Perfroamce Evaluation of Pre-handoff Schemes for Vehicular Ad-Hoc Networks

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***Abstract*—There are two main types of applications for vehicular ad-hoc networks (VANET): safety applications and user applications (such as entertainment and mobile commerce). For user applications, Internet connectivity is a necessity. However, it is challenging to provide fast handoff for vehicles in a VANET due to the rapid movement of vehicles. Previous studies have showed that the time required by the handoff procedure is significant compared with the time of a continuous Internet connection in a VANET. This paper analyzes the performance improvement for VANET handoff with pre-handoff schemes.**

Keywords-VANET;DHCP;Pre-handoff; Internet connectivity

I. INTRODUCTION

With the rapid development of mobile ad hoc networks, many evolving wireless networks with practical uses have been created, such as vehicular ad-hoc networks (VANET), wireless mesh networks, and wireless sensor networks. VANET has attracted a great attention from the viewpoint of both technological and academic fields in the past few years. There are two main types of applications for VANET: safety applications and user applications. Both types of applications make use of vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communications. Especially, for user applications, Internet connectivity is a necessity, which can be achieved by V2I communications [12].

Unlike traditional mobile ad hoc networks, VANET faces a special problem. Owing to the fast movement of vehicles, the time that a vehicle remains in the coverage area of an access point (or base station) is very short. This problem gets worse when vehicles move fast, e.g., on highways. Therefore, vehicles need to frequently disassociate with an old access point and associate with a new access point. For traditional Internet Protocol (IP), this problem results in frequent changes of IP addresses, which means that an ongoing Internet connection suffers from disconnected frequently. To avoid this problem, several well-known protocols have been proposed to maintain an unchanged IP address to provide a continuous IP connection, such as Mobile Internet Protocol version 4 (MIPv4) [10], Mobile Internet Protocol version 6 (MIPv6) [7], and Hierarchical Mobile Internet Protocol version 6 (HMIPv6) [11]. All these schemes employ the concept of home address and care-of-address (CoA). For example, in MIPv6, a mobile host initially obtains an IP address called home address from its home network. After the mobile host moves to a new access router, it obtains a new temporary IP address called CoA, and then registers the CoA to the home agent (HA) in its home network. By doing so, there is no need to change IP address; the initially obtained IP address can be always maintained [11].

There are two types of approaches to obtain a CoA: stateful and stateless. With stateful approach, a mobile host obtains its IP address by dynamic host configuration protocol (DHCP). With stateless approach, a mobile host obtains its IP address by combining its MAC address and the prefix of the attached access router. Both types of approaches require a duplicate address detection (DAD) procedure, which makes sure that an IP address to be released is not already in use. However, the DAD procedure is very time consuming. To overcome this problem, some studies have developed new methods. For example, in [3], Chen et al., proposed a virtual-bus pre-handoff scheme. With this scheme, the vehicles moving in the same direction forms a virtual bus, as shown in Fig. 2. When a virtual bus enters the coverage area of a new access router, the vehicle in the front of the virtual bus performs a pre-handoff procedure for the vehicles in the rear of the virtual bus, thereby reducing the handoff time required by the rear vehicle. In [4], Arnold et al. proposed an IP-passing scheme. With IP-passing scheme, a vehicle that is about to leave the coverage area of an old access router will passes its IP address to a newly arrived vehicle that is to enter the coverage area of the "old" access router. By doing so, there is no need to perform IP address return and acquisition with a DHCP server. Therefore, a great deal of handoff time can be saved. Other schemes that try to reduce the handoff time in a VANET can be found in [5], [8], [9].

This paper studies the performance of VANET with and without pre-handoff procedures. Unlike [4], we do not employ

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the concept of virtual bus. Instead, each vehicle can independently find a vehicle in the front to perform the handoff procedures for it. Especially, we focus on the performance improvement caused by pre-handoff procedures and the parameters that may affect the performance, such as different density of traffic flows, the pre-distance for invoking the pre-handoff procedure, vehicle speed, and the serving rate of DHCP server. We develop analytic modes to analyze the performance. This paper is organized as follows. Section II reviews the step-by-step procedures required by exisiting handoff schemes for VANET. Section III develops an analytic performance model, and Section IV describes the performance analysis results. Finally, Section V concludes this paper.

II. EXISTING HANDOFF SCHEMES FOR VANET

A. Traditional DHCP Procedures

When a mobile host enters the coverage area of a new access point (or base station), it uses DHCP procedures to obtain an IP address from the new DHCP server. With reference to Fig. 1, DHCP procedures are as follows [6]. At the first, a mobile host issues a DHCPDISCOVER message by broadcasting. When the DHCP server receives the DHCPDISCOVER message, the DHCP server uses unicast to reply a DHCPOFFER message to the mobile host. The DHCPOFFER message contains an IP address to be offered to the mobile host and the leased time of the IP address. The offered IP address will be locked by the DHCP server. After the mobile host receives the DHCPOFFER message, it then issues a DHCPREQUEST message to the DHCP server. If the offer is still valid, the DHCP server sends a DHCPACK message to confirm with the mobile host, and binds the MAC address of the mobile host and the offered IP address.

Note that the exact time required by DHCP procedures largely depends on the implementation schemes used by the products. For example, in [1], T. Arnold et al. showed that the DHCP procedure required by Linksys WRT54GL wireless routers is about 2.504 seconds; on the other hand, the time required by Apple Airport Express is about 0.502 seconds. There is a large difference between the two times. This is because when a Linksys WRT54GL wireless router receives a DHCPDISCOVER message, it issues an ARP packet three times to make sure that the offered IP address is not already in use. However, for an Apple Airport Express access point, it issues only one ARP packet.

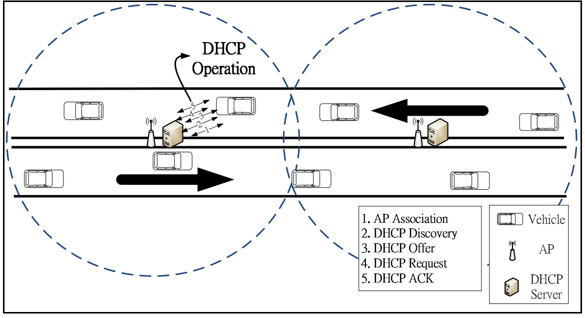

Figure 1. The steps of traditional DHCP scheme

B. Pre-Handoff Procedures

To reduce the time caused by DHCP procedures, some studies have employed the concept of pre-handoff [1-3]. The main idea behind these studies is similar. That is, when a mobile host moves close to the boundary of the coverage area of its current associated access point, it will ask other mobile hosts located in the coverage areas of the nearby regions to execute the pre-handoff procedures for it.

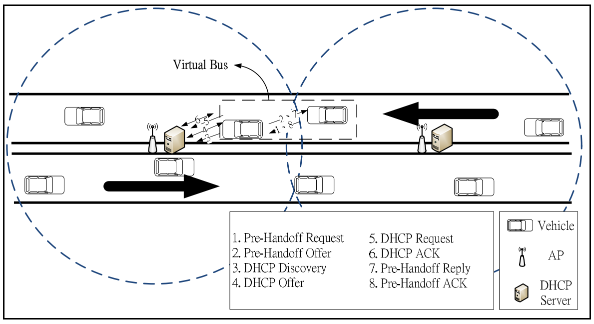

Figure 2. The virtual-bus scheme [4]

Fig. 2 shows the concept the virtual-bus scheme used in [3]. Initially, this scheme is based on NEMO architecture. The front side and the rear side of a true bus are equipped with a mobile router, respectively. The front mobile router is responsible for executing the handoff procedure, while the rear mobile router is used to transmit data packets. All devices in the bus communicate with the rear mobile router. When the rear mobile router finds that the signal strength from its associated access point (or base station) becomes weak, it will ask the front mobile router to invoke a pre-handoff procedure for it. However, if the distance between the two mobile routers, i.e., the distance of the true bus, is too short, the performance improvement made by the virtual bus degrades significantly. Therefore, Chen et al., combines this idea with the V2V communication to form a virtual bus, which consists of several consecutive vehicles. The vehicles whining a virtual bus communicate with each other using V2V one-hop or multi-hope communication.

III. ANALYTIC MODELS

In this section, we assume that CSMA/CA protocol is used in a VANET. Then, the time required to transmit a message can be analyzed by Markov chains. The time required to obtain an IP address is analyzed by queuing models. On the basis of these analysis results, we analyze the handoff performance using DHCP and pre-handoff.

A. Time for Packet Transmission in CSMA/CA

The performance of CSMA/CA protocol can be analyzed by Markov chains. Interested readers are referred to [13] for a detailed analysis. Using the results obtained in [13], we conduct our analysis as follows. Let n denote the number of mobile nodes. Let p denote the collision probability for transmitting a packet. Then p can be calculated by Eq. (1).

$$p = 1-(1-\tau)^{n-1} \qquad (1)$$

Let τ denote the probability of a mobile node sending a packet. τ can be calculated as follows..

$$\tau = \frac{2(1-2p)}{(1-2p)(S+1)+pS(1-(2p)^m)} \qquad (2)$$

where S represents the initial value of the backoff window size used in CSMA/CA protocol, and m represents the maximum number of failure times for transmitting a packet. Let p_{tr} be the probability that at least one of the n mobile nodes will transmit a packet within a time slot. p_{tr} can be calculated as follows.

$$p_{tr} = 1-(1-\tau)^n \qquad (3)$$

Let p_s be the probability for transmitting a packet successfully. p_s can be calculated as follows.

$$p_s = \frac{n\tau(1-\tau)^{n-1}}{p_{tr}} = \frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n} \qquad (4)$$

Let S_i denote the average backoff window size when the transmission of a packet has failed i times. S_i can be calculated as follows.

$$S_i = \begin{cases} (S+1)/2 & i=0 \\ \sum_{j=0}^{i}(S+1)*2^{j-1} & 0<i\le 5 \\ S_{i-1}+S*2^4 & 5<i\le m \end{cases} \qquad (5)$$

Let P denote the payload size of a packet, and let $P*$ denote the size of the longest packet payload involved in a collision. Assume that $E[P*]=E[P]=P$. Let T_s^{bas} denote the average time the channel is sensed busy for a successful transmission. Let T_c^{bas} denote the average time the channel is sensed busy by a mobile node during a collision. Then, T_s^{bas} and T_c^{bas} can be calculated as follows.

$$\begin{cases} T_s^{bas} = H+E[P]+SIFS+\delta+ACK+DIFS+\delta \\ T_c^{bas} = H+E[P^*]+DIFS+\delta \end{cases} \qquad (6)$$

, where H represents the size of a packet header; SIFS, DIFS, and ACK represent the time required to transmit SFIF, DIFS, and ACK, respectively; and δ represents the propagation delay. According to Eqs (3)-(6), we can calculate $T(n)$, the average time for a successful transmission of a packet when the number of mobile stations is n.

$$\begin{aligned} T(n) = {} & [\sum_{i=0}^{m} S_i p_s(1-p_s)]\times t_{slot} + T_s^{bas} \\ & + \sum_{i=1}^{m}(T_c^{bas}+ACK_{out})(1-p_s)^i \\ & + \{[\sum_{i=0}^{m} S_i p_s(1-p_s)]\times p_{tr}-1\}\times(T_s^{bas}+T_c^{bas})/2 \end{aligned} \qquad (7)$$

, where t_{slot} represents the length of a time slot and ACK_{out} represents the length of the timeout of ACK.

B. Time for Acquiring an IP Address

The time for acquiring an IP addresses can be modeled by a queuing model. Since multiple DHCP requests can be issued and processed at the same time, a queuing model with multiple servers is required. Let C represents the number of available IP addresses. This means that at most C DHCP requests can be processed at the same time. Therefore, the time for acquiring an IP address can be modeled by a $M/G/C/C$ queuing model. Since the most time-consuming step required by a DHCP server is DAD, the service time is assumed to be the time required by a DAD procedure. Usually, the number of vehicles within the range of an access point will be less than the number of available IP addresses. In view of this, the $M/G/C/C$ model can be reduced to a $M/G/\infty$ model. Let μ denote the service rate of a DHCP server. In the DAD procedure, a random waiting time ranging from zero to one second is required to acquire an IP address. Herein, we do not consider the case with duplicate IP addresses for its small probability of occurring. Let W denote the waiting time of the queuing model. Then W can be calculated as follows.

$$W = \frac{1}{\mu} \qquad (8)$$

$$\frac{1}{\mu} = U[0,1]+1 \qquad (9)$$

C. Time for Pre-handoff

As shown in Fig. 2, a pre-handoff procedure requires eight messages: four V2V messages with the vehicle in the front and four V2R messages with the DHCP server. We assume that each vehicle is equipped with two network interfaces: one is for V2V communication and the other is for V2R communication. Assume that vehicles arrive according to a Poisson distribution with arrival rate λ. Let $f(x;\lambda)=\lambda^x e^{-\lambda}/x!$ denote the probability that there are exactly x arrivals. According to Eq. (7), the handoff time required by the pre-handoff procedure, denoted by T_{pre}, can be calculated as follows.

$$T_{pre} = Max(4 \cdot \sum_{i=1}^{N_{pre}} T(i) \cdot f(i; \lambda \cdot D_{pre} / V) + W$$
$$+ 4 \cdot \sum_{i=1}^{N_R} T(i) \cdot f(i; \lambda \cdot D_R / V) - D_{pre} / V, 0) + L2 \quad (10)$$

, where $L2$ represents layer-two handoff time; the meaning of the two distances D_{pre} and D_R are illustrated in Fig. 3; N_{pre} and N_R represent the maximum number of vehicles within the range of D_{pre} and D_R.

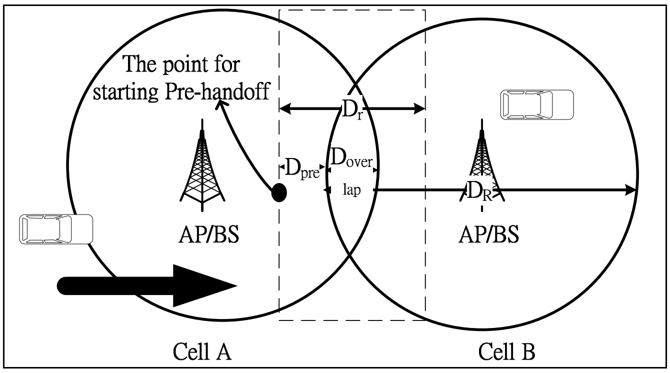

Figure 3. The concept of virtual-bus pre-handoff scheme

In most situations, pre-handoff can be performed successfully. However, it is still likely that a vehicle cannot find a vehicle in the front (predecessor) to perform the pre-handoff procedure. To avoid uncertainty, a vehicle will not ask a predecessor in the overlap region (see Fig. 3) to perform pre-handoff since the vehicles in this region may not associate with the new access point. If the pre-handoff procedure fails, a vehicle will switch to continue a traditional DHCP procedure. In other words, as shown in Fig. 3, only the vehicles within the distance $D_r - (D_{overlap} + D_{pre})$ can assist pre-handoff. Let α denote the failure probability for performing the pre-handoff procedure. α can be calculated as follows.

$$\alpha = 1 - f(0; \lambda \cdot (D_r - (D_{overlap} + D_{pre}) / V)) \quad (11)$$

Therefore, the total handoff time using pre-handoff and DHCP can be calculated as follows.

$$T_{pre+DHCP} = \alpha \cdot T_{pre} + (1 - \alpha) \cdot T_{DHCP} \quad (12)$$

D. Time for Traditional DHCP

As shown in Fig. 1, traditional DHCP requires four messages. In a similar manner, the total time required by traditional DHCP can be calculated as follows.

$$T_{DHCP} = 4 \cdot \sum_{i=1}^{N_R} T[i] \cdot f(i; \lambda \cdot D_R / V)$$
$$+ W + L2 \quad (13)$$

IV. NUMERICAL RESULTS

In this section, we describe our analysis results using the analytic models constructed in the previous section. We compare the performance of DHCP procedures with and without pre-handoff. For simplicity, we call the DHCP scheme without pre-handoff as DHS (DHCP handoff scheme) and the DHCP scheme with pre-handoff as PHS (pre-handoff scheme). We assume that vehicles arrive according to a Poisson distribution with mean arrival rate λ and that the service time of DHCP requests follow a exponential distribution with mean service rate μ. Table II shows the values of the key parameters used in our analysis [3].

TABLE I. SIMULATION PARAMETERS

λ (vehicles /sec)	$1/\mu$ (sec.)	V (km/hour)	D_r (m)	D_{pre} (m)	$D_{overlap}$ (m)
2.2	1.5	80	300	50	50

A. Effects of Pre-handoff Distance

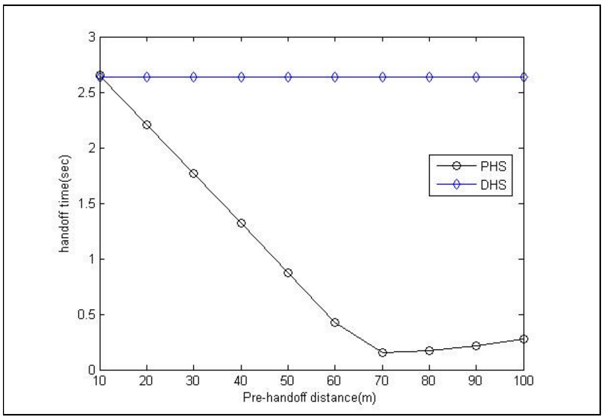

Figure 4. Effects of pre-handoff distance

Fig. 4 shows the handoff time versus pre-handoff distance (see Fig. 3). Since DHS do not uses pre-handoff, its handoff time is not affected by the pre-handoff distance. It can be observed that the best pre-handoff distance is 70 meters. A distance less than 70 meters will increase the handoff time because a shorter pre-handoff distance makes it difficult to take advantage of the pre-handoff procedure. On the other hand, a distance larger than 70 meters may interrupt its current communication with the associated access point (or base station). Therefore, it is important to select an optimal pre-handoff distance. With the use of our analytic models, the optimal value can be easily found.

B. *Effects of DHCP Service Rate*

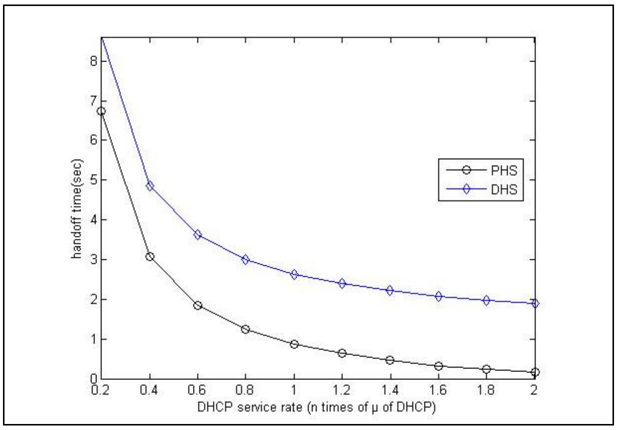

Figure 5. Effects of DHCP service rate

Fig. 5 shows the handoff time versus service rate. It can be observed from Fig. 5 that when the DHCP service rate is reduced to 40%, the performance of both schemes degrades significantly. However, when the service rate is increased to 200%, the performance of both schemes does not further reduce obviously. Another phenomenon that can be observed is that PHS outperforms DHS in most of the cases.

C. *Effects of Vehicle Arrival Rate*

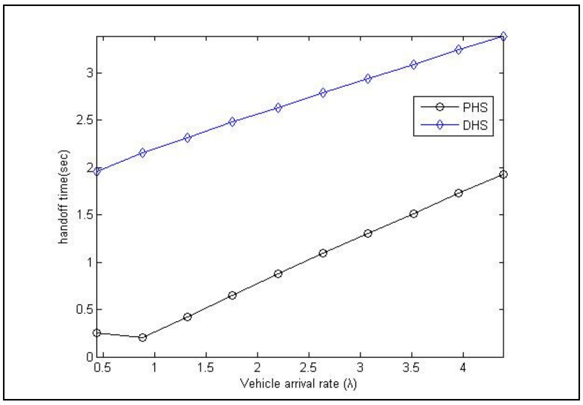

Figure 6. Effects of vehicle arrival rate

Fig. 6 shows the handoff time versus vehicle arrival rate. It can be observed that for DHS, the overall handoff time increases with the increase in the arrival rate. This is because when the arrival rate is small, the number of service requests is small, and the DHCP server can quickly serve the requests, thereby reducing the overall handoff time. On the other hand, for PHS, the overall handoff time decreases with the increase in the arrival rate. This is because when the arrival rate is small, the density of vehicles is small, thereby reducing the probability that a vehicle can find an appropriate preceding vehicle for performing pre-handoff.

V. CONCLUSIONS

In this paper, we constructed analytic models for DHCP procedures with and without pre-handoff for VANET. We also studied the performance effects caused by various parameters on the overall handoff time, such as pre-handoff distance, service rate of the DHCP server, and vehicle arrival rate. Our analysis results showed that DHCP procedures with pre-handoff obviously outperform that without pre-handoff. An important design factor regarding the pre-handoff design is the pre-handoff distance, which is a trade-off that must be determined. With our analytic models, the optimal pre-handoff distance and be easily determined. In addition, the performance impact caused by the change of other parameters can be easily predicted with the proposed models.

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