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IPv6 Wireless Access in Vehicular Environments (IPWAVE): Problem Statement and Use Cases
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Abstract

This document discusses the problem statement and use cases of IPv6-based vehicular networking for Intelligent Transportation Systems (ITS). The main scenarios of vehicular communications are vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) communications. First, this document explains use cases using V2V, V2I, and V2X networking. Next, for IPv6-based vehicular networks, it makes a gap analysis of current IPv6 protocols (e.g., IPv6 Neighbor Discovery, Mobility Management, and Security & Privacy), and then lists up requirements for the extensions of those IPv6 protocols for IPv6-based vehicular networking.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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1. Introduction

Vehicular networking studies have mainly focused on improving safety and efficiency, and also enabling entertainment in vehicular networks. The Federal Communications Commission (FCC) in the US allocated wireless channels for Dedicated Short-Range Communications (DSRC) [DSRC] in the Intelligent Transportation Systems (ITS) with the frequency band of 5.850 - 5.925 GHz (i.e., 5.9 GHz band). DSRC-based wireless communications can support vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) networking. The European Union (EU) allocated radio spectrum for safety-related and non-safety-related applications of ITS with the frequency band of 5.875 - 5.905 GHz, as part of the Commission Decision 2008/671/EC [EU-2008-671-EC].

For direct inter-vehicular wireless connectivity, IEEE has amended standard 802.11 (commonly known as Wi-Fi) to enable safe driving services based on DSRC for the Wireless Access in Vehicular Environments (WAVE) system. The Physical Layer (L1) and Data Link Layer (L2) issues are addressed in IEEE 802.11p [IEEE-802.11p] for the PHY and MAC of the DSRC, while IEEE 1609.2 [WAVE-1609.2] covers security aspects, IEEE 1609.3 [WAVE-1609.3] defines related services at network and transport layers, and IEEE 1609.4 [WAVE-1609.4] specifies the multi-channel operation. IEEE 802.11p was first a separate amendment, but was later rolled into the base 802.11 standard (IEEE 802.11-2012) as IEEE 802.11 Outside the Context of a Basic Service Set (OCB) in 2012 [IEEE-802.11-OCB].

3GPP has standardized Cellular Vehicle-to-Everything (C-V2X) communications to support V2X in LTE mobile networks (called LTE V2X) and V2X in 5G mobile networks (called 5G V2X) [TS-23.285-3GPP] [TR-22.886-3GPP][TS-23.287-3GPP]. With C-V2X, vehicles can directly communicate with each other without relay nodes (e.g., eNodeB in LTE and gNodeB in 5G).

Along with these WAVE standards and C-V2X standards, regardless of a wireless access technology under the IP stack of a vehicle, vehicular networks can operate IP mobility with IPv6 [RFC8200] and Mobile IPv6 protocols (e.g., Mobile IPv6 (MIPv6) [RFC6275], Proxy MIPv6 (PMIPv6) [RFC5213], Distributed Mobility Management (DMM) [RFC7333], Locator/ ID Separation Protocol (LISP) [RFC6830BIS], and Asymmetric Extended Route Optimization (AERO) [RFC6706BIS]). In addition, ISO has approved a standard specifying the IPv6 network protocols and services to be used for Communications Access for Land Mobiles (CALM) [ISO-ITS-IPv6] [ISO-ITS-IPv6-AMD1].

This document describes use cases and a problem statement about IPv6-based vehicular networking for ITS, which is named IPv6 Wireless Access in Vehicular Environments (IPWAVE). First, it introduces the use cases for using V2V, V2I, and V2X networking in ITS. Next, for IPv6-based vehicular networks, it makes a gap analysis of current IPv6 protocols (e.g., IPv6 Neighbor Discovery, Mobility Management, and Security & Privacy), and then lists up requirements for the extensions of those IPv6 protocols, which are tailored to IPv6-based vehicular networking. Thus, this document is intended to motivate development of key protocols for IPWAVE.

2. Terminology

This document uses the terminology described in [RFC8691]. In addition, the following terms are defined below:

- Class-Based Safety Plan: A vehicle can make a safety plan by classifying the surrounding vehicles into different groups for safety purposes according to the geometrical relationship among them. The vehicle groups can be classified as Line-of-Sight Unsafe, Non-Line-of-Sight Unsafe, and Safe groups [CASD].

- Context-Awareness: A vehicle can be aware of spatial-temporal mobility information (e.g., position, speed, direction, and acceleration/deceleration) of surrounding vehicles for both safety and non-safety uses through sensing or communication [CASD].

- DMM: "Distributed Mobility Management" [RFC7333][RFC7429].

- Edge Computing (EC): It is the local computing near an access network (i.e., edge network) for the sake of vehicles and pedestrians.

- Edge Computing Device (ECD): It is a computing device (or server) for edge computing for the sake of vehicles and pedestrians.

- Edge Network (EN): It is an access network that has an IP-RSU for wireless communication with other vehicles having an IP-OBU and wired communication with other network devices (e.g., routers, IP-RSUs, ECDs, servers, and MA). It may have a Global Positioning System (GPS) radio receiver for its position recognition and the localization service for the sake of vehicles.

- IP-OBU: "Internet Protocol On-Board Unit": An IP-OBU denotes a computer situated in a vehicle (e.g., car, bicycle, autobike, motor cycle, and a similar one) and a device (e.g., smartphone and IoT device). It has at least one IP interface that runs in IEEE 802.11-OCB and has an "OBU" transceiver. Also, it may have an IP interface that runs in Cellular V2X (C-V2X) [TS-23.285-3GPP] [TR-22.886-3GPP][TS-23.287-3GPP]. See the definition of the term "OBU" in [RFC8691].

- IP-RSU: "IP Roadside Unit": An IP-RSU is situated along the road. It has at least two distinct IP-enabled interfaces. The wireless PHY/MAC layer of at least one of its IP-enabled interfaces is configured to operate in 802.11-OCB mode. An IP-RSU communicates with the IP-OBU over an 802.11 wireless link operating in OCB mode. Also, it may have an IP interface that runs in C-V2X along with an "RSU" transceiver. An IP-RSU is similar to an Access Network Router (ANR), defined in [RFC3753], and a Wireless Termination Point (WTP), defined in [RFC5415]. See the definition of the term "RSU" in [RFC8691].

- LiDAR: "Light Detection and Ranging". It is a scanning device to measure a distance to an object by emitting pulsed laser light and measuring the reflected pulsed light.

- Mobility Anchor (MA): A node that maintains IPv6 addresses and mobility information of vehicles in a road network to support their IPv6 address autoconfiguration and mobility management with a binding table. An MA has End-to-End (E2E) connections (e.g., tunnels) with IP-RSUs under its control for the address autoconfiguration and mobility management of the vehicles. This MA is similar to a Local Mobility Anchor (LMA) in PMIPv6 [RFC5213] for network-based mobility management.

- OCB: "Outside the Context of a Basic Service Set - BSS". It is a mode of operation in which a Station (STA) is not a member of a BSS and does not utilize IEEE Std 802.11 authentication, association, or data confidentiality [IEEE-802.11-OCB].

- 802.11-OCB: It refers to the mode specified in IEEE Std 802.11-2016 [IEEE-802.11-OCB] when the MIB attribute dot11OCBActivited is ’true’.

- Platooning: Moving vehicles can be grouped together to reduce air-resistance for energy efficiency and reduce the number of drivers such that only the leading vehicle has a driver, and the other vehicles are autonomous vehicles without a driver and closely follow the leading vehicle [Truck-Platooning].

- Traffic Control Center (TCC): A system that manages road infrastructure nodes (e.g., IP-RSUs, MAs, traffic signals, and loop detectors), and also maintains vehicular traffic statistics (e.g., average vehicle speed and vehicle inter-arrival time per road segment) and vehicle information (e.g., a vehicle’s identifier, position, direction, speed, and trajectory as a navigation path). TCC is part of a vehicular cloud for vehicular networks.

- Vehicle: A Vehicle in this document is a node that has an IP-OBU for wireless communication with other vehicles and IP-RSUs. It has a GPS radio navigation receiver for efficient navigation. Any device having an IP-OBU and a GPS receiver (e.g., smartphone and table PC) can be regarded as a vehicle in this document.

- Vehicular Ad Hoc Network (VANET): A network that consists of vehicles interconnected by wireless communication. Two vehicles in a VANET can communicate with each other using other vehicles as relays even where they are out of one-hop wireless communication range.

- Vehicular Cloud: A cloud infrastructure for vehicular networks, having compute nodes, storage nodes, and network forwarding elements (e.g., switch and router).

- V2D: "Vehicle to Device". It is the wireless communication between a vehicle and a device (e.g., smartphone and IoT device).

- V2I2D: "Vehicle to Infrastructure to Device". It is the wireless communication between a vehicle and a device (e.g., smartphone and IoT device) via an infrastructure node (e.g., IP-RSU).

- V2I2V: "Vehicle to Infrastructure to Vehicle". It is the wireless communication between a vehicle and another vehicle via an infrastructure node (e.g., IP-RSU).

- V2I2X: "Vehicle to Infrastructure to Everything". It is the wireless communication between a vehicle and another entity (e.g., vehicle, smartphone, and IoT device) via an infrastructure node (e.g., IP-RSU).

- V2X: "Vehicle to Everything". It is the wireless communication between a vehicle and any entity (e.g., vehicle, infrastructure node, smartphone, and IoT device), including V2V, V2I, and V2D.

- VIP: "Vehicular Internet Protocol". It is an IPv6 extension for vehicular networks including V2V, V2I, and V2X.

- VMM: "Vehicular Mobility Management". It is an IPv6-based mobility management for vehicular networks.

- VND: "Vehicular Neighbor Discovery". It is an IPv6 ND extension for vehicular networks.

- VSP: "Vehicular Security and Privacy". It is an IPv6-based security and privacy for vehicular networks.

- WAVE: "Wireless Access in Vehicular Environments" [WAVE-1609.0].

3. Use Cases

This section explains use cases of V2V, V2I, and V2X networking. The use cases of the V2X networking exclude the ones of the V2V and V2I networking, but include Vehicle-to-Pedestrian (V2P) and Vehicle-to-Device (V2D).

IP is widely used among popular end-user devices (e.g., smartphone and tablet) in the Internet. Applications (e.g., navigator application) for those devices can be extended such that the V2V use

cases in this section can work with IPv6 as a network layer protocol and IEEE 802.11-OCB as a link layer protocol. In addition, IPv6 security needs to be extended to support those V2V use cases in a safe, secure, privacy-preserving way.

The use cases presented in this section serve as the description and motivation for the need to extend IPv6 and its protocols to facilitate "Vehicular IPv6". Section 5 summarizes the overall problem statement and IPv6 requirements. Note that the adjective "Vehicular" in this document is used to represent extensions of existing protocols such as IPv6 Neighbor Discovery, IPv6 Mobility Management (e.g., PMIPv6 [RFC5213] and DMM [RFC7429]), and IPv6 Security and Privacy Mechanisms rather than new "vehicular-specific" functions. Refer to Section 5 for the problem statement of the requirements of vehicular IPv6.

3.1. V2V

The use cases of V2V networking discussed in this section include

- Context-aware navigation for safe driving and collision avoidance;
- Cooperative adaptive cruise control in a roadway;
- Platooning in a highway;
- Cooperative environment sensing.

These four techniques will be important elements for self-driving vehicles.

Context-Aware Safety Driving (CASD) navigator [CASD] can help drivers to drive safely by alerting them to dangerous obstacles and situations. That is, a CASD navigator displays obstacles or neighboring vehicles relevant to possible collisions in real-time through V2V networking. CASD provides vehicles with a class-based automatic safety action plan, which considers three situations, namely, the Line-of-Sight unsafe, Non-Line-of-Sight unsafe, and safe situations. This action plan can be put into action among multiple vehicles using V2V networking.

Cooperative Adaptive Cruise Control (CACC) [CA-Cruise-Control] helps individual vehicles to adapt their speed autonomously through V2V communication among vehicles according to the mobility of their predecessor and successor vehicles in an urban roadway or a highway. Thus, CACC can help adjacent vehicles to efficiently adjust their speed in an interactive way through V2V networking in order to avoid a collision.

Platooning [Truck-Platooning] allows a series (or group) of vehicles (e.g., trucks) to follow each other very closely. Trucks can use V2V communication in addition to forward sensors in order to maintain constant clearance between two consecutive vehicles at very short gaps (from 3 meters to 10 meters). Platooning can maximize the throughput of vehicular traffic in a highway and reduce the gas consumption because the leading vehicle can help the following vehicles to experience less air resistance.

Cooperative-environment-sensing use cases suggest that vehicles can share environmental information (e.g., air pollution, hazards/ obstacles, slippery areas by snow or rain, road accidents, traffic congestion, and driving behaviors of neighboring vehicles) from various vehicle-mounted sensors, such as radars, LiDARs, and cameras, with other vehicles and pedestrians. [Automotive-Sensing] introduces millimeter-wave vehicular communication for massive automotive sensing. A lot of data can be generated by those sensors, and these data typically need to be routed to different destinations. In addition, from the perspective of driverless vehicles, it is expected that driverless vehicles can be mixed with driver-operated vehicles. Through cooperative environment sensing, driver-operated vehicles can use environmental information sensed by driverless vehicles for better interaction with the other vehicles and environment. Vehicles can also share their intended maneuvering information (e.g., lane change, speed change, ramp in-and-out, cut-in, and abrupt braking) with neighboring vehicles. Thus, this information sharing can help the vehicles behave as more efficient traffic flows and minimize unnecessary acceleration and deceleration to achieve the best ride comfort.

To encourage more vehicles to participate in this cooperative environmental sensing, a reward system will be needed. Sensing activities of each vehicle need to be logged in either a central way through a logging server (e.g., TCC) in the vehicular cloud or a distributed way (e.g., blockchain [Bitcoin]) through other vehicles or infrastructure. In the case of a blockchain, each sensing message from a vehicle can be treated as a transaction and the neighboring vehicles can play the role of peers in a consensus method of a blockchain such as Proof of Work (PoW) and Proof of Stake (PoS) [Bitcoin][Vehicular-BlockChain].

The existing IPv6 protocol does not support wireless single-hop V2V communications as well as wireless multihop V2V communications. Thus, the IPv6 needs to support both single-hop and multihop communications in a wireless medium so that vehicles can communicate with each other by V2V communications to share either an emergency situation or road hazard in a highway.

To support applications of these V2V use cases, the functions of IPv6 such as VND and VSP are prerequisites for IPv6-based packet exchange and secure, safe communication between two vehicles.

3.2. V2I

The use cases of V2I networking discussed in this section include

- Navigation service;
- Energy-efficient speed recommendation service;
- Accident notification service;
- Electric vehicle (EV) charging service.

A navigation service, for example, the Self-Adaptive Interactive Navigation Tool(SAINT) [SAINT], using V2I networking interacts with a TCC for the large-scale/long-range road traffic optimization and can guide individual vehicles along appropriate navigation paths in real time. The enhanced version of SAINT [SAINTplus] can give fast moving paths to emergency vehicles (e.g., ambulance and fire engine) to let them reach an accident spot while redirecting other vehicles near the accident spot into efficient detour paths.

Either a TCC or an ECD can recommend an energy-efficient speed to a vehicle that depends on its traffic environment and traffic signal scheduling [SignalGuru]. For example, when a vehicle approaches an intersection area and a red traffic light for the vehicle becomes turned on, it needs to reduce its speed to save fuel consumption. In this case, either a TCC or an ECD, which has the up-to-date trajectory of the vehicle and the traffic light schedule, can notify the vehicle of an appropriate speed for fuel efficiency. [Fuel-Efficient] studies fuel-efficient route and speed plans for platooned trucks.

The emergency communication between accident vehicles (or emergency vehicles) and a TCC can be performed via either IP-RSU or 4G-LTE networks. The First Responder Network Authority (FirstNet) [FirstNet] is provided by the US government to establish, operate, and maintain an interoperable public safety broadband network for safety and security network services, e.g., emergency calls. The construction of the nationwide FirstNet network requires each state in the US to have a Radio Access Network (RAN) that will connect to the FirstNet’s network core. The current RAN is mainly constructed using 4G-LTE for the communication between a vehicle and an infrastructure node (i.e., V2I) [FirstNet-Report], but it is expected

that DSRC-based vehicular networks [DSRC] will be available for V2I and V2V in the near future.

An EV charging service with V2I can facilitates the efficient battery charging of EVs. In the case where an EV charging station is connected to an IP-RSU, an EV can be guided toward the deck of the EV charging station through a battery charging server connected to the IP-RSU. In addition to this EV charging service, other value-added services (e.g., air firmware/software update and media streaming) can be provided to an EV while it is charging its battery at the EV charging station.

The existing IPv6 protocol does not support wireless multihop V2I communications in a highway where RSUs are sparsely deployed, so a vehicle can reach the wireless coverage of an RSU through the multihop data forwarding of intermediate vehicles. Thus, IPv6 needs to be extended for multihop V2I communications.

To support applications of these V2I use cases, the functions of IPv6 such as VND, VMM, and VSP are prerequisites for IPv6-based packet exchange, transport-layer session continuity, and secure, safe communication between a vehicle and a server in the vehicular cloud.

3.3. V2X

The use case of V2X networking discussed in this section is for a pedestrian protection service.

A pedestrian protection service, such as Safety-Aware Navigation Application (SANA) [SANA], using V2I2P networking can reduce the collision of a vehicle and a pedestrian carrying a smartphone equipped with a network device for wireless communication (e.g., Wi-Fi) with an IP-RSU. Vehicles and pedestrians can also communicate with each other via an IP-RSU. An edge computing device behind the IP-RSU can collect the mobility information from vehicles and pedestrians, compute wireless communication scheduling for the sake of them. This scheduling can save the battery of each pedestrian’s smartphone by allowing it to work in sleeping mode before the communication with vehicles, considering their mobility.

For Vehicle-to-Pedestrian (V2P), a vehicle can directly communicate with a pedestrian’s smartphone by V2X without IP-RSU relaying. Light-weight mobile nodes such as bicycles may also communicate directly with a vehicle for collision avoidance using V2V.

The existing IPv6 protocol does not support wireless multihop V2X (or V2I2X) communications in an urban road network where RSUs are deployed at intersections, so a vehicle (or a pedestrian’s

smartphone) can reach the wireless coverage of an RSU through the multihop data forwarding of intermediate vehicles (or pedestrians' smartphones). Thus, IPv6 needs to be extended for multihop V2X (or V2I2X) communications.

To support applications of these V2X use cases, the functions of IPv6 such as VND, VMM, and VSP are prerequisites for IPv6-based packet exchange, transport-layer session continuity, and secure, safe communication between a vehicle and a pedestrian either directly or indirectly via an IP-RSU.

4. Vehicular Networks

This section describes an example vehicular network architecture supporting V2V, V2I, and V2X communications in vehicular networks. It describes an internal network within a vehicle or an edge network (called EN). It explains not only the internetworking between the internal networks of a vehicle and an EN via wireless links, but also the internetworking between the internal networks of two vehicles via wireless links.

4.1. Vehicular Network Architecture

Figure 1 shows an example vehicular network architecture for V2I and V2V in a road network [OMNI-Interface]. The vehicular network architecture contains vehicles (including IP-OBU), IP-RSUs, Mobility Anchor, Traffic Control Center, and Vehicular Cloud as components. Note that the components of the vehicular network architecture can be mapped to those of an IP-based aeronautical network architecture in [OMNI-Interface], as shown in Figure 2.

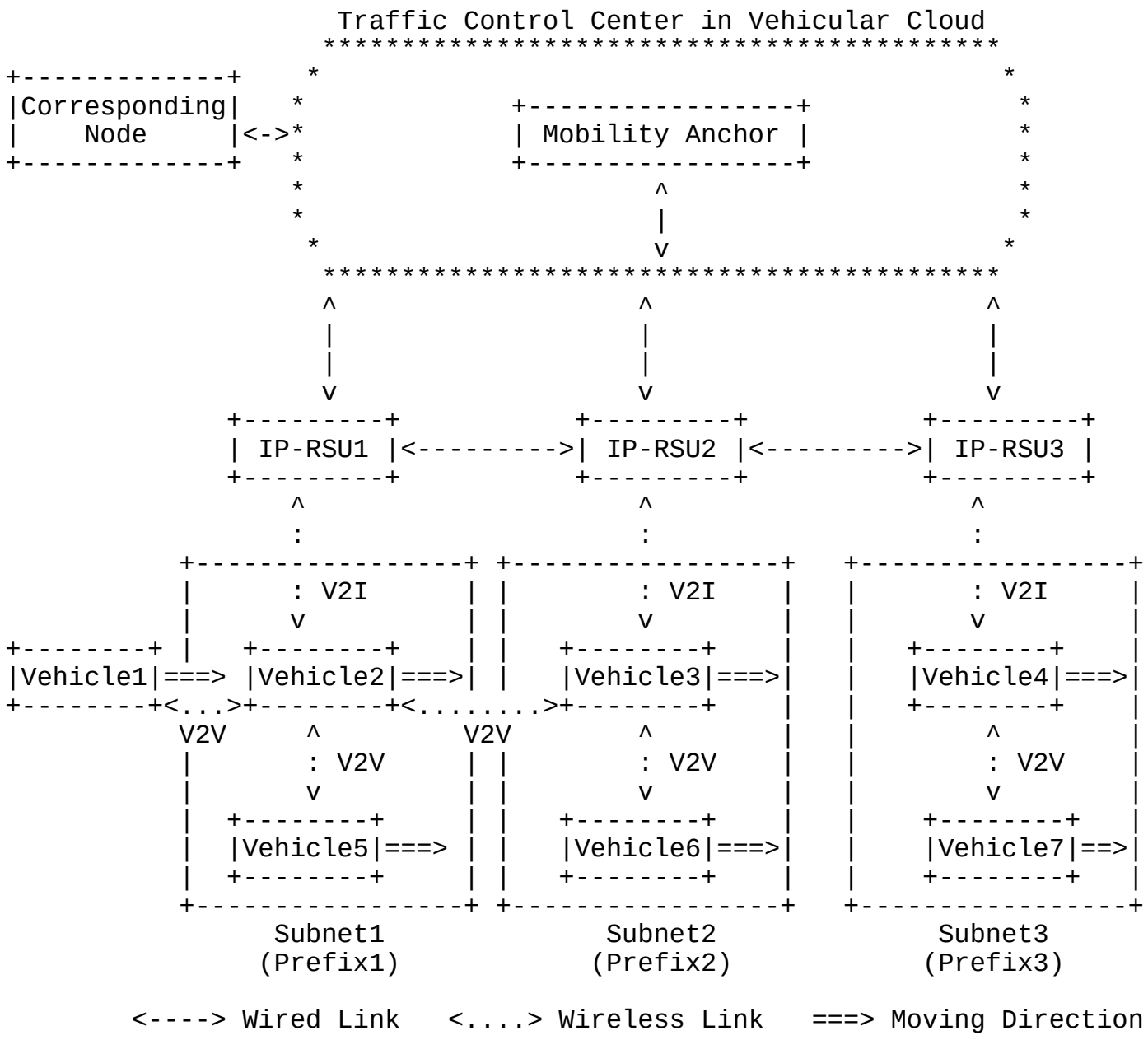

Figure 1: An Example Vehicular Network Architecture for V2I and V2V

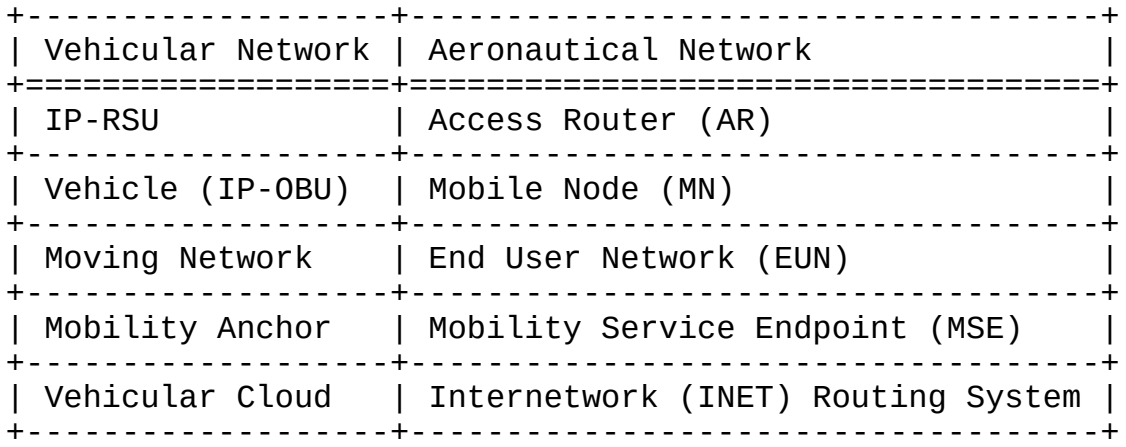

Figure 2: Mapping between Vehicular Network Components and Aeronautical Network Components

These components are not mandatory, and they can be deployed into vehicular networks in various ways. Some of them (e.g., Mobility Anchor, Traffic Control Center, and Vehicular Cloud) may not be needed for the vehicular networks according to target use cases in Section 3.

An existing network architecture (e.g., an IP-based aeronautical network architecture [OMNI-Interface][UAM-ITS], a network architecture of PMIPv6 [RFC5213], and a low-power and lossy network architecture [RFC6550]) can be extended to a vehicular network architecture for multihop V2V, V2I, and V2X, as shown in Figure 1. In a highway scenario, a vehicle may not access an RSU directly because of the distance of the DSRC coverage (up to 1 km). For example, RPL (IPv6 Routing Protocol for Low-Power and Lossy Networks) [RFC6550] can be extended to support a multihop V2I since a vehicle can take advantage of other vehicles as relay nodes to reach the RSU. Also, RPL can be extended to support both multihop V2V and V2X in the similar way.

Wireless communications needs to be considered for end systems for Urban Air Mobility (UAM) such as flying cars and taxis [UAM-ITS]. These UAM end systems may have multiple wireless transmission media interfaces (e.g., cellular, communications satellite (SATCOM), short-range omni-directional interfaces), which are offered by different data link service providers. To support not only the mobility management of the UAM end systems, but also the multihop and multilink communications of the UAM interfaces, the UAM end systems can employ an Overlay Multilink Network (OMNI) interface [OMNI-Interface] as a virtual Non-Broadcast Multiple Access (NBMA) connection to a serving ground domain infrastructure. This infrastructure can be configured over the underlying data links. The

OMNI interface and its link model provide a means of multilink, multihop and mobility coordination to the legacy IPv6 ND messaging [RFC4861] according to the NBMA principle. Thus, the OMNI link model can support efficient UAM internetworking services without additional mobility messaging, and without any modification to the IPv6 ND messaging services or link model.

As shown in this figure, IP-RSUs as routers and vehicles with IP-OBU have wireless media interfaces for VANET. Furthermore, the wireless media interfaces are autoconfigured with a global IPv6 prefix (e.g., 2001:DB8:1:1::/64) to support both V2V and V2I networking. Note that 2001:DB8::/32 is a documentation prefix [RFC3849] for example prefixes in this document, and also that any routable IPv6 address needs to be routable in a VANET and a vehicular network including IP-RSUs.

In Figure 1, three IP-RSUs (IP-RSU1, IP-RSU2, and IP-RSU3) are deployed in the road network and are connected with each other through the wired networks (e.g., Ethernet). A Traffic Control Center (TCC) is connected to the Vehicular Cloud for the management of IP-RSUs and vehicles in the road network. A Mobility Anchor (MA) may be located in the TCC as a mobility management controller. Vehicle2, Vehicle3, and Vehicle4 are wirelessly connected to IP-RSU1, IP-RSU2, and IP-RSU3, respectively. The three wireless networks of IP-RSU1, IP-RSU2, and IP-RSU3 can belong to three different subnets (i.e., Subnet1, Subnet2, and Subnet3), respectively. Those three subnets use three different prefixes (i.e., Prefix1, Prefix2, and Prefix3).

Multiple vehicles under the coverage of an RSU share a prefix such that mobile nodes share a prefix of a Wi-Fi access point in a wireless LAN. This is a natural characteristic in infrastructure-based wireless networks. For example, in Figure 1, two vehicles (i.e., Vehicle2, and Vehicle5) can use Prefix 1 to configure their IPv6 global addresses for V2I communication.

A single subnet prefix announced by an RSU can span multiple vehicles in VANET. For example, in Figure 1, for Prefix 1, three vehicles (i.e., Vehicle1, Vehicle2, and Vehicle5) can construct a connected VANET. Also, for Prefix 2, two vehicles (i.e., Vehicle3 and Vehicle6) can construct another connected VANET, and for Prefix 3, two vehicles (i.e., Vehicle4 and Vehicle7) can construct another connected VANET.

In wireless subnets in vehicular networks (e.g., Subnet1 and Subnet2 in Figure 1), vehicles can construct a connected VANET (with an arbitrary graph topology) and can communicate with each other via V2V communication. Vehicle1 can communicate with Vehicle2 via V2V

communication, and Vehicle2 can communicate with Vehicle3 via V2V communication because they are within the wireless communication range of each other. On the other hand, Vehicle3 can communicate with Vehicle4 via the vehicular infrastructure (i.e., IP-RSU2 and IP-RSU3) by employing V2I (i.e., V2I2V) communication because they are not within the wireless communication range of each other.

For IPv6 packets transported over IEEE 802.11-OCB, [RFC8691] specifies several details, including Maximum Transmission Unit (MTU), frame format, link-local address, address mapping for unicast and multicast, stateless autoconfiguration, and subnet structure. An Ethernet Adaptation (EA) layer is in charge of transforming some parameters between the IEEE 802.11 MAC layer and the IPv6 network layer, which is located between the IEEE 802.11-OCB's logical link control layer and the IPv6 network layer. This IPv6 over 802.11-OCB can be used for both V2V and V2I in IPv6-based vehicular networks.

An IPv6 mobility solution is needed for the guarantee of communication continuity in vehicular networks so that a vehicle's TCP session can be continued, or UDP packets can be delivered to a vehicle as a destination without loss while it moves from an IP-RSU's wireless coverage to another IP-RSU's wireless coverage. In Figure 1, assuming that Vehicle2 has a TCP session (or a UDP session) with a corresponding node in the vehicular cloud, Vehicle2 can move from IP-RSU1's wireless coverage to IP-RSU2's wireless coverage. In this case, a handover for Vehicle2 needs to be performed by either a host-based mobility management scheme (e.g., MIPv6 [RFC6275]) or a network-based mobility management scheme (e.g., PMIPv6 [RFC5213]).

In the host-based mobility scheme (e.g., MIPv6), an IP-RSU plays a role of a home agent. On the other hand, in the network-based mobility scheme (e.g., PMIPv6, an MA plays a role of a mobility management controller such as a Local Mobility Anchor (LMA) in PMIPv6, which also serves vehicles as a home agent, and an IP-RSU plays a role of an access router such as a Mobile Access Gateway (MAG) in PMIPv6 [RFC5213]. The host-based mobility scheme needs client functionality in IPv6 stack of a vehicle as a mobile node for mobility signaling message exchange between the vehicle and home agent. On the other hand, the network-based mobility scheme does not need such a client functionality for a vehicle because the network infrastructure node (e.g., MAG in PMIPv6) as a proxy mobility agent handles the mobility signaling message exchange with the home agent (e.g., LMA in PMIPv6) for the sake of the vehicle.

There are a scalability issue and a route optimization issue in the network-based mobility scheme (e.g., PMIPv6) when an MA covers a large vehicular network governing many IP-RSUs. In this case, a distributed mobility scheme (e.g., DMM [RFC7429]) can mitigate the

scalability issue by distributing multiple MAs in the vehicular network such that they are positioned closer to vehicles for route optimization and bottleneck mitigation in a central MA in the network-based mobility scheme. All these mobility approaches (i.e., a host-based mobility scheme, network-based mobility scheme, and distributed mobility scheme) and a hybrid approach of a combination of them need to provide an efficient mobility service to vehicles moving fast and moving along with the relatively predictable trajectories along the roadways.

In vehicular networks, the control plane can be separated from the data plane for efficient mobility management and data forwarding by using the concept of Software-Defined Networking (SDN) [RFC7149][DMM-FPC]. Note that Forwarding Policy Configuration (FPC) in [DMM-FPC], which is a flexible mobility management system, can manage the separation of data-plane and control-plane in DMM. In SDN, the control plane and data plane are separated for the efficient management of forwarding elements (e.g., switches and routers) where an SDN controller configures the forwarding elements in a centralized way and they perform packet forwarding according to their forwarding tables that are configured by the SDN controller. An MA as an SDN controller needs to efficiently configure and monitor its IP-RSUs and vehicles for mobility management, location management, and security services.

The mobility information of a GPS receiver mounted in its vehicle (e.g., position, speed, and direction) can be used to accommodate mobility-aware proactive handover schemes, which can perform the handover of a vehicle according to its mobility and the wireless signal strength of a vehicle and an IP-RSU in a proactive way.

Vehicles can use the TCC as their Home Network having a home agent for mobility management as in MIPv6 [RFC6275] and PMIPv6 [RFC5213], so the TCC (or an MA inside the TCC) maintains the mobility information of vehicles for location management. IP tunneling over the wireless link should be avoided for performance efficiency. Also, in vehicular networks, asymmetric links sometimes exist and must be considered for wireless communications such as V2V and V2I.

4.2. V2I-based Internetworking

This section discusses the internetworking between a vehicle’s internal network (i.e., moving network) and an EN’s internal network (i.e., fixed network) via V2I communication. The internal network of a vehicle is nowadays constructed with Ethernet by many automotive vendors [In-Car-Network]. Note that an EN can accommodate multiple routers (or switches) and servers (e.g., ECDs, navigation server, and DNS server) in its internal network.

A vehicle’s internal network often uses Ethernet to interconnect Electronic Control Units (ECUs) in the vehicle. The internal network can support Wi-Fi and Bluetooth to accommodate a driver’s and passenger’s mobile devices (e.g., smartphone or tablet). The network topology and subnetting depend on each vendor’s network configuration for a vehicle and an EN. It is reasonable to consider the interaction between the internal network and an external network within another vehicle or an EN.

As shown in Figure 3, as internal networks, a vehicle’s moving network and an EN’s fixed network are self-contained networks having multiple subnets and having an edge router (e.g., IP-OBU and IP-RSU) for the communication with another vehicle or another EN. The internetworking between two internal networks via V2I communication requires the exchange of the network parameters and the network prefixes of the internal networks. For the efficiency, the network prefixes of the internal networks (as a moving network) in a vehicle need to be delegated and configured automatically. Note that a moving network’s network prefix can be called a Mobile Network Prefix (MNP) [OMNI-Interface].

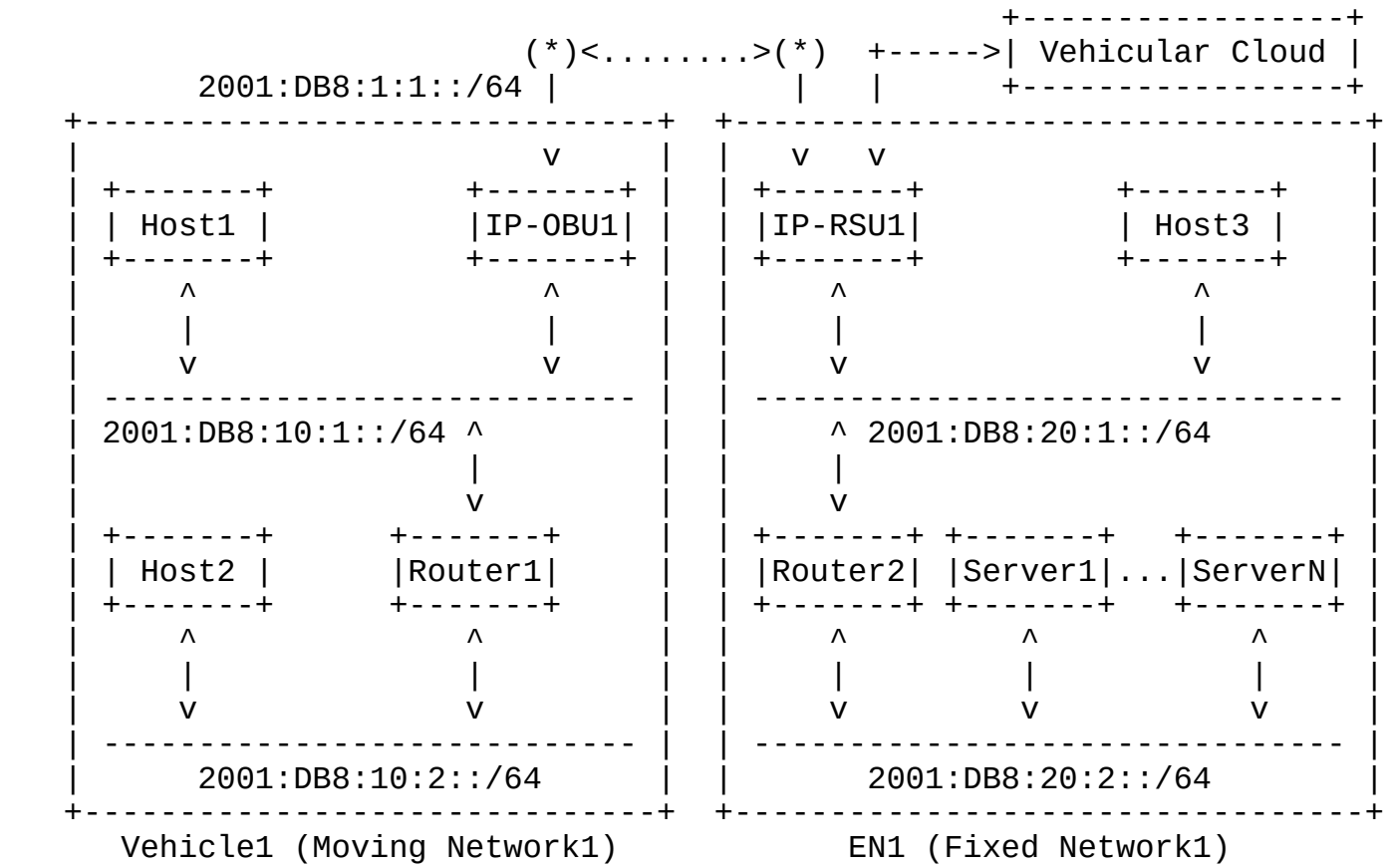

Figure 3: Internetworking between Vehicle and Edge Network

Figure 3 also shows the internetworking between the vehicle's moving network and the EN's fixed network. There exists an internal network (Moving Network1) inside Vehicle1. Vehicle1 has two hosts (Host1 and Host2), and two routers (IP-OBU1 and Router1). There exists another internal network (Fixed Network1) inside EN1. EN1 has one host (Host3), two routers (IP-RSU1 and Router2), and the collection of servers (Server1 to ServerN) for various services in the road networks, such as the emergency notification and navigation. Vehicle1's IP-OBU1 (as a mobile router) and EN1's IP-RSU1 (as a fixed router) use 2001:DB8:1:1::/64 for an external link (e.g., DSRC) for V2I networking. Thus, a host (Host1) in Vehicle1 can communicate with a server (Server1) in EN1 for a vehicular service through Vehicle1's moving network, a wireless link between IP-OBU1 and IP-RSU1, and EN1's fixed network.

For the IPv6 communication between an IP-OBU and an IP-RSU or between two neighboring IP-OBUs, they need to know the network parameters, which include MAC layer and IPv6 layer information. The MAC layer

information includes wireless link layer parameters, transmission power level, and the MAC address of an external network interface for the internetworking with another IP-OBU or IP-RSU. The IPv6 layer information includes the IPv6 address and network prefix of an external network interface for the internetworking with another IP-OBU or IP-RSU.

Through the mutual knowledge of the network parameters of internal networks, packets can be transmitted between the vehicle's moving network and the EN's fixed network. Thus, V2I requires an efficient protocol for the mutual knowledge of network parameters.

As shown in Figure 3, global IPv6 addresses are used for the wireless link interfaces for IP-OBU and IP-RSU, but IPv6 Unique Local Addresses (ULAs) [RFC4193] can also be used for those wireless link interfaces as long as IPv6 packets can be routed to them in the vehicular networks [OMNI-Interface]. For the guarantee of the uniqueness of an IPv6 address, the configuration and control overhead of the DAD of the wireless link interfaces should be minimized to support the V2I and V2X communications of vehicles moving fast along roadways.

4.3. V2V-based Internetworking

This section discusses the internetworking between the moving networks of two neighboring vehicles via V2V communication.

Figure 4 shows the internetworking between the moving networks of two neighboring vehicles. There exists an internal network (Moving Network1) inside Vehicle1. Vehicle1 has two hosts (Host1 and Host2), and two routers (IP-OBU1 and Router1). There exists another internal network (Moving Network2) inside Vehicle2. Vehicle2 has two hosts (Host3 and Host4), and two routers (IP-OBU2 and Router2). Vehicle1's IP-OBU1 (as a mobile router) and Vehicle2's IP-OBU2 (as a mobile router) use 2001:DB8:1:1::/64 for an external link (e.g., DSRC) for V2V networking. Thus, a host (Host1) in Vehicle1 can communicate with another host (Host3) in Vehicle2 for a vehicular service through Vehicle1's moving network, a wireless link between IP-OBU1 and IP-OBU2, and Vehicle2's moving network.

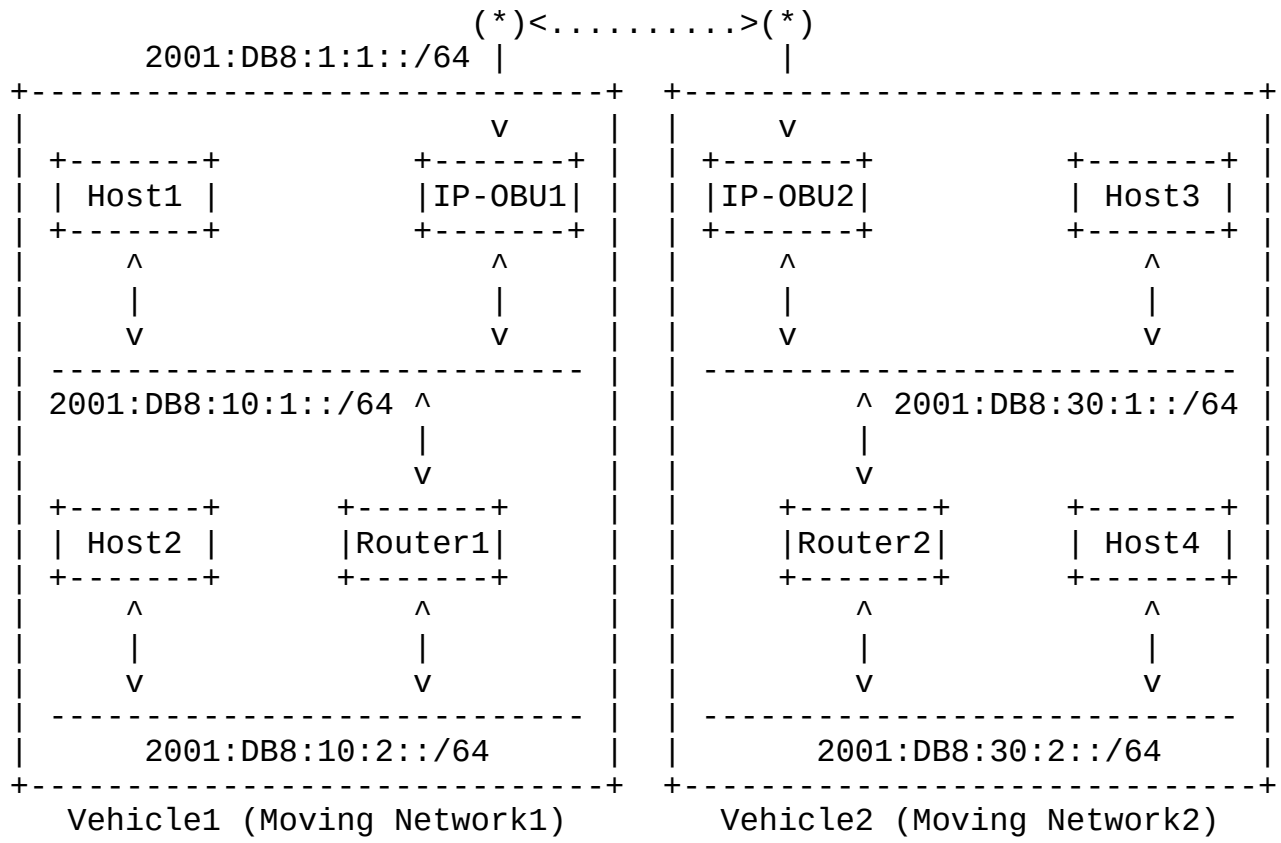

Figure 4: Internetworking between Two Vehicles

As a V2V use case in Section 3.1, Figure 5 shows the linear network topology of platooning vehicles for V2V communications where Vehicle3 is the leading vehicle with a driver, and Vehicle2 and Vehicle1 are the following vehicles without drivers.

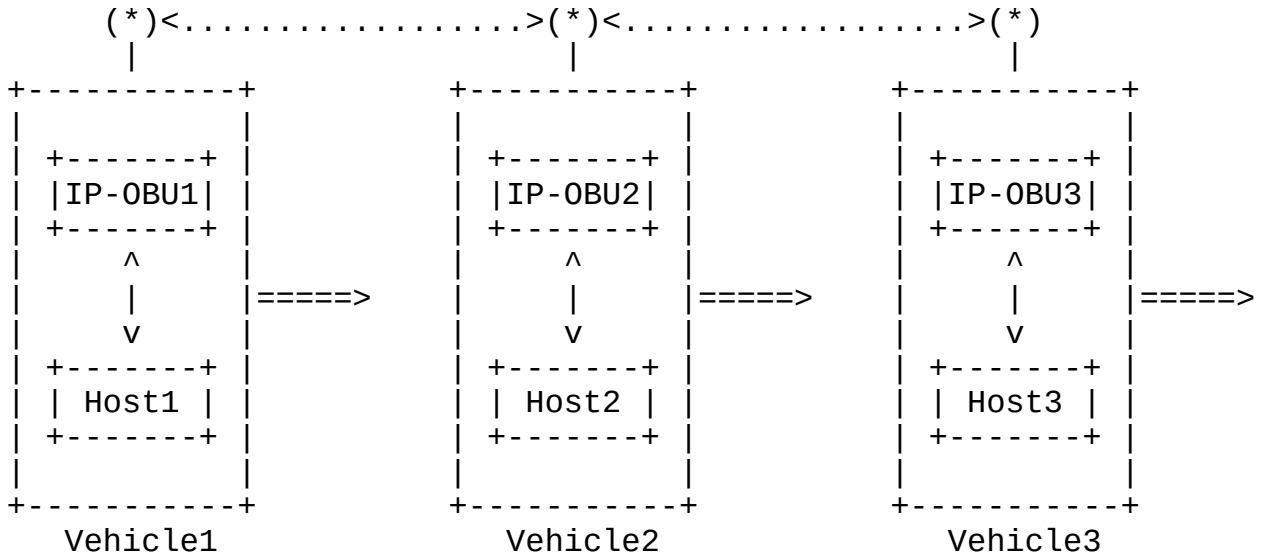

Figure 5: Multihop Internetworking between Two Vehicle Networks

As shown in Figure 5, multihop internetworking is feasible among the moving networks of three vehicles in the same VANET. For example, Host1 in Vehicle1 can communicate with Host3 in Vehicle3 via IP-OBU1 in Vehicle1, IP-OBU2 in Vehicle2, and IP-OBU3 in Vehicle3 in the linear network, as shown in the figure.

5. Problem Statement

In order to specify protocols using the architecture mentioned in Section 4.1, IPv6 core protocols have to be adapted to overcome certain challenging aspects of vehicular networking. Since the vehicles are likely to be moving at great speed, protocol exchanges need to be completed in a time relatively short compared to the lifetime of a link between a vehicle and an IP-RSU, or between two vehicles.

Note that if two vehicles are moving in the opposite directions in a roadway, the relative speed of this case is two times the relative speed of a vehicle passing through an RSU. The time constraint of a wireless link between two nodes needs to be considered because it may affect the lifetime of a session involving the link.

The lifetime of a session varies depending on the session’s type such as a web surfing, voice call over IP, and DNS query. Regardless of a session’s type, to guide all the IPv6 packets to their destination host, IP mobility should be supported for the session.

Thus, the time constraint of a wireless link has a major impact on IPv6 Neighbor Discovery (ND). Mobility Management (MM) is also vulnerable to disconnections that occur before the completion of identity verification and tunnel management. This is especially true given the unreliable nature of wireless communication. This section presents key topics such as neighbor discovery and mobility management.

5.1. Neighbor Discovery

IPv6 ND [RFC4861][RFC4862] is a core part of the IPv6 protocol suite. IPv6 ND is designed for point-to-point links and transit links (e.g., Ethernet). It assumes the efficient and reliable support of multicast and unicast from the link layer for various network operations such as MAC Address Resolution (AR), Duplicate Address Detection (DAD), and Neighbor Unreachability Detection (NUD).

Vehicles move quickly within the communication coverage of any particular vehicle or IP-RSU. Before the vehicles can exchange application messages with each other, they need to be configured with a link-local IPv6 address or a global IPv6 address, and run IPv6 ND.

The requirements for IPv6 ND for vehicular networks are efficient DAD and NUD operations. An efficient DAD is required to reduce the overhead of the DAD packets during a vehicle’s travel in a road network, which guaranteeing the uniqueness of a vehicle’s global IPv6 address. An efficient NUD is required to reduce the overhead of the NUD packets during a vehicle’s travel in a road network, which guaranteeing the accurate neighborhood information of a vehicle in terms of adjacent vehicles and RSUs.

The legacy DAD assumes that a node with an IPv6 address can reach any other node with the scope of its address at the time it claims its address, and can hear any future claim for that address by another party within the scope of its address for the duration of the address ownership. However, the partitioning and merging of VANETs makes this assumption frequently invalid in vehicular networks. The merging and partitioning of VANETs frequently occurs in vehicular networks. This merging and partitioning should be considered for the IPv6 ND such as IPv6 Stateless Address Autoconfiguration (SLAAC) [RFC4862]. Due to the merging of VANETs, two IPv6 addresses may conflict with each other though they were unique before the merging. Also, the partitioning of a VANET may make vehicles with the same prefix be physically unreachable. Also, SLAAC needs to prevent IPv6 address duplication due to the merging of VANETs. According to the merging and partitioning, a destination vehicle (as an IPv6 host) needs to be distinguished as either an on-link host or an off-link

host even though the source vehicle uses the same prefix as the destination vehicle.

To efficiently prevent IPv6 address duplication due to the VANET partitioning and merging from happening in vehicular networks, the vehicular networks need to support a vehicular-network-wide DAD by defining a scope that is compatible with the legacy DAD. In this case, two vehicles can communicate with each other when there exists a communication path over VANET or a combination of VANETs and IP-RSUs, as shown in Figure 1. By using the vehicular-network-wide DAD, vehicles can assure that their IPv6 addresses are unique in the vehicular network whenever they are connected to the vehicular infrastructure or become disconnected from it in the form of VANET.

ND time-related parameters such as router lifetime and Neighbor Advertisement (NA) interval need to be adjusted for vehicle speed and vehicle density. For example, the NA interval needs to be dynamically adjusted according to a vehicle’s speed so that the vehicle can maintain its neighboring vehicles in a stable way, considering the collision probability with the NA messages sent by other vehicles.

For IPv6-based safety applications (e.g., context-aware navigation, adaptive cruise control, and platooning) in vehicular networks, the delay-bounded data delivery is critical. IPv6 ND needs to work to support those IPv6-based safety applications efficiently.

Thus, in IPv6-based vehicular networking, IPv6 ND should have minimum changes for the interoperability with the legacy IPv6 ND used in the Internet, including the DAD and NUD operations.

5.1.1. Link Model

A prefix model for a vehicular network needs to facilitate the communication between two vehicles with the same prefix regardless of the vehicular network topology as long as there exist bidirectional E2E paths between them in the vehicular network including VANETs and IP-RSUs. This prefix model allows vehicles with the same prefix to communicate with each other via a combination of multihop V2V and multihop V2I with VANETs and IP-RSUs. Note that the OMNI link model supports these multihop V2V and V2I through an OMNI multilink service [OMNI-Interface].

IPv6 protocols work under certain assumptions for the link model that do not necessarily hold in a vehicular wireless link [VIP-WAVE][RFC5889]. For instance, some IPv6 protocols assume symmetry in the connectivity among neighboring interfaces [RFC6250]. However, radio interference and different levels of transmission

power may cause asymmetric links to appear in vehicular wireless links. As a result, a new vehicular link model needs to consider the asymmetry of dynamically changing vehicular wireless links.

There is a relationship between a link and a prefix, besides the different scopes that are expected from the link-local and global types of IPv6 addresses. In an IPv6 link, it is assumed that all interfaces which are configured with the same subnet prefix and with on-link bit set can communicate with each other on an IPv6 link. However, the vehicular link model needs to define the relationship between a link and a prefix, considering the dynamics of wireless links and the characteristics of VANET.

A VANET can have a single link between each vehicle pair within wireless communication range, as shown in Figure 5. When two vehicles belong to the same VANET, but they are out of wireless communication range, they cannot communicate directly with each other. Suppose that a global-scope IPv6 prefix (or an IPv6 ULA prefix) is assigned to VANETs in vehicular networks. Even though two vehicles in the same VANET configure their IPv6 addresses with the same IPv6 prefix, they may not communicate with each other not in one hop in the same VANET because of the multihop network connectivity between them. Thus, in this case, the concept of an on-link IPv6 prefix does not hold because two vehicles with the same on-link IPv6 prefix cannot communicate directly with each other. Also, when two vehicles are located in two different VANETs with the same IPv6 prefix, they cannot communicate with each other. When these two VANETs converge to one VANET, the two vehicles can communicate with each other in a multihop fashion, for example, when they are Vehicle1 and Vehicle3, as shown in Figure 5.

From the previous observation, a vehicular link model should consider the frequent partitioning and merging of VANETs due to vehicle mobility. Therefore, the vehicular link model needs to use an on-link prefix and off-link prefix according to the network topology of vehicles such as a one-hop reachable network and a multihop reachable network (or partitioned networks). If the vehicles with the same prefix are reachable from each other in one hop, the prefix should be on-link. On the other hand, if some of the vehicles with the same prefix are not reachable from each other in one hop due to either the multihop topology in the VANET or multiple partitions, the prefix should be off-link.

The vehicular link model needs to support multihop routing in a connected VANET where the vehicles with the same global-scope IPv6 prefix (or the same IPv6 ULA prefix) are connected in one hop or multiple hops. It also needs to support the multihop routing in multiple connected VANETs through infrastructure nodes (e.g., IP-RSU)

where they are connected to the infrastructure. For example, in Figure 1, suppose that Vehicle1, Vehicle2, and Vehicle3 are configured with their IPv6 addresses based on the same global-scope IPv6 prefix. Vehicle1 and Vehicle3 can also communicate with each other via either multihop V2V or multihop V2I2V. When Vehicle1 and Vehicle3 are connected in a VANET, it will be more efficient for them to communicate with each other directly via VANET rather than indirectly via IP-RSUs. On the other hand, when Vehicle1 and Vehicle3 are far away from direct communication range in separate VANETs and under two different IP-RSUs, they can communicate with each other through the relay of IP-RSUs via V2I2V. Thus, two separate VANETs can merge into one network via IP-RSU(s). Also, newly arriving vehicles can merge two separate VANETs into one VANET if they can play the role of a relay node for those VANETs.

Thus, in IPv6-based vehicular networking, the vehicular link model should have minimum changes for the interoperability with the legacy IPv6 link model in an efficient fashion to support the IPv6 DAD and NUD operations.

5.1.2. MAC Address Pseudonym

For the protection of drivers' privacy, a pseudonym of a MAC address of a vehicle's network interface should be used, so that the MAC address can be changed periodically. However, although such a pseudonym of a MAC address can protect to some extent the privacy of a vehicle, it may not be able to resist attacks on vehicle identification by other fingerprint information, for example, the scrambler seed embedded in IEEE 802.11-OCB frames [Scrambler-Attack]. The pseudonym of a MAC address affects an IPv6 address based on the MAC address, and a transport-layer (e.g., TCP and SCTP) session with an IPv6 address pair. However, the pseudonym handling is not implemented and tested yet for applications on IP-based vehicular networking.

In the ETSI standards, for the sake of security and privacy, an ITS station (e.g., vehicle) can use pseudonyms for its network interface identities (e.g., MAC address) and the corresponding IPv6 addresses [Identity-Management]. Whenever the network interface identifier changes, the IPv6 address based on the network interface identifier needs to be updated, and the uniqueness of the address needs to be checked through the DAD procedure. For vehicular networks with high mobility and density, this DAD needs to be performed efficiently with minimum overhead so that the vehicles can exchange application messages (e.g., collision avoidance and accident notification) with each other with a short interval (e.g., 0.5 second) [NHTSA-ACAS-Report].

5.1.3. Routing

For multihop V2V communications in either a VANET or VANETs via IP-RSUs, a vehicular ad hoc routing protocol (e.g., AODV or OLSRv2) may be required to support both unicast and multicast in the links of the subnet with the same IPv6 prefix. However, it will be costly to run both vehicular ND and a vehicular ad hoc routing protocol in terms of control traffic overhead [ID-Multicast-Problems].

A routing protocol for a VANET may cause redundant wireless frames in the air to check the neighborhood of each vehicle and compute the routing information in a VANET with a dynamic network topology because the IPv6 ND is used to check the neighborhood of each vehicle. Thus, the vehicular routing needs to take advantage of the IPv6 ND to minimize its control overhead.

5.2. Mobility Management

The seamless connectivity and timely data exchange between two end points requires efficient mobility management including location management and handover. Most vehicles are equipped with a GPS receiver as part of a dedicated navigation system or a corresponding smartphone App. Note that the GPS receiver may not provide vehicles with accurate location information in adverse environments such as a building area or a tunnel. The location precision can be improved with assistance of the IP-RSUs or a cellular system with a GPS receiver for location information.

With a GPS navigator, efficient mobility management can be performed with the help of vehicles periodically reporting their current position and trajectory (i.e., navigation path) to the vehicular infrastructure (having IP-RSUs and an MA in TCC). This vehicular infrastructure can predict the future positions of the vehicles from their mobility information (i.e., the current position, speed, direction, and trajectory) for efficient mobility management (e.g., proactive handover). For a better proactive handover, link-layer parameters, such as the signal strength of a link-layer frame (e.g., Received Channel Power Indicator (RCPI) [VIP-WAVE]), can be used to determine the moment of a handover between IP-RSUs along with mobility information.

By predicting a vehicle’s mobility, the vehicular infrastructure needs to better support IP-RSUs to perform efficient SLAAC, data forwarding, horizontal handover (i.e., handover in wireless links using a homogeneous radio technology), and vertical handover (i.e., handover in wireless links using heterogeneous radio technologies) in advance along with the movement of the vehicle.

For example, as shown in Figure 1, when a vehicle (e.g., Vehicle2) is moving from the coverage of an IP-RSU (e.g., IP-RSU1) into the coverage of another IP-RSU (e.g., IP-RSU2) belonging to a different subnet, the IP-RSUs can proactively support the IPv6 mobility of the vehicle, while performing the SLAAC, data forwarding, and handover for the sake of the vehicle.

For a mobility management scheme in a shared link, where the wireless subnets of multiple IP-RSUs share the same prefix, an efficient vehicular-network-wide DAD is required. If DHCPv6 is used to assign a unique IPv6 address to each vehicle in this shared link, the DAD is not required. On the other hand, for a mobility management scheme with a unique prefix per mobile node (e.g., PMIPv6 [RFC5213] and OMNI [OMNI-Interface]), DAD is not required because the IPv6 address of a vehicle's external wireless interface is guaranteed to be unique. There is a tradeoff between the prefix usage efficiency and DAD overhead. Thus, the IPv6 address autoconfiguration for vehicular networks needs to consider this tradeoff to support efficient mobility management.

Therefore, for the proactive and seamless IPv6 mobility of vehicles, the vehicular infrastructure (including IP-RSUs and MA) needs to efficiently perform the mobility management of the vehicles with their mobility information and link-layer information. Also, in IPv6-based vehicular networking, IPv6 mobility management should have minimum changes for the interoperability with the legacy IPv6 mobility management schemes such as PMIPv6, DMM, LISP, and AERO.

6. Security Considerations

This section discusses security and privacy for IPv6-based vehicular networking. Security and privacy are key components of IPv6-based vehicular networking along with neighbor discovery and mobility management.

Security and privacy are paramount in V2I, V2V, and V2X networking. Vehicles and infrastructure must be authenticated in order to participate in vehicular networking. Also, in-vehicle devices (e.g., ECU) and a driver/passenger's mobile devices (e.g., smartphone and tablet PC) in a vehicle need to communicate with other in-vehicle devices and another driver/passenger's mobile devices in another vehicle, or other servers behind an IP-RSU in a secure way. Even though a vehicle is perfectly authenticated and legitimate, it may be hacked for running malicious applications to track and collect its and other vehicles' information. In this case, an attack mitigation process may be required to reduce the aftermath of malicious behaviors.

Strong security measures shall protect vehicles roaming in road networks from the attacks of malicious nodes, which are controlled by hackers. For safe driving applications (e.g., context-aware navigation, cooperative adaptive cruise control, and platooning), as explained in Section 3.1, the cooperative action among vehicles is assumed. Malicious nodes may disseminate wrong driving information (e.g., location, speed, and direction) for disturbing safe driving. For example, a Sybil attack, which tries to confuse a vehicle with multiple false identities, may disturb a vehicle from taking a safe maneuver.

Even though vehicles can be authenticated with valid certificates by an authentication server in the vehicular cloud, the authenticated vehicles may harm other vehicles, so their communication activities need to be logged in either a central way through a logging server (e.g., TCC) in the vehicular cloud or a distributed way (e.g., blockchain [Bitcoin]) along with other vehicles or infrastructure. For the non-repudiation of the harmful activities of malicious nodes, a blockchain technology can be used [Bitcoin]. Each message from a vehicle can be treated as a transaction and the neighboring vehicles can play the role of peers in a consensus method of a blockchain such as PoW and PoS [Bitcoin][Vehicular-BlockChain].

To identify malicious vehicles among vehicles, an authentication method is required. A Vehicle Identification Number (VIN) and a user certificate (e.g., X.509 certificate [RFC5280]) along with an in-vehicle device's identifier generation can be used to efficiently authenticate a vehicle or its driver (having a user certificate) through a road infrastructure node (e.g., IP-RSU) connected to an authentication server in the vehicular cloud. This authentication can be used to identify the vehicle that will communicate with an infrastructure node or another vehicle. In the case where a vehicle has an internal network (called Moving Network) and elements in the network (e.g., in-vehicle devices and a user's mobile devices), as shown in Figure 3, the elements in the network need to be authenticated individually for safe authentication. Also, Transport Layer Security (TLS) certificates [RFC8446][RFC5280] can be used for an element's authentication to allow secure E2E vehicular communications between an element in a vehicle and another element in a server in a vehicular cloud, or between an element in a vehicle and another element in another vehicle.

For secure V2I communication, a secure channel (e.g., IPsec) between a mobile router (i.e., IP-OBU) in a vehicle and a fixed router (i.e., IP-RSU) in an EN needs to be established, as shown in Figure 3 [RFC4301][RFC4302][RFC4303][RFC4308][RFC7296]. Also, for secure V2V communication, a secure channel (e.g., IPsec) between a mobile router (i.e., IP-OBU) in a vehicle and a mobile router (i.e., IP-OBU) in

another vehicle needs to be established, as shown in Figure 4. For secure communication, an element in a vehicle (e.g., an in-vehicle device and a driver/passenger's mobile device) needs to establish a secure connection (e.g., TLS) with another element in another vehicle or another element in a vehicular cloud (e.g., a server). Even though IEEE 1609.2 [WAVE-1609.2] specifies security services for applications and management messages. This WAVE specification is optional, so if WAVE does not support the security of a WAVE frame, either the network layer or the transport layer needs to support security services for the WAVE frames.

For the setup of a secure channel over IPsec or TLS, the multihop V2I communications over DSRC is required in a highway for the authentication by involving multiple intermediate vehicles as relay nodes toward an IP-RSU connected to an authentication server in the vehicular cloud. The V2I communications over 5G V2X (or LTE V2X) is required to allow a vehicle to communicate directly with a gNodeB (or eNodeB) connected to an authentication server in the vehicular cloud.

To prevent an adversary from tracking a vehicle with its MAC address or IPv6 address, especially for a long-living transport-layer session (e.g., voice call over IP and video streaming service), a MAC address pseudonym needs to be provided to each vehicle; that is, each vehicle periodically updates its MAC address and its IPv6 address needs to be updated accordingly by the MAC address change [RFC4086][RFC4941]. Such an update of the MAC and IPv6 addresses should not interrupt the E2E communications between two vehicles (or between a vehicle and an IP-RSU) for a long-living transport-layer session. However, if this pseudonym is performed without strong E2E confidentiality (using either IPsec or TLS), there will be no privacy benefit from changing MAC and IPv6 addresses, because an adversary can observe the change of the MAC and IPv6 addresses and track the vehicle with those addresses. Thus, the MAC address pseudonym and the IPv6 address update should be performed with strong E2E confidentiality.

For the IPv6 ND, the DAD is required to ensure the uniqueness of the IPv6 address of a vehicle's wireless interface. This DAD can be used as a flooding attack that uses the DAD-related ND packets disseminated over the VANET or vehicular networks. Thus, the vehicles and IP-RSUs need to filter out suspicious ND traffic in advance.

For mobility management, a malicious vehicle can construct multiple virtual bogus vehicles, and register them with IP-RSUs and MA. This registration makes the IP-RSUs and MA waste their resources. The IP-RSUs and MA need to determine whether a vehicle is genuine or bogus in mobility management. Also, the confidentiality of control packets and data packets among IP-RSUs and MA, the E2E paths (e.g., tunnels)

need to be protected by secure communication channels. In addition, to prevent bogus IP-RSUs and MA from interfering with the IPv6 mobility of vehicles, mutual authentication among them needs to be performed by certificates (e.g., TLS certificate).

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Appendix A. Changes from draft-ietf-ipwave-vehicular-networking-14

The following changes are made from draft-ietf-ipwave-vehicular-networking-14:

- This version is revised based on the comments from eight reviewers: Nancy Cam-Winget (Cisco), Fred L. Templin (The Boeing Company), Jung-Soo Park (ETRI), Zeungil (Ben) Kim (Hyundai Motors), Kyoungjae Sun (Soongsil University), Zhiwei Yan (CNNIC), Yong-Joon Joe (LSware), and Peter E. Yee (Akayla).

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Appendix C. Contributors

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