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Mobility support for vehicular networks based on vehicle trees

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ABSTRACT

The high speed of vehicles results in frequent mobility handovers which degrade communication quality, so it is significant to reduce the handover latency in a vehicular network. Taking this objective into account, this paper proposes a mobility handover scheme based on vehicle trees. In this scheme, a vehicle tree is made up of a few vehicles and performs the handovers as a unit. Consequently, the vehicles in a vehicle tree can be configured with a care-of address only through one addressing operation, and the address binding operations for these vehicles can be performed in parallel. Moreover, the vehicles in a vehicle tree can perform the link-layer handovers only via one channel scanning operation. The performance of the proposed scheme is evaluated, and the data results show that this scheme can greatly reduce the handover delay.

1. Introduction

Nowadays, it is important for us to enjoy various services via the Internet anytime and anywhere. Also, vehicles play an important role in our daily life because our daily transportation relies on these vehicles. Therefore, the demand for enjoying the Internet services in vehicles dramatically grows. A vehicular network is considered to be able to satisfy this demand, so it recently attracts more and more attention. A notable feature of a vehicular network is that it is made up of a large number of mobile nodes [1] whereas a significant advantage of the Internet Protocol version 6 (IPv6) is that it has rich address resources [2]. Therefore, connecting a vehicular network to the IPv6 Internet might be an ideal method of providing the Internet services to users in vehicles.

The high speed of vehicles in a vehicular network results in frequent mobility handovers which degrade communication quality [1]. Therefore, it is significant to reduce the handover latency in a vehicular network [3]. At present, various IP-based mobility support standards such as mobile IPv6 (MIPv6) [4] are proposed to guarantee communication continuity when a node moves between IP domains. However, most of these standards cannot work efficiently in a vehicular network due to considerable handover delay [5], so the mobility support issue for a vehicular network needs further research [1]. In the handover process, the care-of address (CoA) configuration in the network-layer (L3) handover and channel scanning in the link-layer (L2) handover are the most time-consuming, and they account for a large proportion of the total handover delay [6].

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This paper focuses on reducing the CoA configuration latency and channel scanning latency in order to lower the total handover delay. Based on this idea, this paper proposes the concept of a vehicle tree (VT) and the mobility handover scheme based on VTs, and it has the following contributions and advantages:

1) The architecture based on VTs is proposed. A VT is made up of vehicles and performs the handover as a unit.
2) In the L3 handover, the vehicles in a VT are configured with a CoA through one address configuration operation and the address binding operations for these vehicles are performed in parallel, so the average L3 handover delay is reduced.
3) The vehicles in a VT perform the L2 handover via one channel scanning operation, so the average L2 handover delay is lowered.

The remainder of the paper is organized as follows. In Section 2 the related work on the handover schemes is discussed, in Section 3 the architecture based on VTs is presented, in Section 4 the handover scheme is proposed, and in Sections 5 and 6 the performance of the proposed scheme is evaluated. In Section 7, the paper concludes with a summary.

2. Related work

When a node moves between IP domains, it needs to perform the L3 handover to ensure communication correctness. At present, various IP-based mobility standards such as MIPv6 [4] are proposed by the Internet engineering task force (IETF) to address the L3 handover issue. However, most of these standards cannot work efficiently in a vehicular network due to considerable handover delay [5], so the mobility support issue for a vehicular network needs further research [7]. Currently, some research works have been done to address this issue, and they improve the handover performance to various extents.

2.1. Handover schemes

Chiu K et al. [8] propose a vehicular fast handover scheme-VFHS. In VFHS, the physical layer information is shared with the link layer to reduce the handover delay. VFHS enables a vehicle to access the Internet through relay vehicles, but it does not discuss the IP mobility issue. Lee JH et al. [9] present a network mobility protocol based on PMIPv6 (proxy MIPv6)-P-NEMO to ensure communication continuity. In P-NEMO, a vehicle does not take part in the handover or location update management, so the packet loss caused by a vehicle's mobility is avoided. Virtual Bus [10] is a mobility pre-handover scheme. When a vehicle is going to perform the L3 handover, it first asks a neighbor vehicle to perform the CoA pre-configuration and pre-handover. As a result, the handover delay and packet loss are reduced.

Boukerche A et al. [11] apply clusters in vehicular networks so that a cluster head can be in charge of the mobility handover for other vehicles. Kim Mun-Suk et al. [12] propose an enhanced PFMIPv6 (ePFMIPv6) for a vehicular network. In ePFMIPv6, the serving mobile access gateway (MAG) in advance establishes the tunnels towards multiple candidate MAGs so that the messages can be forwarded to the next MAG during the handover process. In this way, the handover delay and packet loss are lowered, but the cost is increased. The network mobility (NEMO) standard [13] basically reduces the mobility handover because a mobile network performs a handover as a unit. In NEMO, each mobile router has a home network address. When a mobile router enters a new IP domain, it obtains a new CoA and registers the new CoA with its home agent. The mobile router provides connections to mobile nodes. A mobility handover scheme for vehicular ad hoc networks [14] is proposed and it uses the tunneling mechanism to achieve the mobility handover. During the handover process, a vehicle can receive data from its serving AP, so the packet loss is reduced. However, the tunneling increases the handover delay to some extent.

2.2. Our solution

The existing handover schemes for a vehicular network improve the handover performance to various extents. However, in these solutions, each vehicle independently performs the handover. That is, each vehicle independently performs the CoA configuration and channel scanning. Since the CoA configuration in the L3 handover and the channel scanning in the L2 handover are the most time-consuming and occupy a large proportion of the total handover delay [6], the performance improvement is limited.

The proposed scheme aims to reduce the CoA configuration latency and channel scanning latency for each vehicle in order to lower the total handover delay, and it has the following innovations:

1) A VT performs the handover as a unit.
2) The vehicles in a VT are configured with a CoA via one addressing operation.
3) The vehicles in a VT perform the L2 handover via one channel scanning operation,.

3. Architecture

3.1. Vehicle tree

In this scheme, a vehicular network is made up of access points (APs) and vehicles, and the lanes with the same direction between two APs form a tree domain (TD). An AP belongs to more than one TD. When a vehicle passes an AP to enter a new TD from the current TD, for the new TD this AP is called a starting AP and for the current TD it is referred to as an ending AP. A TD is uniquely identified by the starting AP. A starting AP may identify multiple TDs, and for each of these TDs it has a unique address. As shown in Fig. 1 which includes three APs AP1, AP2 and AP3, four lanes between AP1 and AP2 construct two TDs TD3 and TD4, and four lanes between AP1 and AP3 also form two TDs TD1 and TD2. For both TD1 and TD4, AP1 is a starting AP and has two unique IPv6 address, namely 3E01:3F89:1:1::1/64 in TD1 and 3E01:3F89:1:4::1/64 in TD4.

This scheme defines two kinds of vehicles:

New vehicle: a vehicle which is not configured with a home address (HoA).

Configured vehicle: a vehicle which is configured with an HoA.

In a TD, multiple configured vehicles form a tree structure which is called a vehicle tree (VT), and the vehicle at the head of a VT is called a root. A VT performs the handover as a unit. If a vehicle does not perform the handover, then it cannot join a VT which is performing the handover. In this case, the vehicle may become the root and construct a VT. As shown in Fig. 1, there are two VTs in TD1. The first VT is made up of configured vehicles V1, V2 and V3, and V1 is the root. Since the first VT is performing the handover, vehicle V4 which does not perform the handover becomes the root and constructs the second VT which is composed of vehicles V4, V5 and V6.

3.2. Address structure

Based on the proposed architecture, the address structure is proposed, as shown in Table 1.

In Table 1, an address is made up of two parts. The first part is the m-bit TD ID which is a global routing prefix and uniquely identifies a TD. The TD IDs of all the CoAs acquired in one TD are the same, and the value is equal to the one of the staring AP in the same TD. The second part is the vehicle ID which uniquely identifies a vehicle in one TD. The address of an AP is preset, and the vehicle ID is 1, as shown in Fig. 1. In Table 1, the vehicle ID space of an AP is $[2,2^{128-m}-2]$ and is divided into two parts. Vehicle ID space $[2, 2^{127-m}-1]$ is used for HoA configuration and is called the home vehicle ID space, and vehicle ID space $[2^{127-m},2^{128-m}-2]$ is used for CoA configuration and called the care-of vehicle ID space.

If the TD ID of an AP's address is the same as the one of a vehicle's HoA, then the AP is called the vehicle's home AP. The TD identified by a vehicle's home AP is called the vehicle's home TD. The TD where a vehicle acquires a CoA is called the vehicle's foreign TD, and the starting AP in the foreign TD is called the vehicle's foreign AP. When a configured vehicle is located in the home TD, its CoA is equal to its HoA.

3.3. Link connection delay

An AP or a vehicle regularly broadcasts a *BasicSafetyMessage* within one-hop scope [15,16], and the payload includes its HoA, geographic coordinates, speed, mobile angle, upper limit and lower limit of the home vehicle ID space, handover flag, and root flag. If a vehicle's handover flag is equal to 1, it means that the VT the vehicle belongs to is performing the handover operation. Otherwise, it means that the VT does not perform the handover. When a vehicle's root flag is equal to 1, it means that the vehicle is the root of a VT. Otherwise, the vehicle is not the root of a VT.

This scheme adopts the link connection delay to establish a VT. It is assumed that vehicles V_i and V_j are neighbors, their geographic coordinates are (x_i, y_i) and (x_j, y_j) respectively, their speeds are v_i and v_j receptively, their mobile angles are θ_i and θ_j ($0 \le \theta_i, \theta_j < 2\pi$) respectively, and the transmission radius is r. Then, formula (1) can be used to estimate