehicles are connected. However, when the vehicle density is low or the speeds of vehicles are varied, the vehicle may not be able to communicate with the intended vehicle either directly or through multi-hop relays because of network fragmentation. Hence, when network fragmentation occurs, a vehicle cannot pass its IP address to the intended vehicle through existing IP passing protocols and thus incurs longer handoff latency and higher packet loss rate, and these would lower down the throughput of the network. To improve existing IP passing protocols, we propose an IP passing protocol for VANETs with network fragmentation. The proposed protocol can postpone the time to release IP addresses to the DHCP server (extend IP lifetime) and select a faster way to get the vehicle's new IP address. During the extended IP lifetime, the vehicle can acquire an IP address through multi-hop relays from the vehicles on the lanes of the same or opposite direction, and thus reduces handoff delay and maintain the connectivity to the Internet. Simulation results have shown that the proposed scheme is able to reduce IP acquisition time, handoff latency, packet loss rate, and extend IP lifetime.

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1. Introduction

Due to the advancement of wireless communication technology, users may enjoy many kinds of services through Internet ubiquitously. As the wireless transmission rate increases, users can make a VoIP call, browse website, download data, watch TV, and get road traffic information or real-time weather report from Internet through wireless communications.

Since every vehicle can be equipped with a short or medium-range wireless transceiver, vehicles may communicate with each other. Vehicles may acquire information and services through the V2V (Vehicle-to-Vehicle) or I2V (Infrastructure-to-Vehicle) communications. The V2V communication is based on the dedicated short range communications (DSRC) technology; while the V2I communication is based on GPRS/3G, Wi-Fi or WiMAX.

In VANETs, when a vehicle is moving form one base station (BS) to another BS, if it wants to maintain its connectivity to the Internet, it needs to acquire a new access channel (layer 2 handoff) and a new IP address (layer 3 handoff). Since the handoff procedure requires a lot of time to complete the association and the moving speed of a vehicle is so high that it is

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Y.-S. Chen et al. / Computers and Mathematics with Applications I (IIII) III-III

hard to maintain a seamless handoff and stable connectivity to the Internet. To achieve a seamless handoff for an IP-based communication, the IP of the mobile device must be assigned and reassigned efficiently.

The Mobile Internet Protocol version 4 (MIPv4) [1] has been proposed by the Internet Engineering Task Force (IETF). Since Mobile Internet Protocol version 4 (MIPv4) may face problems like the shortage of IP address and the weak security mechanism, MIPv6 [2] is proposed to alleviate the above problems. Mobile IP has an important characteristic that it configures the IP address by neighbor discovery or auto-configuration. There are two auto-configuration mechanisms: the stateful and stateless mechanisms. Dynamic Host Configuration Protocol (DHCP) [3] which has been adopted in both IPv4 and IPv6, is a stateful auto-configured mechanism that each IP address is auto-configured and managed by a DHCP server [4]. The stateless auto-configured mechanism is adopted by IPv6, which creates link-local IPv6 address. Addressing in vehicular networks could be achieved by using DHCP, which has been extensively used in computer networks. The MIPv6 can provide enough IP address and better security mechanism than MIPv4. However, the DHCP process often requires a lot of time to complete the association and it may consume too much time to achieve a seamless handoff. Hence how to reduce the time for acquiring a new IP address is an important issue.

When a vehicle is leaving the communication region of its serving BS and is moving to the boundary of the target BS's communication region, it may acquire a new IP address through IP passing [5,6] from the vehicles on the lanes of the same or opposite direction so as to reduce handoff delay. However, when the vehicle density is low or the speeds of vehicles are varied, the vehicle may not be able to communicate with the intended vehicle either directly or through multi-hop relays because of network fragmentation. Hence, when network fragmentation occurs, a vehicle cannot pass its IP to the intended vehicle through existing IP passing protocols and thus incurs longer handoff latency and higher packet loss rate.

To improve existing IP passing protocols [5,6], we propose an IP passing protocol for VANETs with network fragmentation. In the proposed protocol, when a vehicle is going to leave the target BS and network fragmentation occurs, although the vehicle cannot pass its IP address to the intended vehicle, it still will pass its IP address to the vehicle that remains in the target BS and thus postpones the time to release its IP address to the DHCP server (extend IP lifetime). During the extended IP lifetime, as a vehicle is going to enter the target BS, it can acquire an IP address through multi-hop relays from the vehicle which carries the released IP address, and thus it can reduce the handoff delay and maintain the connectivity to the Internet. Simulation results have shown that the proposed scheme is able to reduce IP acquisition time, handoff latency, packet loss rate, and extend IP lifetime.

The remainder of this paper is organized as follows. Section 2 reviews some related works. Section 3 overviews the system architecture, and the basic ideas of the proposed schemes. Section 4 describes the proposed IP passing protocol. Mathematical analysis is shown in Section 5. Performance evaluation is presented in Section 6. Section 7 concludes this paper.

2. Related works

The handoff delay contains layer 2 and layer 3 handoff delays. On layer 2, the mobile device spends time to scan signal strength from the BS (802.11 or 802.16), while on layer 3, it spends time to configure IP address. Many researches focus on layer 3 handoff and mobility management [5,7–9]. In the following subsections, we first review some related works of mobility management, followed by the related works of MIPv6.

2.1. Mobility management for VANETs

Arnold and Zhao [5]has proposed a solution which allows a vehicle to pass its IP address to a vehicle that is behind of it. A vehicle needs to know when it should pass its IP address to another vehicle. By setting a minimum Signal to Noise Ratio (SNR) threshold, a vehicle is able to determine whether or not it has an adequate connection to the AP. For example, when vehicle *A* is going to leave its serving AP's coverage area, if there is a vehicle *B* behind of vehicle *A* and is going to enter the coverage area of vehicle *A*'s serving AP. Vehicle *A* can pass its IP address to vehicle *B*, so that vehicle *B* can reuse vehicle *A*'s IP address to access to the Internet via the same AP. This process involves three main steps: gathering the IP information, passing the IP address from vehicle *A* to vehicle *B*, and configuring vehicle *B*'s interface on the fly. This solution can reduce the average IP acquisition latency and no AP modification is required.

Fazio et al. [7,8] proposed an automatic IP address algorithm, named as Vehicular Address Configuration (VAC). It assigns IP address to vehicles using a distributed DHCP service. The VAC protocol adopts a dynamic leader-based approach where addresses are assigned by dynamically elected leader which runs the DHCP. Leaders are chosen in such a way that each node in the group is in the communication range of the group leader. Theoretically the size of a vehicular ad-hoc network is infinite. As a result it is not possible for each leader in the network to communicate with every other leader. The main tasks of VAC are (1) Building and maintenance of the leader chain: elects leaders in the network and changes them when node mobility makes it necessary; (2) Address configuration and maintenance: management of addresses that can be assigned to nodes in the network.

Mohandas and Liscano [9] proposed a centralized addressing scheme for VANET using DHCP so as to deal with the current addressing mechanism in VANET that does not succeed in configuring a vehicle with a unique address. Furthermore, there is a need for address reconfigurations depending on the mobility patterns. In this paper, each vehicle in the vehicular network

Y.-S. Chen et al. / Computers and Mathematics with Applications II (IIIII) III-III

is equipped with a radio device with two interfaces. One interface can be used for vehicle to roadside communication and the other interface can be used for inter-vehicle communication. Each interface can have its own IP address. In this approach, a vehicle is not configured with an address for inter-vehicle communication, it broadcasts an address request. The nearest roadside unit that receives this message acts as a DHCP relay and forwards the address request to centralized DHCP server. This address request is termed DHCP DISCOVER message in DHCP terminology. The server that receives this message will respond with a DHCP OFFER message with the available network address. The roadside unit acting as a relay agent will forward this message to the vehicle that request an address.

Chen et al. [6] proposed a network mobility protocol for VANETs. In this paper, the protocol contains two algorithms, (1) The NEMO Scheme for a real bus: the bus is equipped with two mobile routers, the first mobile router performs the pre-handoff procedure and the second mobile router serves the mobile nodes and maintain the connectivity to the Internet. If there is at least a vehicle on the lanes of the opposite direction has an available IP address, the pre-handoff procedure is performed; (2) Virtual bus network mobility protocol: The vehicle is only equipped with a mobile router but still with WiMAX and Wi-Fi interfaces. Two or more neighboring vehicles on the lanes of the same or opposite direction may be grouping as a virtual bus. If no vehicle on the lanes of the same direction is at the target BS's communication region and the mobile router of the virtual bus cannot acquire the target BS's IP address at the serving BS communication region. In the worst case, the vehicle can get the IP address from the DHCP server. In addition to the above mentioned, when a vehicle is leaving the communication region of its serving base station (BS) and is moving to the boundary of the target BS's communication region, it may acquire a new IP address through multi-hop relays from a vehicle on the lanes of the same or opposite direction and it can assist a vehicle behind of it to perform the pre-handoff. A vehicle can acquire a new IP address from a vehicle on the lanes of the same direction by IP passing or it can exchange its IP address with vehicles on the lanes of the opposite direction. By using the relay ability of each vehicle, the handoff efficiency can also be improved.

Min et al. [10] proposed a new scheme of Global Mobility Management (GMM) for inter-VANETs handover of vehicles. In the network configuration of the proposed GMM scheme, the Global Vehicle Mobility Manager (GVMM) manages MAC address, permanent IP address (PoA), care-of address (CoA), identification of local VANET (VID), identification of V2V group (GID), and IP address of Local Vehicle Mobility Manager (LVMM). Also, it manages binding information related to communication between a Vehicle (VC) and the correspondent VCs. In the area of a LVMM, the access point (AP) forwards the MAC address of VC to LVMM, when a VC enter the AP's communication area. This supports the fast handover process using L2 triggering and route optimization for packet transmission. This scheme has lower latency time and packet transmission delay than existing ones.

Chen et al. [11] proposed a cross-layer design vehicle-aided handover scheme in VANETs. A new developed wireless network technique, termed WiMAX Mobile Multi-hop 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 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 vehicle (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 vehicle (DVs). A DV can thus perform a rapid handover when it enters the transmission range of any approaching RVs. The effectiveness of VFHS is that it can reduce handover latency and packet loss rate.

Peiyuan et al. [12] proposed a reliable broadcast routing scheme based on mobility prediction (RB-MP) to achieve an efficient multi-hop broadcast. This scheme selects the reliable and efficient rebroadcast nodes, according to the prediction holding times (PHT) provided by position and relative velocity. The proposed scheme has better performance in terms of the packet delay and efficiency percentage.

Han et al. [13] proposed a social cluster-based P2P framework that estimates similarity and connection condition among peers to provide mobile peers efficient resource discovery and retrieval. A mobile peer's preference and its connectivity such as the lifetime or the bandwidth for a wireless link. Specifically, there are two major components in this framework. First, a social cluster-based overlay structure and lifetime-aware flooding scheme enable mobile peers to discover resource through the Internet and VANETs. Second, a connectivity-aware retrieval scheme considers connection lifetime and bandwidth schedules and determines how to retrieve resource from available peer. This paper is able to quickly locate more available peers holding required contents and achieve a higher retrieval ratio.

Sheu et al. [14] present a scheme to assign IP address to each newly-joined node. First, some nodes are selected as coordinators. Then a new node will use the exchanged hello messages to find the closest coordinator and obtain a new IP address from that coordinator. In order to efficiently maintain the IP-address pools, the distributed coordinators are organized in a tree topology by exchanging hello messages. Simulation results show that the proposed scheme has a low latency for obtaining a new IP address and that it can efficiently maintain consistent IP-address pools.

Farhan and Zeadally [15] proposed an agent-based architecture for fast context transfer during handoffs. Multimedia applications often involve multiple media types such as voice, text, video, and graphics. Many of these applications have low delay requirements and do not perform well under large delay conditions. To provide efficient support for mobile multimedia applications as well as seamless network connectivity, it is crucial to minimized handoff delays. This work presents the design, implementation, and evaluation of an architecture based on agent technology to minimize handoff delays. In this

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Y.-S. Chen et al. / Computers and Mathematics with Applications I (IIII) III-III

paper, the proposed agent-based context transfer approach improves handoff delay performance by 54.8% compared to the traditional client/server context transfer approach which performs handoffs by exchanging multiple messages.

2.2. MIPv6 based mobility solutions

MIPv6 [2] has been proposed to support network layer mobility. MIPv6 allows a mobile node (MN) to maintain the connection to the Internet while moving from one subnet to another. Each MN is identified by its Home address (HoA). When connecting through a foreign network, an MN receives the Router Advertisement, this messages include a foreign network prefix and an auto-configured Care-of address (CoA). After configuring CoA, the MN must perform the duplicate address detection (DAD) procedure to guarantee that CoA is unique. If the CoA is useful, the MN sends its location information to its home agent (HA) to perform binding update, which intercepts packets intended for the MN and tunnels them to its current location. In order to improve the efficiency of MIPv6 to support the real time handoff, FMIPv6, PMIPv6 and HMIPv6 are proposed. Fast Mobile IPv6 (FMIPv6) [16] supports predictive fast handoff mode and reactive fast handoff mode. The main difference between these two mode is on the time to establish the tunnel between the Previous Access Router (PAR) and New Access Router (NAR). By the predictive handover, the tunnel is established before layer 2 handover, but by the reactive handover, the tunnel is established directly after layer 2 handover, and the predictive fast handoff mode has shorter latency than the reactive one. Proxy Mobile IPv6 (PMIPv6) [17] protocol is intended for providing networkbased IP mobility management support to a mobile node, without requiring the participation of the mobile node in any IP mobility related signaling, PMIPv6 adds two components: Local Mobility Anchor (LMA) and the Mobile Access Gateway (MAG). The LMA is responsible for maintaining the mobile node's reach ability state and is the topological anchor point for the mobile node's home network prefix. The MAG is the entity that performs the mobility management on behalf of a mobile node, and it resides on the access link where the mobile node is anchored. The MAG is responsible for detecting the mobile node's movements to and from the access link and for initiating binding registrations to the mobile node's LMA. There can be multiple LMA anchors in a PMIPv6 domain each serving a different group of mobile nodes. Hierarchical Mobile IPv6 (HMIPv6)[18] introduces a new function, the MAP, and minor extensions to the mobile node operation. The correspondent node and home agent operation will not be affected. Just like Mobile IPv6, it allows mobility within or between different types of access networks. A mobile node entering a MAP domain will receive router advertisements containing information on one or more local MAPs. The MN can bind its current location (on-link CoA) with an address on the MAP's subnet (RCoA). Acting as a local HA, the MAP will receive all packets on behalf of the mobile node it is serving and will encapsulate and forward them directly to the mobile node's current address. If the mobile node changes its current address within a local MAP domain (LCoA), it only needs to register the new address with the MAP. Hence, only the Regional CoA (RCoA) needs to be registered with correspondent nodes and the HA. The RCoA does not change as long as the MN moves within a MAP domain.

Many researches are based on improved MIPv6's technologies, e.g. FMIPv6, HMIPv6 and PMIPv6. Ruidong et al. [19] proposed an enhanced fast handover scheme for Mobile IPv6. In this paper, each Access Router (AR) maintains a CoA table and generates the new CoA for the MN that will move to its domain. At the same time, the binding updates to home agent and correspondent node are to be performed from the time when the new CoA for MN is know by Previous AR (PAR). Also the localized authentication procedure cooperated with the proposed scheme is provided. The proposed enhanced fast handover scheme can achieve low handover latency and low packet delay. Cheol et al. [20] proposed a Fast Handover Solution using Multi-tunnel in HMIPv6 (FM-HMIPv6). This paper introduces a solution to support a fast handover mechanism using multitunnels between MAP and neighbor ARs in HMIPv6 network. In this protocol, the MN can handover without receiving any information about the new AR and this eliminates difficulties to know or predict exactly the new AR which is not specified in standard fast handover scheme. It reduces layer-2 and layer-3 handover and efficiently reduces handover latency through the minimized number of wireless signaling messages and pre-DAD. Obele et al. [21] proposed an optimized PMIPv6 that relies on a rich set of informational resources to reduce handover delay. It then proposes a more efficient intra mobile access gateway routing scheme. Lee and Park [22] proposed a fast handover scheme for the PMIPv6 based on 802.11 network. This scheme uses Inter-Access Point Protocol (IAPP) to transfer context information such as the mobile node's authentication information and Home Network Prefix (HNP). This work can solve mobile node's moving among MAGs in PMIPv6 domain, but this handover could cause undesirable delay to the mobile nodes running real time applications like VoIP.

As VANETs become more and more popular, mobility management of VANETs becomes more and more important. Although the existing IP passing and mobility solutions may reduce handoff delay, but they cannot work properly on VANETs with network fragmentation because messages cannot be transmitted to the intended vehicles. Hence, when network fragmentation occurs, it may incur longer handoff latency and higher packet loss rate. To improve existing works, we propose an IP passing protocol for VANETs with network fragmentation.

3. Preliminaries

In this section, we first describe the assumptions and system architecture, and then we explain the challenges and basic ideas of this work.







MN NIC: Mobile node Network Interface Card

Fig. 2. Protocol stacks the mobile node.

3.1. System architecture

The system architecture of our protocol is shown in Fig. 1. The proposed protocol is design for VANETs with network fragmentation in a highway with two lanes in each direction. We assume that there are base stations (BS) (e.g. WiMAX, 3G or 4G BS) scattered along the roadside. The home agent (HA) records the vehicle's new location and the correspondence node (CN) serves as a remote server e.g. FTP or Web server etc. Each vehicle, regarded as a mobile node (MN), is equipped with two communication interfaces, one for communicating with the BS (e.g. WiMax, 3G or 4G Bs) and one for communicating with other vehicles. Each vehicle can connect to the Internet via WiMAX (or 3G/4G) interface and can communicates with other vehicles via IEEE 802.11 (Wi-Fi or DSRC) interface. Fig. 2 shows the protocol stack of the mobile node. In addition, each vehicle is equipped with registers to keep the IP address of the serving BS's communication region, location obtained by GPS, driving speed and other related information. Two or more neighboring vehicles on the lanes of the same or opposite direction may be form as a virtual bus [6], which may acquire or pass IP addresses by the cooperation of the vehicles in the virtual bus as shown in Fig. 3.

3.2. Basic idea and challenges

On the highway, when a vehicle moves to a new subnet, the vehicle will receive broadcast packet from the target BS and most importantly perform the handoff procedure. The traditional handoff procedure includes two parts, the layer 2 (link layer) and layer 3 (network layer) handoff procedures. The handoff procedure contains signal measurement, network layer movement detection, duplicate address detection (DAD) procedure and registration. The DAD procedure is time consuming and thus will cause the link to be disconnected.

Y.-S. Chen et al. / Computers and Mathematics with Applications I (IIII) III-III



Fig. 3. Forming virtual buses in VANETs.

On the highway, since the vehicle is moving so fast that the handoff latency must be reduced. Hence, how to acquire IP addresses immediately is a very important issue. The concepts of IP passing [5] and virtual bus [6] are adopted in our protocol so as to reduce the time to acquire a new IP address. However, the vehicle may not be able to acquire its new IP address through IP passing and virtual bus because of network fragmentation. To solve the problem, two strategies have been adopted in the proposed protocol. First, when a vehicle is going to leave the target BS and network fragmentation occurs, although the vehicle cannot pass its IP address to the vehicle that is going to enter the target BS, still it will pass its IP address to the vehicle that remains in the target BS and thus postpones the time to release its IP address to the DHCP server (extend IP lifetime). Second, during the extended IP lifetime, as a vehicle is going to enter the target BS, it can acquire an IP address through multi-hop relays from the vehicle which carries the released IP and thus provide more chances for a vehicle to acquire a new IP address through IP passing.

4. The proposed IP passing protocol

In this section, we first show the flowchart of the proposed protocol, then we describe the two phases of the proposed protocol. For the ease of describing the proposed protocol, we define the following notations as shown in Table 1:

- LMN: the vehicle which is going to leave the serving BS.
- KMN: the vehicle which keeps the IP released by LMN.
- EMN: the vehicle which is going to enter the target BS.

The handoff procedure contains phases as follows, the information collecting phase, the fast IP acquiring phase, the cooperation of mobile node (vehicle) phase, the make before break phase, and the route redirection phase. In the information collecting phase, each mobile node (vehicle) will broadcast its own and its neighboring vehicles' locations, moving speeds, and directions periodically. Besides, it should also rebroadcast the messages it received according to the TTL (time to live) of the messages to determine the IP passing direction. If the TTL of message is greater than 0, then the message should be rebroadcast. The TTL is set according to the intended size of the virtual bus and the communication range of the base station. After collecting the information of the nearby vehicle, a vehicle can realize the neighboring vehicle' locations, moving speeds, and directions and thus can group proper vehicles to form a virtual bus and can select proper cooperative vehicles to assist it to pass IP address at the proper moment.

Fig. 4 shows the flowchart of the proposed IP passing protocol, which contains two phases, the extension of IP lifetime phase and the IP acquisition phase.

4.1. Extension of IP lifetime

As shown in Fig. 4, when LMN is going to leave the target BS's communication region, if LMN can communicate with EMN, it follows the existing IP passing protocol to pass its IP address to EMN. However, if LMN cannot pass its IP address to EMN due to network fragmentation, LMN will pass its IP address to KMN through the virtual bus as shown in Fig. 5, such that LMN does not need to release its IP address to the DHCP server. Instead, its IP address is kept in KMN so that the IP address will have more chances to be passed to EMN. If there is no vehicle behind LMN that is on the lanes of the same direction, LMN will try to pass its IP address to the vehicle that is on the lanes of the opposite direction, as shown in Fig. 6. The IP address can also be passed to the vehicle on lanes of both directions through the cooperation of vehicles on the lanes of different directions as shown in Fig. 7. If LMN cannot find any proper KMN, it will release its IP address via the DHCP server.

Note that, when KMN receives the IP passing packet from LMN, it will reply a keep IP ACK packet to LMN and keep LMN's IP address. After LMN receives the keep IP ACK packet, it will break the connection with the target BS. As time goes by, KMN may approach the border of target BS's communication region, it will become LMN and try to pass the IP address to EMN or other KMN.

Y.-S. Chen et al. / Computers and Mathematics with Applications II (IIIII) III-III

Notation	Definition
<u> </u>	
KMN	The vehicle (mobile node) receives and keeps the passed IP
LMN -	The vehicle (mobile node) leaves target BS's communication region
EMN	The vehicle (mobile node) enters target BS's communication region
	N The vehicle (KMN) moves from time T1 to T2
	MN The vehicle (KMN) moves from time T3 to T4
€MN' EM	The vehicle (EMN) moves from time T1 to T2

4.2. IP acquisition and handoff procedure

In VANETs, how to reduce the IP acquisition time is a very important issue. As EMN enters the target BS's communication region, EMN still connects to Internet via IEEE 802.16 (WiMAX) with previous access router (pAR) and performs the following IP acquisition procedure as shown in Figs. 4 and 8. For the ease of describing the IP acquisition procedure, we define the following notations:

- T_{acquisition}: the time that EMN has already spent on acquiring an IP address from KMN.
- T_{th}: the amount of time for EMN to send an IP request packet to KMN and receive an IP address from KMN.
- *T*_{DHCP}: the amount of time for EMN to send an IP request packet to the DHCP server and receive an IP address from the DHCP server.
 - S1: EMN broadcast an IP request packet to KMN and sets its timer and *T*_{acquisition} as 0. At the same time, it sends an IP request packet to the DHCP server. Note that any vehicle kept an IP address passed by LMN and is in the target BS's communication region can perform as a KMN.
 - S2: EMN selects a faster way to acquire a new IP address: When $T_{acquisition} + T_{th} \ge T_{DHCP}$, it indicates that EMN can receive an IP address from the DHCP server earlier than acquiring an IP address from KMN. Under such condition, EMN will not broadcasts an IP request packet to KMN. If Timer $\ge T_{th}$ and EMN has not received an IP address from KMN, it indicates that the IP request packet sent by EMN or the IP address sent by KMN is lost. Under such condition, EMN will set $T_{acquisition}$ as $T_{acquisition} + T$ imer, and then reset its timer as 0 and check if there is still enough time to get an IP address from KMN. If the remaining time is enough (e.g. $T_{acquisition} + T_{th} < T_{DHCP}$), EMN will rebroadcast the IP request packet, if the remaining time is not enough, EMN will wait for the DHCP server to assign an IP address. Any KMN that has received the IP request packet sent by EMN will send an IP address to EMN. As soon as EMN has received an IP address, it will send an IP passing ACK packet to the KMN that has sent the IP address first and send a DHCP abort packet to the DHCP server. The KMN that receives the IP passing ACK packet will delete the IP it passed. The other KMN that does not receive the IP passing ACK packet will still keeps the IP address passed by LMN.

Figs. 9 and 10 show how EMN acquires an IP address from KMN which is on the lanes of the opposite and the same directions, respectively. During time T1 to time T2, EMN moves from the serving BS to the target BS's communication region. EMN can get an IP address from KMN, because LMN has passed its IP address to KMN which is on the opposition direction, KMN keeps the IP address and then gets the chance to pass the IP address to EMN. EMN can also acquires its IP address from the vehicles on the lanes of both directions as shown in Fig. 11. The message flow diagram of the proposed IP passing protocol is shown in Fig. 12.

After EMN acquired an IP address, EMN performs the binding update and the bidirectional tunneling process.

5. Mathematical analysis

To evaluate the performance of our protocol, we first analyze the performance of the proposed protocol and then we analyze the performance of the IP passing protocol [5] and compare it with the performance of the proposed protocol.

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Y.-S. Chen et al. / Computers and Mathematics with Applications I (IIII) III-III



Fig. 4. The flowchart of our scheme.

5.1. Analysis results of the proposed protocol

We use Markov chains to analyze the average IP acquisition time and the probability that KMN passes an IP address to EMN successfully of the proposed protocol. Two scenarios are considered in our analysis, the first scenario considers only the vehicles on the lanes of the same direction as shown in Fig. 13; while the second scenario considers the vehicles on the lanes of both directions as shown in Fig. 14.

The notations used in the first scenario are defined as follows:

- *m*: the maximum possible number of vehicles which are on the lanes of the same direction and between KMN and EMN.
- R_i^S : the ID of the *i*-th vehicle which is on the lanes of the same direction with KMN and is between KMN and EMN, where $1 \le i \le m$.

Y.-S. Chen et al. / Computers and Mathematics with Applications II (IIIII) III-III



Fig. 5. LMN passes its IP address to KMN which is on the lanes of the same direction.



Fig. 6. LMN passes its IP address to KMN which is on the lanes of the opposite direction.



Fig. 7. LMN passes its IP address to KMN through the cooperation of the vehicles on the lanes of both directions.



Fig. 8. IP acquisition and handoff procedure.



Fig. 9. EMN acquires an IP address from the vehicles on the lanes of the opposite direction.



Fig. 10. EMN acquires an IP address from the vehicles on the lanes of the same direction.



Fig. 11. EMN acquires an IP address via the cooperation of vehicles on the lanes of both directions.

- $P_{R_i^S}$: the probability that the IP address kept in KMN can be passed from vehicle KMN to R_i^S successfully if i = 1, or the probability that the IP address kept in KMN can be passed from R_{i-1}^S to R_i^S successfully if $2 \le i \le m$ (e.g. the distance between two adjacent vehicles is smaller than their communication range).
- P_{EMN} : the probability that the IP address kept in KMN can be passed from R_m^S to EMN successfully.
- *T*_{S_average}: the average IP acquisition time for EMN.

Assume that the communication range of vehicles is r meters and the vehicle density of the lanes of the same direction is λ_s vehicles/meter. Vehicles are scattered along the highway with a Poisson distribution. The average number of vehicles on the lanes of the same direction within r meters can be derived as $r\lambda_s$. The probability that two adjacent vehicles can communicate immediately is equal to the probability that there are at least two vehicles on the lanes of the same direction within the communication range r. The probability P_{immed}^s is derived as Eq. (1).

$$P_{\text{immed}}^{S} = P(x > 1; r\lambda_{s}) = 1 - P(x = 1; r\lambda_{s}) - P(x = 0; r\lambda_{s}) = 1 - r\lambda_{s}e^{-r\lambda_{s}} - e^{-r\lambda_{s}}.$$
(1)



Fig. 12. The message flow diagram of IP passing protocol and handoff procedure.



Fig. 13. Markov chains of the scenario that there are vehicles on the lanes of same direction.

Assume that the moving speed of vehicles R_{i-1}^S and R_i^S are $V_{(i-1)s}$ and V_{is} m/s, respectively. The relative speed of vehicles R_{i-1}^S and R_i^S is defined as $\Delta v = V_{is} - V_{(i-1)s}$. If $\Delta v \leq 0$, since the distance between vehicles R_{i-1}^S and R_i^S will not become shorter as time goes by, we let $P_{R_i^S} = P_{immed}^S$.

If $\Delta v > 0$, the distance between vehicles R_{i-1}^S and R_i^S will become shorter as time goes by. Assume that the available time that vehicle R_{i-1}^S can pass an IP address to the next vehicle is T_{is} seconds, where $T_{is} < T_{DHCP}$. Vehicle R_{i-1}^S can pass an IP address to the next vehicle is T_{is} seconds, where $T_{is} < T_{DHCP}$. Vehicle R_{i-1}^S can pass an IP address to vehicle R_i^S within T_{is} seconds if their distance is smaller than $r + T_{is}\Delta v$ meters. Hence, the probability that vehicle R_{i-1}^S can pass an IP address to vehicle R_i^S within T_{is} is the probability that there are at least two vehicles within $r + T_{is}\Delta v$

11



Fig. 14. Markov chains of the scenario that there are vehicles on the lanes of both directions.

meters. $P_{R^{S}}$ can be defined as Eq. (2):

$$P_{R_i^S} = P(x > 1; (r + T_{is} \triangle v) \lambda_s), \quad \text{if } \triangle v > 0,$$
(2)

where $P(x > 1; (r + T_{is} \triangle v)\lambda_s) = 1 - P(x = 1; (r + T_{is} \triangle v)\lambda_s) - P(x = 0; (r + T_{is} \triangle v)\lambda_s) = 1 - (r + T_{is} \triangle v)\lambda_s e^{-(r + T_{is} \triangle v)\lambda_s} - e^{-(r + T_{is} \triangle v)\lambda_s}$

The probability that the IP address can be passed from KMN to the *i*-th vehicle is

$$\prod_{a=1}^{l} P_{R_a^S}$$

The probability that the IP address can be passed from KMN through *i* vehicles to EMN successfully (denoted as $P_{S_{pass}}$) is derived as Eq. (3):

$$P_{S_{\rm pass}} = P_{\rm EMN} \prod_{a=1}^{i} P_{R_a^S}.$$
(3)

EMN may acquire an IP address either from KMN or from the DHCP server. Therefore, the average IP acquisition time for EMN $T_{S_average}$ is derived as Eq. (4):

$$T_{S_{average}} = T_{S_{pass}} \cdot P_{S_{pass}} + T_{DHCP} \cdot (1 - P_{S_{pass}}), \tag{4}$$

where $T_{S_{pass}}$ is the time required for passing an IP address from KMN to EMN through the vehicles on the same direction. The additional notations used in the second scenario are defined as follows:

- *n*: the maximum possible number of vehicles which are on the lanes of the opposite direction and between KMN and EMN.
- R_j^0 : is the ID of the *j*-th vehicle which is on the lanes of the opposite direction with KMN and is between KMN and EMN, where $1 \le j \le n$.
- $P_{R_i^{OS}}$: is the probability that the IP address kept in KMN can be passed from vehicle R_{j-1}^{O} to vehicle R_i^{S} successfully, where $2 \le i \le m$.
- $P_{R_j^0}$: is the probability that the IP address kept in KMN can be passed from vehicle R_{j-1}^0 to vehicle R_j^0 successfully, where $2 \le j \le n$.
- $P_{R_j^{SO}}$: is the probability that the IP address kept in KMN can be passed from vehicle R_{i-1}^S to vehicle R_j^O successfully, where $2 \le j \le n$.
- $1 P_{R_{i+1}^{S}} P_{R_{j+1}^{SO}}$: is the probability that the IP address kept in KMN cannot be passed either from vehicle R_i^S to ve



Fig. 15. (a) IP acquisition time vs. vehicle speed; (b) IP acquisition time vs. vehicle density; (c) IP acquisition time vs. network fragmentation ratio; (d) IP acquisition time vs. length of IP passing (hops).

800

400 200

0

10 12 14 16 18 20

Length of IP passing (hops)

₫ 600

- $1 P_{R_{i+1}^0} P_{R_{i+1}^{OS}}$: is the probability that the IP address kept in KMN cannot be passed either from vehicle R_i^0 to vehicle R_{i+1}^0 or from vehicle R_i^0 to vehicle R_{i+1}^S successfully, where $1 \le i \le m-1$ and $1 \le j \le n-1$.
- $P_{S_{EMN}}$: is the probability that the IP address kept in KMN can be passed from vehicle R_m^S to EMN successfully.
- P_{O_EMN} : is the probability that the IP address kept in KMN can be passed from vehicle R_n^O to EMN successfully.
- T_{SO_average}: is the average time that EMN acquires an IP address either from KMN through the vehicles on the lanes of both directions or from the DHCP server.

Assume that the vehicle density of the lanes of the opposite direction is λ_o vehicles/meter, the available time that vehicle R_{j-1}^{0} can pass an IP address to the next vehicle is T_{j0} seconds, where $T_{j0} < T_{DHCP}$, and the moving speed of vehicles R_{j-1}^{0} and R_j^0 are $V_{(j-1)o}$ and V_{jo} , respectively. $P_{R_i^0}$ can be derived in a similar manner as $P_{R_i^S}$, excepts that Δv is set as $V_{jo} - V_{(j-1)o}$ and λ_s and T_{is} are replaced by λ_o and T_{io} , respectively.

The probability that two adjacent vehicles from different directions can communicate immediately is equal to the probability that there are at least one vehicle within the communication range r on each direction. The probability P_{inmed}^{SO} is derived as Eq. (5).

$$P_{\text{immed}}^{\text{SO}} = P(x > 0; r\lambda_s) \cdot P(x > 0; r\lambda_o) = (1 - e^{-r\lambda_s}) \cdot (1 - e^{-r\lambda_o}).$$
(5)

The relative speed of vehicles R_{i-1}^S and R_i^O is defined as $\Delta v_{so} = V_{jo} + V_{(i-1)s}$ and the relative speed of vehicles R_{i-1}^O and R_i^S is defined as $\Delta v_{os} = V_{(j-1)o} + V_{is}$. If vehicles R_{i-1}^S and R_j^O are approaching each other, vehicle R_{i-1}^S can pass an IP address to vehicle R_i^0 within T_{is} seconds if their distance is smaller than $r + T_{is} \triangle v_{s0}$ meters. Hence, the probability that vehicle R_{i-1}^S can pass an IP address to vehicle R_i^0 within T_{is} is the probability that there are at least one vehicle within $r + T_{is} \Delta v_{so}$ meters on each direction.

 $P_{R_i^{SO}}$ can be defined as Eq. (6):

P acquisition time (ms)

acquisition time (ms)

Ĕ. 1000

1500

500

0.0 0 04 0.5 0.6 0.7 0.8 0.9 1.0

Network fragmentation ratio

$$P_{R_{i}^{SO}} = P(X > 0; (r + T_{is} \triangle v_{so})\lambda_{s}) \cdot P(X > 0; (r + T_{is} \triangle v_{so})\lambda_{o}),$$
(6)

1.0



Fig. 16. (a) IP lifetime vs. vehicle speed; (b) IP lifetime vs. vehicle density; (c) IP lifetime vs. network fragmentation ratio; (d) IP lifetime vs. length of IP passing (hops).

where $P(x > 0; (r + T_{is} \triangle v_{so})\lambda_s) \cdot P(x > 0; (r + T_{is} \triangle v_{so})\lambda_o) = (1 - P(x = 0; (r + T_{is} \triangle v_{so})\lambda_s)) \cdot (1 - P(x = 0; (r + T_{is} \triangle v_{so})\lambda_o)) = (1 - e^{-(r + T_{is} \triangle v_{so})\lambda_s}) \cdot (1 - e^{-(r + T_{is} \triangle v_{so})\lambda_o}).$

If vehicles R_{i-1}^{S} and R_{j}^{O} are leaving each other, we let $P_{R_{i}^{SO}} = P_{immed}^{SO}$.

 $P_{R_i^{OS}}$ can be derived in a similar manner as $P_{R_i^{SO}}$, excepts that $\triangle v_{so}$ and T_{is} are replaced by $\triangle v_{os}$ and T_{jo} , respectively.

The probability that the IP address can be passed from KMN to the second vehicle (R_2^S) on the lanes of the same direction with KMN (denoted as $P_{all R_2^S}$) is derived as follows:

$$P_{\text{all}_R_2^{\text{S}}} = P_{R_1^{\text{S}}} \cdot P_{R_2^{\text{S}}} + P_{R_1^{\text{O}}} \cdot P_{R_2^{\text{OS}}}.$$

The probability that the IP address can be passed from KMN to the second vehicle (R_2^0) on the lanes of the opposite direction with KMN (denoted as $P_{all R_2^0}$) is derived as follows:

$$P_{\text{all}_R_2^0} = P_{R_1^0} \cdot P_{R_2^0} + P_{R_1^1} \cdot P_{R_2^{0}}.$$

The probability that the IP address can be passed from KMN to the *i*-th vehicle (R_i^S) on the lanes of the same direction with KMN (denoted as $P_{all_{\mathcal{R}_i^S}}$) is derived as follows:

$$P_{\mathrm{all}_R_i^{\mathrm{S}}} = P_{\mathrm{all}_R_{i=1}^{\mathrm{S}}} \cdot P_{R_i^{\mathrm{S}}} + P_{\mathrm{all}_R_{i=1}^{\mathrm{O}}} \cdot P_{R_i^{\mathrm{OS}}}.$$

The probability that the IP address can be passed from KMN to the *j*-th vehicle (R_j^0) on the lanes of the opposite direction with KMN (denoted as P_{all,R_i^0}) is derived as follows:

$$P_{\text{all}_R_i^O} = P_{\text{all}_R_{i-1}^O} \cdot P_{R_i^O} + P_{\text{all}_R_{i-1}^S} \cdot P_{R_i^S}$$

We can use dynamic programming to calculate P_{all,R_i^S} and P_{all,R_j^O} . The probability that the IP address can be passed from KMN to EMN successfully from both directions (denoted as $P_{SO pass}$) is derived as Eq. (7):

$$P_{SO_{pass}} = P_{O_{EMN}} \cdot P_{all_{R_i}^O} + P_{S_{EMN}} \cdot P_{all_{R_i}^S}.$$

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Y.-S. Chen et al. / Computers and Mathematics with Applications II (IIIII) III-III



Fig. 17. (a) Handoff latency vs. vehicle speed; (b) Handoff latency vs. vehicle density; (c) Handoff latency vs. network fragmentation ratio; (d) Handoff latency vs. length of IP passing (hops).

EMN may acquire an IP address either from KMN or from the DHCP server. Therefore, the average IP acquisition time for EMN $T_{SO_average}$ is derived as Eq. (8):

$$T_{SO_average} = T_{SO_pass} \cdot P_{SO_pass} + T_{DHCP} \cdot (1 - P_{SO_pass}),$$
(8)

where $T_{SO_{pass}}$ is the time required for passing an IP address from KMN to EMN through the vehicles on both directions.

5.2. Comparison of the mathematical analysis results

In the IP passing protocol, since the IP address can only be passed immediately, the probability that two adjacent vehicles can pass IP to each other is equal to $P_{immed}^{SO} = (1 - e^{-r\lambda_s}) \cdot (1 - e^{-r\lambda_o})$ as shown in Eq. (5). Since $P_{R_j^{SO}} = (1 - e^{-(r+T_{is} \Delta v_{so})\lambda_s}) \cdot (1 - e^{-(r+T_{is} \Delta v_{so})\lambda_s}) \cdot (1 - e^{-(r+T_{is} \Delta v_{so})\lambda_s}) \circ P_{R_j^{SO}} = P_{immed}^{SO}$, and $P_{R_i^{OS}} = (1 - e^{-(r+T_{jo} \Delta v_{os})\lambda_s}) \cdot (1 - e^{-(r+T_{jo} \Delta v_{os})\lambda_s}) \circ P_{R_i^{OS}} = P_{immed}^{SO}$ (depends on the relative speed of two adjacent vehicles), we can imply that $P_{R_j^{SO}} \ge P_{immed}^{SO}$ and $P_{R_i^{OS}} \ge P_{immed}^{SO}$. Hence, the probability that IP address can be passed from LMN to EMN successfully (denoted as P_{pass}) is less or equal to P_{SO_pass} , which is the probability that the IP address can be passed from KMN to EMN successfully from both directions. The average IP acquisition time of the IP passing protocol (denoted as $T_{average}$) can also be derived from Eq. (8) except that P_{SO_pass} is replaced by P_{pass} . Since $P_{SO_pass} \ge P_{pass}$ and T_{DHCP} is much greater than T_{SO_pass} , we can imply that $T_{average} \ge T_{SO_average}$. Therefore, the IP acquisition time of the proposed protocol is no greater than that of the IP passing protocol.

6. Performance evaluation

To further evaluate the performance of our protocol, we simulate the original mobility support of IPv6 [2], the IP passing protocol [5] and our protocol on Network Simulator-2 (ns-2) [23]. The IP passing protocol is chosen for the comparison because our protocol is improved from it and it performs better than the other IP acquisition protocols when there is no network fragmentation. Although MIPv6 is not the most advanced protocol, yet it is a representative criterion for

Table 2 Simulation parameters

indiation parameters.			
Network size	$5000 \text{ m} \times 50 \text{ m}$		
Transmission range of WiMAX	1000 m		
Transmission range of WLAN	250 m		
Vehicle speed	5–100 km/h		
Number of vehicles	5-100 vehicles		
Network fragmentation ratio	0%-100%		
Length of IP passing (hops)	1-20		
Packet size	512 bytes		
Packet rate	200 packets/s		
Simulation time	200 s		

comparison. For the simplicity of describing the simulation results, the original mobility support in IPv6 is denoted as MIPv6, the IP passing for VANETs is denoted as IP passing, our protocol is denoted as our scheme, and the analyzed result of our scheme is denoted as our scheme-A. Each simulation result is derived from the average of 100 simulations. The performances metrics observed in our simulations are shown as follows:

- The *IP acquisition time* is defined as the interval from the time when EMN sends the IP acquisition packet to the time when EMN gets its IP address either from KMN or from the DHCP server.
- The *IP lifetime* is defined as the interval from the time when LMN intends to release its IP address to the time when the IP address is released back to the DHCP server.
- The *Handoff latency* is defined as the interval from the time when the last packet is received from the old BS to the time when the first packet is received from the new BS.
- The Packet loss rate is defined as the number of missed packets divided by the number of transmitted packets.
- The Throughput is defined as the amount of received data per second.
- The *Message overhead* is the total number of IP-passing packets and the packets to discover CV-MH (cooperative vehicle mobile host).

The simulation parameters are shown in Table 2.

6.1. IP acquisition time

Fig. 15 shows the impacts of vehicle speed, vehicle density, network fragmentation ratio and length of IP passing to IP acquisition time. Among all the performance metrics, we have only analyzed the expected IP acquisition time, hence scheme-A is compared only in this section. As the vehicle speed, vehicle density, network fragmentation ratio and length of IP passing increase, the IP acquisition time also increases because higher speed tolerates shorter handoff delay, higher vehicle density incurs higher contentions and collisions, higher network fragmentation ratio hinders more IP passing to be success, and longer length of IP passing incurs longer propagation delay. Among the three schemes, the IP acquisition time of our scheme is the lowest, follows by the IP passing scheme and MIPv6 scheme. Our scheme performs the best because our scheme can provide more chance than IP passing scheme does to make IP passing successfully. The MIPv6 scheme are quite close to the simulation results, which indicates that our analysis is proper.

6.2. IP lifetime

Fig. 16 shows the impacts of vehicle speed, vehicle density, network fragmentation ratio and length of IP passing to IP lifetime. Since MIPv6 will always release its IP address to the DHCP server immediately, its IP lifetime is 0 and hence its IP lifetime is not compared with other protocols. As the vehicle density, network fragmentation ratio and length of IP passing increases, the IP lifetime also increases. As the vehicle speed increases, the IP lifetime decreases. The IP lifetime of our scheme is longer than that of the IP passing scheme because in our scheme, even LMN cannot pass its IP address to EMN, it will still pass its IP address to the vehicle that remains in the target BS and thus postpones the time to release its IP to the DHCP server and extends IP lifetime. However, in the IP passing scheme, if LMN cannot pass its IP address to EMN, it will release its IP address to the DHCP server.

6.3. Handoff latency

Fig. 17 shows the impacts of vehicle speed, vehicle density, network fragmentation ratio and length of IP passing to handoff latency. Since the handoff latency is proportional to the IP acquisition time, the result is similar to that of the IP acquisition time. As the vehicle speed, vehicle density, network fragmentation ratio and length of IP passing increase, the handoff latency also increases. Among the three schemes, the handoff latency of our scheme is the lowest, follows by the IP passing scheme and MIPv6 scheme. Our scheme performs the best because our scheme has the lowest IP acquisition time; while MIPv6 has the highest IP acquisition time.



17



Fig. 18. (a) Packet loss rate vs. vehicle speed; (b) Packet loss rate vs. vehicle density; (c) Packet loss rate vs. network fragmentation ratio; (d) Packet loss rate vs. length of IP passing (hops).

6.4. Packet loss rate

100

Fig. 18 shows the impacts of vehicle speed, vehicle density, network fragmentation ratio and length of IP passing to packet loss rate. As the vehicle speed, vehicle density, network fragmentation ratio and length of IP passing increases, the packet loss rate also increases. Among the three schemes, the packet loss rate of our scheme is the lowest, follows by the IP passing scheme and MIPv6 scheme. Our scheme performs the best because the handoff latency of our scheme is the shortest and thus its connection to Internet is the most stable and can achieve the lowest packet loss rate. The MIPv6 scheme performs the worst because its handoff latency is the longest and thus its connection to Internet is more likely to be broken and causes higher packet loss rate.

6.5. Throughput

Fig. 19 shows the impacts of vehicle speed, vehicle density, network fragmentation ratio and length of IP passing to throughput. As the vehicle speed, vehicle density, network fragmentation ratio and length of IP passing increases, the throughput decreases. Among the three schemes, the throughput of our scheme is the highest, follows by the IP passing scheme and MIPv6 scheme. As the handoff latency and packet loss rate increase, the throughput decreases. Our scheme performs the best because the handoff latency and packet loss rate of our scheme are the lowest; while the handoff latency and packet loss rate of the MIPv6 scheme is the highest.

6.6. Message overhead

Fig. 20 shows the impacts of vehicle speed, vehicle density, network fragmentation ratio and length of IP passing to message overhead. As the vehicle density, network fragmentation ratio and length of IP passing increases, the message overhead also increases. The message overhead of our scheme is higher than that of the IP passing scheme because in our scheme, even LMN cannot pass its IP address to EMN, it will still pass its IP address to the vehicle that remains in the target



Fig. 19. (a) Throughput vs. vehicle speed; (b) Throughput vs. vehicle density; (c) Throughput vs. network fragmentation ratio; (d) Throughput vs. length of IP passing (hops).

BS and thus incurs more message overhead. Besides, each vehicle needs to broadcast its information to the nearby vehicles and EMN will broadcast an IP request to KMN and send an IP request packet to the DHCP server.

6.7. Analysis and discussions

Among all the simulation parameters, network fragmentation ratio has the greatest impact to the performance of the IP passing protocol because the IP address cannot be passed to the intended vehicle when network fragmentation occurs. Since the proposed protocol is designed for VANETs with network fragmentation, network fragmentation ratio incurs less impact to the proposed protocol. Vehicle speed and vehicle density also has great impact to the performance of the IP passing protocol because vehicle speed and vehicle density will affect network fragmentation ratio. Higher vehicle speed and lower vehicle density will incur higher network fragmentation ratio.

Among all the performance metrics, a longer IP life time can provide a vehicle more chances to acquire its IP address through IP passing. With more chances to acquire an IP address through IP passing, the IP acquisition time can be reduced because IP passing is much faster than acquiring an IP address through the DHCP server. With a shorter IP acquisition time, the handoff delay can be reduced and thus the connectivity to the Internet becomes more stable, and hence the packet loss rate can be reduced and the throughput can be enhanced. However, to keep the IP address in KMN and to acquire an IP address from both of the DHCP server and KMN, more packets need to be sent and this is the "price" we must pay in the proposed protocol.

7. Conclusions

In this paper, we have proposed an IP passing protocol for vehicular ad hoc networks with network fragmentation. Although IP passing may reduce handoff latency, but it cannot solve the network fragmentation problem because the IP address cannot be passed to the intended vehicle. In the proposed protocol, LMN will pass its IP address to the vehicle that remains in the target BS and thus postpones the time to release its IP to the DHCP server. During the extended IP lifetime, as a vehicle is going to enter the target BS, it can acquire an IP address through multi-hop relays from the vehicle which carries

18



Fig. 20. (a) Message overhead vs. vehicle speed; (b) Message overhead vs. vehicle density; (c) Message overhead vs. network fragmentation ratio; (d) Message overhead vs. length of IP passing (hops).

the released IP, and thus it can reduce the handoff delay and maintain the connectivity to Internet. Simulation results have shown that the proposed scheme is able to reduce IP acquisition time, packet loss rate, and extend IP lifetime with extra message overhead.

In the future, we plan to design an IP acquisition protocol that can adjust its IP acquisition strategy according to the speed and density of vehicles so as to reduce the message overhead and achieve a shorter IP acquisition time.

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19

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Y.-S. Chen et al. / Computers and Mathematics with Applications I (IIII) III-III

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