IPv6 Neighbor Discovery for Prefix and Service Discovery in Vehicular Networks

Junsik Jeong*, Yiwen (Chris) Shen†, Younghwa Jo*, and Jaehoon (Paul) Jeong§
* Department of DMC Engineering, Sungkyunkwan University, Republic of Korea
† Department of Computer Science & Engineering, Sungkyunkwan University, Republic of Korea
‡ Department of Software Platform, Sungkyunkwan University, Republic of Korea
§ Department of Interaction Science, Sungkyunkwan University, Republic of Korea
Email: {jjs9915, chrisshen, jyh1127, pauljeong}@skku.edu

***Abstract*—This paper proposes an extension of IPv6 neighbor discovery (ND) for rapid network prefix and service discovery in vehicular networks. It is assumed that a vehicle as a moving network (MN) or a road-side unit (RSU) as a fixed network (FN) has an external network interface, and hosts in an MN periodically announce their services to their local DNS Server called recursive DNS server (RDNSS) of the MN. We define new options for prefix and service discovery in IPv6 ND through which an MN or an FN can fast exchange prefix and service information by sending the neighbor solicitation (NS) and neighbor advertisement (NA) messages containing a sender's prefix and service information. Through theoretical analysis comparing our proposed method with conventional methods separating prefix discovery and service discovery, our approach can reduce the delay of the prefix and service discovery to provide better intelligent transportation services (e.g., cooperative adaptive cruise control for collision avoidance) in vehicular environment.**

I. Introduction

As one of the most active research areas these days, the advanced vehicular ad hoc networks (VANETs) [1]–[5] describe an emerging environment where vehicles as moving networks (MNs) with multiple in-vehicle devices or hosts are inter-connected and also various services in a vehicle interact with other services located not only inside but also outside the vehicle. Prefix discovery [6] and service discovery [7] are the two most important aspects for packet exchanging. Prefix discovery is a process through which a host discovers all the set of the address prefixes in networks for fast packet exchanging. Service discovery is for a service querier (e.g., a host) to discover a service installed in another host. A rapid prefix and service discovery between vehicles is desirable for the rapid mobility changing in a vehicular environment.

The current prefix discovery defined in IPv6 neighbor discovery (ND) [6] and service discovery defined in DNS-based service discovery [7] using mDNS [8] are performed in separate processes. For a vehicular environment with a rapid mobility changing, the separated processes may substantially delay the service interaction among hosts located in different vehicles. As a new VANET scenario has been emerging, few studies have been conducted to find a new mechanism for the prefix and service discovery in such an environment.

Moreover, the logic of the conventional service discovery [7] using mDNS [8] is that a service querier initiates a service query and a responder responds to the query. The process of the conventional service discovery letting an individual host discover a service may take a long time. However, for vehicular environments, MNs may have some common services for safety driving (e.g., Cooperative Adaptive Cruise Control, Cooperative Dash Camera Sharing) and need to immediately know the service profiles (e.g., IP address and port number) due to the rapid mobility. It is reasonable and necessary to switch the demand-based service discovery to active service discovery. MNs should be able to communicate with each other once they are within their communication range.

On the other hand, to enable the VANET in road networks, the dedicated short-range communications (DSRC) [9] has been standardized as IEEE 802.11p [10] (now incorporated into IEEE 802.11-2012 [11]), which is an extension of IEEE 802.11a [11], considering the characteristics of vehicular networks, such as high-speed mobility and network fragmentation. For wireless access in vehicular environments (WAVE), the IEEE has standardized IEEE 1609 family standards, such as IEEE 1609.3 and 1609.4 [9]. The IEEE 1609 standards specify IPv6 as the network-layer protocol. With this trend, it is time to enable vehicular networking with IPv6 to let various Internet-based applications run on top of transport-layer protocols, such as TCP, UDP, and SCTP. IPv6 [12] is suitable for a network layer in vehicular networks in that the protocol has abundant address space, autoconfiguration features, and protocol extension ability through extension headers.

To support the interaction between vehicles or between a vehicle and an RSU, this paper proposes an extension of IPv6 ND [6] for rapid network prefix and service discovery in vehicular networks with new ND options. Note that the preliminary idea of the paper was published in our IETF Internet draft [13]. The main contributions of this paper are as follows:

- Interaction scenarios of the prefix exchange and service discovery among moving networks and fixed networks.
- An enhanced neighbor discovery process for vehicular networks.
- New options for prefix and service discovery in IPv6 ND.

The remaining part of this paper is composed as follows: Section II summarizes the related work. Section III describes the design of our new IPv6 neighbor discovery for prefix and service discovery in vehicular networks. Section IV explains ND extension for prefix and service discovery protocol. Sec-

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tion V analyzes the delay of prefix and service discovery. In Section VI, we conclude this paper along with future work.

II. Related Work

VANETs have been extensively studied for the past decade. A vehicle in VANETs is expected to become a moving network containing hosts, moving servers, and routers. As the related standards [14] and protocols [10], [15], which specify the physical and the medium access control (MAC) layer, are built, the above layers such as the internet layer and the transport layer have been drawn many attentions. In the recent conferences of the Internet Engineering Task Force (IETF), several Internet drafts considering network services in VANET have been proposed. Jeong et al. [16] survey the work for the IP-based vehicular networks dealing with IP address autoconfiguration, architecture, routing, and mobility management. Petrescu et al. [17] describes two use-cases requiring IP, such as cooperative adaptive cruise control and platooning, and the possible problems based on the current IPv6.

RFC 4861 [6] specifies the detailed operations in the neighbor discovery of IPv6 (IPv6 ND) to determine a host's link-layer address, purge cached values, find neighboring routers, track reachable neighbors, detect changes in link-layer addresses. Using IPv6 ND, a router multicasts the neighbor solicitation (NS) message, and receives the neighbor advertisement (NA) message from its neighbors to determine the link-layer address of a neighbor based on its IP address [6]; a host multicasts router solicitation (RS) message, and receives router advertisement (RA) message from neighboring routers to discover prefixes residing on-link [6]. To detect off-link neighbors, the neighbor unreachability detection (NUD) is performed by two ways: hints from upper-layer, or receipt of an NA message [6]. In the highly dynamic topology of vehicular environments, the NUD may require a lot of traffic and increase delay, which contradicts to the low latency requirement for driving safety applications.

To study the performance of IP in WAVE, Céspedes et al. propose a vehicular IP in WAVE (VIP-WAVE) framework [18] to explore the feasibility and the performance of IP in the IEEE WAVE standard. VIP-WAVE defines the IP configuration for vehicle-to-infrastructure IP services, including the assignment, maintenance, and duplicate detection of IPv6 global addresses [18]. VIP-WAVE also designs a mobility management scheme based on Proxy Mobile IPv6 [18], which supports seamless infrastructure-based communications based on on-demand neighbor discovery. Moreover, it designs a relay detection and routing mechanism to deliver IP packet. However, the on-demand neighbor discovery may be inappropriate for the high mobility in the vehicular environments, since it requires several rounds message exchange before the actual data transmission.

To forward IP packets to their destinations, many routing protocols are proposed. The dynamic destination-sequenced distance-vector (DSDV) routing protocol [19] suggests a table-driven routing scheme for mobile ad hoc networks (MANET). DSDV combines distance-vector routing algorithm, such as Bellman-Ford algorithm [19], and a destination sequence

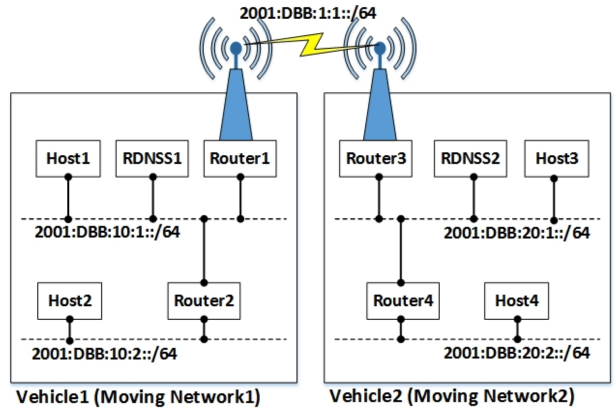


Fig. 1. Internetworking between Moving Networks

mechanism to solve the routing loops and counting-to-infinity problem. By DSDV, a mobile host periodically advertises its routing table to its neighboring hosts. The routing table includes a sequence number for each destination. Only when receiving a routing table with an entry having a new sequence number, a host updates the corresponding routing entry in its own routing table.

For service discovery, a domain name system based service discovery (DNS-SD) mechanism [7] is proposed to facilitate the service discovery. The DNS-SD specifies rules to name service records that are compatible with conventional DNS service records (SRV) and DNS TXT [7]. With looking up a type of service and a domain of the service, a client can discover a list of instances of the service by standard DNS queries. In a scenario without a conventional managed DNS server, multicast DNS (mDNS) protocol [8] is proposed to perform DNS-like operations for finding available services. The mDNS defines a series of mechanism in which clients send DNS-like queries by IP multicast, and responders reply those queries. The mDNS is an on-demand service discovery started by a client, but in the vehicular environments, the process of the query and response in mDNS may not be suitable for many safety services requiring rapid access without an intervene by a client.

To improve prefix discovery and service discovery, a proactive mechanism to quickly obtain prefix information and available services among vehicles is necessary. We propose a new IPv6 ND extension to combine prefix discovery and service discovery in vehicular networks. It is expected that the proposed method can reduce the latency of prefix discovery and service discovery.

III. Proposed IPv6 Neighbor Discovery for Prefix and Service Discovery

In this section, we propose an IPv6 ND extension for vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) networking. Fig. 1 shows the V2V networking of two vehicles whose internal networks are Moving Network1 and Moving Network2, respectively. Vehicle1 has the DNS Server (RDNSS1), the two hosts (Host1 and Host2), and the two routers (Router1 and Router2). Vehicle2 has the DNS Server

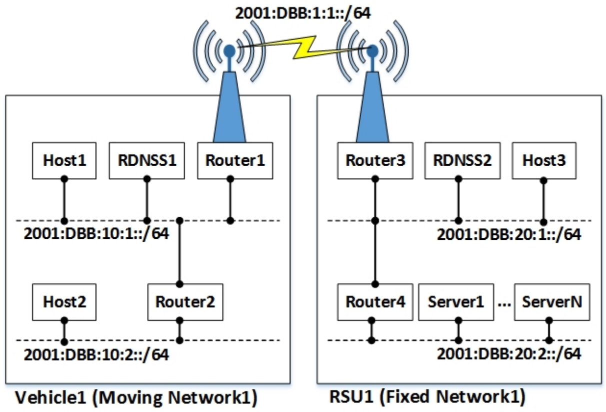
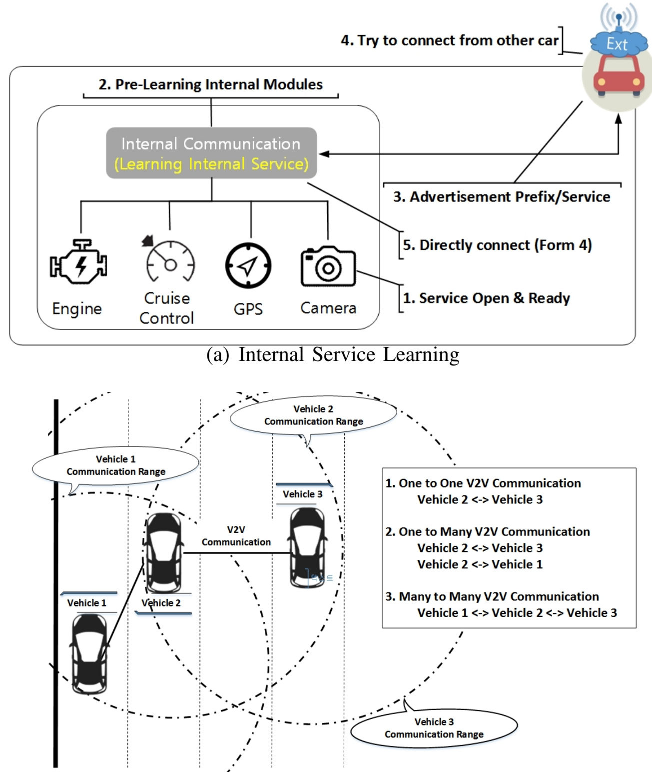


Fig. 2. Internetworking between Moving Network and Fixed Network

(RDNSS2), the two hosts (Host3 and Host4), and the two routers (Router3 and Router4). It is assumed that Host1 and Host3 are running a Cooperative Adaptive Cruise Control (C-ACC) program for physical collision avoidance. Also, it is assumed that Host2 and Host4 are running a Cooperative Dash Camera Sharing (C-DCS) program for sharing road hazards or obstacles to avoid road accidents. Vehicle1's Router1 and Vehicle2's Router3 use 2001:DB8:1:1::/64 for an external link (e.g., DSRC) for V2V networking for various vehicular services. The vehicular applications, such as C-ACC and C-DCS, can be registered into the DNS Server (i.e., RDNSS) through DNSNA protocol in [20] along with IPv6 ND DNS options in [21]. Vehicle1's Router1 and Vehicle2's Router3 can know what vehicular applications exist in their internal network by referring to their own RDNSS through the DNSNA protocol [20]. They can also know what network prefixes exist in their internal network through an intra-domain routing protocol, such as OSFP [22]. Each vehicle announces its network prefixes and services through ND options defined in below.

Fig. 2 shows the V2I networking of a vehicle and an RSU whose internal networks are Moving Network1 and Fixed Network1, respectively. Vehicle1 has the DNS Server (RDNSS1), the two hosts (Host1 and Host2), and the two routers (Router1 and Router2). RSU1 has the DNS Server (RDNSS2), one host (Host3), the two routers (Router3 and Router4). It is assumed that RSU1 has a collection of servers (Server1 to ServerN) for various services in the road networks, such as road emergency notification and navigation services. Vehicle1's Router1 and RSU1's Router3 use 2001:DB8:1:1::/64 for an external link (e.g., DSRC) for I2V networking for various vehicular services. The vehicular applications, such as road emergency notification and navigation services, can be registered into the DNS Server (i.e., RDNSS) through DNSNA protocol in [20] along with IPv6 ND DNS options in [21]. Vehicle1's Router1 and RSU1's Router3 can know what vehicular applications exist in their internal network by referring to their own RDNSS through the DNSNA protocol [20]. They can also know what network prefixes exist in their internal network through an intra-domain routing protocol, such as OSFP [22]. Each vehicle and each



(a) Internal Service Learning

(b) V2V Communication

Fig. 3. Scenarios in Vehicular Communications

RSU announce their network prefixes and services through ND options defined in below.

A. Scenarios in Vehicular Communications

Fig. 3 shows the scenarios in vehicular communications. We consider three scenarios as follows:

1) One to One Communication: We consider the scenario of one-to-one communication between vehicles. Before a sender vehicle (called Sender) communicates with a receiver vehicle (called Receiver), Sender collects a service catalog having a list of services existing in its internal network, and then lets its external module with external interfaces (i.e., DSRC and 3G/4G-LTE) advertise its available services. When Receiver comes close to Sender for wireless communication, Receiver broadcasts its an IPv6 Neighbor Solicitation (NS) message that asks for services provided by its neighboring vehicles as Senders. When a vehicle receives an NS, it generates an IPv6 Neighbor Advertisement (NA) message, which has service information, such as IPv6 address, Protocol, and Port number, in order to notify the NS sender of its services.

2) One to Many Communication: We consider the scenario of one-to-many communication among vehicles. One-to-many communication runs in the similar way with the one-to-one case. One difference between them is that one-to-many communication allows one vehicles transmitted packet to be forwarded to its neighboring vehicles in a fashion of multicasting. We need to consider a maximum service connection number and a logic to broadcast service information efficiently and exchange data for services within a connected VANET.

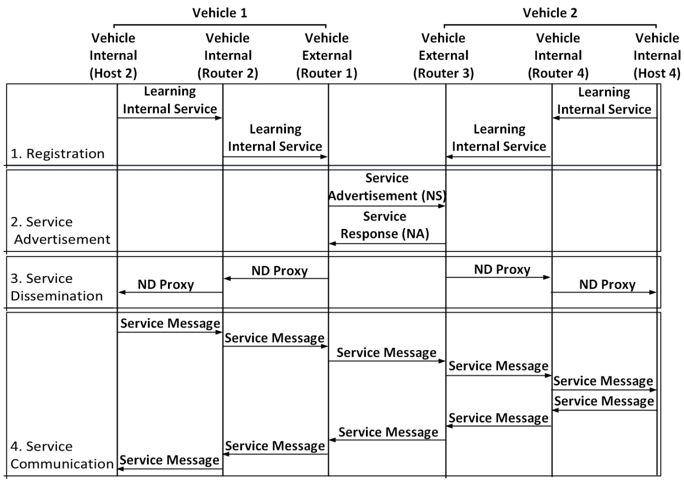


Fig. 4. Procedure of Service Discovery for Vehicular Networking

3) Many to Many Communication: Many-to-many communication can be regarded as multiple instances of one-to-many communication. That is, each vehicle among vehicles in a connected VANET can broadcast its service information by taking a turn.

B. Procedure of Service Discovery for Vehicular Networking

The service discovery for vehicular networking among vehicles consists of three phases, such as (i) registration phase for service discovery (using DNSNA), (ii) service advertisement of vehicles, and (iii) service dissemination toward in-vehicle modules. Fig. 4 shows the procedure of service discovery for vehicular networking.

1) Registration Phase for Service Discovery: Vehicles exchange their prefix information for communication with each other when they come close enough to send NS packets. To deliver prefix information, the external module of a vehicle needs to learn the information of internal modules and check the status of each internal module periodically. Receiver obtains the information of Sender's prefix information including its internal modules in an NS packet, and then Sender obtains the information of Receiver's prefix information including its internal modules in an NA packet. This extension of IPv6 Neighbor Discovery (ND) can reduce the delay to set up the communication between two vehicles without using additional discovery protocol.

2) Service Advertisement of Vehicles: Based on received prefix information, Receiver sends an NA packet that contains its available service information. This information contains a service module's IPv6 address, service protocol (e.g., TCP and UDP), and service port. When this information matches Sender's active service, the Sender and Receiver can immediately communicate with each other through such a common service.

3) Service Dissemination toward In-Vehicle Modules: To disseminate the services advertised by other vehicles toward in-vehicle modules in a vehicle, an external module with an external wireless communication device needs to play a role of ND Proxy to toss NS packets to its internal network. This ND Proxy can allow vehicles to perform rapider discovery and exchange of prefixes and services than the existing SDP protocol.

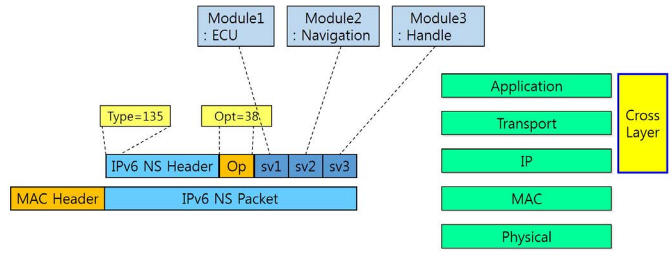


Fig. 5. Extension of IPv6 ND Protocol for Rapid Service Discovery

TABLE I
VEHICULAR PREFIX INFORMATION OPTION FIELDS

Field	Description
Type	8-bit identifier of the VSI option type as assigned by the IANA: TBD
Length	8-bit unsigned integer. The length of the option (including the Type and Length fields) is in units of 8 octets. The value is 3.
Prefix Length	8-bit unsigned integer.The number of leading bits in the Prefix that are valid. The value ranges from 0 to 128.
Distance	8-bit unsigned integer.The distance between the subnet announcing this prefix and the subnet corresponding to this prefix in terms of the number of hops.
Reserved	This field is unused. It MUST be initialized to zero by the sender and MUST be ignored by the receiver.
Prefix	A 128-bit IPv6 address or a prefix of an IPv6 address. The Prefix Length field contains the number of valid leading bits in the prefix. The bits in the prefix after the prefix length are reserved and MUST be initialized to zero by the sender and ignored by the receiver.

IV. ND EXTENSION FOR PREFIX AND SERVICE DISCOVERY

In this section, we propose the prefix exchange and service discovery protocol in IPv6 NS/NA.

This section defines two new ND options for prefix and service discovery: (i) the Vehicular Prefix Information (VPI) option and (ii) the Vehicular Service Information (VSI) option. It also describes the ND protocol for such prefix and service discovery. Fig. 5 shows the extension of IPv6 ND Protocol for Rapid Service Discovery.

A. Vehicular Prefix Information Option

The VPI option contains one IPv6 prefix in the internal network. Fig. 6 shows the format of the VPI option. The description of the fields in Fig. 6 is shown in Table I.

B. Vehicular Service Information Option

The VSI option contains one vehicular service in the internal network. Fig. 7 shows the format of the VSI option. The description of the fields in Fig. 7 is shown in Table II.

C. Vehicular Neighbor Discovery

With VPI and VSI options, a node (e.g., vehicle or RSU) can announce the network prefixes and services in its internal

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |    Length     | Prefix Length |   Distance    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           Reserved                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
:                            Prefix                             :
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Fig. 6. Vehicular Prefix Information (VPI) Option Format

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |    Length     |           Reserved1           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Protocol    |   Reserved2   |          Port Number          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
:                        Service Address                        :
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Fig. 7. Vehicular Service Information (VSI) Option Format

network via ND messages, such as Neighbor Solicitation (NS) and Neighbor Advertisement (NA) [6].

A node periodically announces an NS message containing the VPI and VSI options with its prefixes and services in all-nodes multicast address to reach all neighboring nodes. When another neighboring node receives this NS message, it responds to this NS message by sending an NA message containing the VPI and VSI options with its prefixes and services via unicast toward the NS-originating node.

Through this procedure, vehicles and RSUs can rapidly discover the network prefixes and services of the other party without any additional service discovery protocol.

V. Delay Analysis for Prefix and Service Discovery

In this section, we analyze the delay of the prefix and service discovery based on our new IPv6 ND extension in comparison with the delay of the prefix discovery using a routing protocol (e.g., DSDV [19], RIP [23], or OSPF [22]) and the service discovery using mDNS [8] in vehicular environments. We

TABLE II
Vehicular Service Information Option Fields

Field	Description
Type	8-bit identifier of the VSI option type as assigned by the IANA: TBD
Length	8-bit unsigned integer. The length of the option (including the Type and Length fields) is in units of 8 octets. The value is 3.
Reserved1	This field is unused. It MUST be initialized to zero by the sender and MUST be ignored by the receiver.
Protocol	8-bit unsigned integer to indicate the upper-layer protocol, such as transport-layer protocol(e.g., TCP, UDP, and SCTP).
Reserved2	This field is unused. It MUST be initialized to zero by the sender and MUST be ignored by the receiver.
Port Number	16-bit unsigned integer to indicate the port number for the protocol.
Service Address	128-bit IPv6 address of a vehicular service.

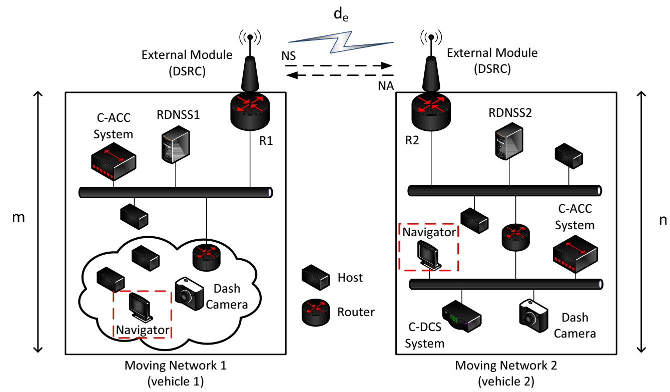


Fig. 8. Delay Analysis for Prefix and Service Discovery

consider a scenario that two moving networks (MN) (i.e., two vehicles) communicate with each other to exchange driving safety information as shown in Fig. 8. The parameters for delay analysis are listed in Table III.

TABLE III
The Parameters for Delay Analysis

Parameter	Description
D_n	The delay of prefix and service discovery with the proposed IPv6 ND
D_o	The delay of prefix and service discovery with a routing algorithm and mDNS
D_{sd}	The delay of service discovery with mDNS
D_{pd}	The delay of prefix discovery with a routing algorithm
h_1	Hop count between a service querier (a host) and an external interface (a router) in MN1
h_2	Hop count between an external interface (a router) and a service querier (a host) in MN2
d_e	The E2E delay of MN1 and MN2
α	One-way link delay of one hop

We assume that the depths (i.e., hop counts) of MN1 and MN2 are m and n, respectively, as shwon in Fig. 8. The delay of the prefix discovery with the worst case for the conventional way (the exchange of RS and RA) can be described as:

$$D_{pd} = \max(O(m), O(n)). \quad (1)$$

For the service discovery using mDNS in Fig. 8, we assume that the two MNs belong to a local domain, i.e., all services' names should be ended in ".local." (i.e., link-local). Also, one-way link delay of one hop inside an MN in a vehicle is α, and the End-to-End (E2E) delay between the external interfaces of the two MNs is d_e. To calculate the delay of a service discovery, we consider a scenario that a host's program (e.g., navigator) in MN1 needs to communicate with another host's program (e.g., navigator) in MN2 for an intelligent transportation service (e.g., cooperative navigation service) as shown in Fig. 8. The hop count from a host (a service querier) to the external module in MN1 is h_1, and the hop count from the external module to another host (a service querier) in MN2 is h_2. The service discovery of each host is executed sequentially, and then the delay for discovering all services using mDNS can be obtained by:

$$D_{sd} = (2\alpha \cdot (h_1 + h_2) + 2d_e) \cdot e. \quad (2)$$

where e is the number of host in MN1.

Conventionally, the prefix discovery and the service discovery are done separately, therefore, the total delay can be approximated as:

$$D_o = \max(O(m), O(n)) + (2\alpha \cdot (h_1 + h_2) + 2d_e) \cdot e. \quad (3)$$

Our proposed method combines the two discovery processes together into extended IPv6 ND to reduce the delay for vehicular environments. As shown in Fig. 8, a host installed in MN1 may register its services into the RDNSS1 by using DNSNA protocol [20], and R1 may obtain the prefix information and the registered services from the DNS zone file managed by RDNSS1. As shown in Fig. 8, R1 sends an NS message to the external module (R2) of MN2 when MN2 moves into MN1's communication range. R2 replies to the NS message by sending a NA message containing prefix information and registered services in MN2. Then, both R1 and R2 as ND Proxies disseminate the received prefix information and service information to the other nodes in their MN. The total delay of prefix and service discovery in our proposed method can be computed as follows:

$$D_n = \alpha \cdot \max(h_1, h_2) + d_e. \quad (4)$$

Clearly, D_n is much smaller than D_o by combining the prefix discovery and service discovery into the extended IPv6 ND in a proactive fashion.

VI. Conclusion

In this paper, we propose an new method for prefix and service discovery in vehicular networks. We define new options for prefix and service discovery in IPv6 ND through which an MN or an FN can fast exchange prefix and service information by sending the Neighbor Solicitation (NS) and Neighbor Advertisement (NA) messages containing a sender's prefix and service information. Through theoretical analysis comparing with conventional methods separating prefix discovery and service discovery, our approach can reduce the delay of the prefix and service discovery to provide better intelligent transportation services (e.g., cooperative adaptive cruise control for collision avoidance) in vehicular environment. For the security issues of the neighbor discovery protocol, this paper can take benefits from the secure neighbor discovery (SEND) [24], which can be used in our proposed method in order to protect ND from possible security attacks. As future work, we will implement the proposed protocol, and consider the exchange of security information for trustworthy communications among vehicles.

VII. Acknowledgments

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