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IP 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 on IP-based vehicular networks, which are considered a key component of 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 surveys use cases using V2V, V2I, and V2X networking. Second, it analyzes proposed protocols for IP-based vehicular networking and highlights the limitations and difficulties found on those protocols. Third, it presents a problem exploration for key aspects in IP-based vehicular networking, such as IPv6 Neighbor Discovery, Mobility Management, and Security & Privacy. For each key aspect, this document discusses a problem statement to evaluate the gap between the state-of-the-art techniques and requirements in IP-based vehicular networking.

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1. Introduction

Vehicular networking studies have mainly focused on driving safety, driving efficiency, and entertainment in road networks. The Federal Communications Commission (FCC) in the US allocated wireless channels for Dedicated Short-Range Communications (DSRC) [DSRC], service in the Intelligent Transportation Systems (ITS) Radio Service in the 5.850 - 5.925 GHz band (5.9 GHz band). DSRC-based wireless communications can support vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) networking. Also, the European Union (EU) passed a decision to allocate radio spectrum for safety-related and non-safety-related applications of ITS with the frequency band of 5.875 - 5.905 GHz, which is called Commission Decision 2008/671/EC [EU-2008-671-EC].

For direct inter-vehicular wireless connectivity, IEEE has amended WiFi standard 802.11 to enable driving safety services based on the DSRC in terms of standards for the Wireless Access in Vehicular Environments (WAVE) system. L1 and 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. Note that IEEE 802.11p has been published as IEEE 802.11 Outside the Context of a Basic Service Set (OCB) called IEEE 802.11-OCB [IEEE-802.11-OCB] in 2012.

Along with these WAVE standards, IPv6 [RFC8200] and Mobile IP protocols (e.g., MIPv4 [RFC5944] and MIPv6 [RFC6275]) can be applied (or easily modified) to vehicular networks. In Europe, ETSI has standardized a GeoNetworking (GN) protocol [ETSI-GeoNetworking] and a protocol adaptation sub-layer from GeoNetworking to IPv6 [ETSI-GeoNetwork-IP]. Note that a GN protocol is useful to route an event or notification message to vehicles around a geographic position, such as an acciendent area in a roadway. 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].

This document discusses problem statements and use cases related to IP-based vehicular networking for Intelligent Transportation Systems (ITS), which is denoted as IP Wireless Access in Vehicular Environments (IPWAVE). First, it surveys the use cases for using V2V, V2I, and V2X networking in the ITS. Second, for literature review, it analyzes proposed protocols for IP-based vehicular networking and highlights the limitations and difficulties found on those protocols. Third, for problem statement, it presents a problem exploration with key aspects in IPWAVE, such as IPv6 Neighbor Discovery, Mobility Management, and Security & Privacy. For each key aspect of the problem statement, it analyzes the gap between the state-of-the-art techniques and the requirements in IP-based vehicular networking. It also discusses potential topics relevant to IPWAVE Working Group (WG), such as Vehicle Identities Management, Multihop V2X Communications, Multicast, DNS Naming Services, Service Discovery, and IPv6 over Cellular Networks. Therefore, with the problem statement, this document will open a door to develop key protocols for IPWAVE that will be essential to IP-based vehicular networks.

2. Terminology

This document uses the following definitions:

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

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

- Road-Side Unit (RSU): A node that has physical communication devices (e.g., DSRC, Visible Light Communication, 802.15.4, LTE-V2X, etc.) for wireless communications with vehicles and is also connected to the Internet as a router or switch for packet forwarding. An RSU is typically deployed on the road infrastructure, either at an intersection or in a road segment, but may also be located in car parking area.

- On-Board Unit (OBU): A node that has a DSRC device for wireless communications with other OBUs and RSUs, and may be connected to in-vehicle devices or networks. An OBU is mounted on a vehicle. It is assumed that a radio navigation receiver (e.g., Global Positioning System (GPS)) is included in a vehicle with an OBU for efficient navigation.

- o Vehicle Detection Loop (or Loop Detector): An inductive device used for detecting vehicles passing or arriving at a certain point, for instance approaching a traffic light or in motorway traffic. The relatively crude nature of the loop's structure means that only metal masses above a certain size are capable of triggering the detection.

- o Vehicular Cloud: A cloud infrastructure for vehicular networks, having compute nodes, storage nodes, and network nodes.

- o Traffic Control Center (TCC): A node that maintains road infrastructure information (e.g., RSUs, traffic signals, and loop detectors), 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 included in a vehicular cloud for vehicular networks.

3. Use Cases

This section provides 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).

3.1. V2V

The use cases of V2V networking discussed in this section include

- o Context-aware navigation for driving safety and collision avoidance;

- o Cooperative adaptive cruise control in an urban roadway;

- o Platooning in a highway;

- o 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 letting the drivers recognize dangerous obstacles and situations. That is, CASD navigator displays obstables 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, such as the Line-of-Sight unsafe, Non-Line-of-Sight unsafe and safe

situations. This action plan can be performed among vehicles through V2V networking.

Cooperative Adaptive Cruise Control (CACC) [CA-Cruise-Control] helps 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. CACC can help adjacent vehicles to efficiently adjust their speed in a cascade way through V2V networking.

Platooning [Truck-Platooning] allows a series of vehicles (e.g., trucks) to move together with a very short inter-distance. 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). This 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 from various vehicle-mounted sensors, such as radars, LiDARs and cameras with other vehicles and pedestrians. [Automotive-Sensing] introduces a millimeter-wave vehicular communication for massive automotive sensing. Data generated by those sensors can be substantially large, and these data shall 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 context.

3.2. V2I

The use cases of V2I networking discussed in this section include

o Navigation service;

o Energy-efficient speed recommendation service;

o Accident notification service.

A navigation service, such as the Self-Adaptive Interactive Navigation Tool (called SAINT) [SAINT], using V2I networking interacts with TCC for the large-scale/long-range road traffic optimization and can guide individual vehicles for appropriate navigation paths in real time. The enhanced SAINT (called SAINT+) [SAINTplus] can give the fast moving paths for emergency vehicles

(e.g., ambulance and fire engine) toward accident spots while providing other vehicles with efficient detour paths.

A TCC can recommend an energy-efficient speed to a vehicle driving in different traffic environments. [Fuel-Efficient] studies fuel-efficient route and speed plans for platooned trucks.

The emergency communication between accident vehicles (or emergency vehicles) and TCC can be performed via either 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, such as 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 FirstNet's network core. The current RAN is mainly constructed by 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 near future.

3.3. V2X

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

A pedestrian protection service, such as Safety-Aware Navigation Application (called SANA) [SANA], using V2I2P networking can reduce the collision of a vehicle and a pedestrian carrying a smartphone equipped with the access technology with an RSU (e.g., WiFi). Vehicles and pedestrians can also communicate with each other via an RSU that delivers scheduling information for wireless communication in order to save the smartphones' battery through sleeping mode.

For Vehicle-to-Pedestrian (V2P), a vehicle and a pedestrian's smartphone can directly communicate with each other via V2X without the relaying of an RSU as in a V2V scenario such that the pedestrian's smartphone is regarded as a vehicle with a wireless media interface to be able to communicate with another vehicle. In Vehicle-to-Device (V2D), a device can be a mobile node such as bicycle and motorcycle, and can communicate directly with a vehicle for collision avoidance.

4. Analysis for Existing Protocols

4.1. Existing Protocols for Vehicular Networking

We describe some currently existing protocols and proposed solutions with respect to the following aspects that are relevant and essential for vehicular networking:

- IPv6 over 802.11-OCB;
- IP address autoconfiguration;
- Routing;
- Mobility management;
- DNS naming service;
- Service discovery;
- Security and privacy.

4.1.1. IPv6 over 802.11-OCB

For IPv6 packets transporting over IEEE 802.11-OCB, [IPv6-over-802.11-OCB] specifies several details, such as Maximum Transmission Unit (MTU), frame format, link-local address, address mapping for unicast and multicast, stateless autoconfiguration, and subnet structure. Especially, an Ethernet Adaptation (EA) layer is in charge of transforming some parameters between IEEE 802.11 MAC layer and IPv6 network layer, which is located between IEEE 802.11-OCB's logical link control layer and IPv6 network layer.

4.1.2. IP Address Autoconfiguration

For IP address autoconfiguration, Fazio et al. proposed a vehicular address configuration (VAC) scheme using DHCP where elected leader-vehicles provide unique identifiers for IP address configurations in vehicles [Address-Autoconf]. Kato et al. proposed an IPv6 address assignment scheme using lane and position information [Address-Assignment]. Baldessari et al. proposed an IPv6 scalable address autoconfiguration scheme called GeoSAC for vehicular networks [GeoSAC]. Wetterwald et al. conducted for heterogeneous vehicular networks (i.e., employing multiple access technologies) a comprehensive study of the cross-layer identities management, which constitutes a fundamental element of the ITS architecture [Identity-Management].

4.1.3. Routing

For routing, Tsukada et al. presented a work that aims at combining IPv6 networking and a Car-to-Car Network routing protocol (called C2CNet) proposed by the Car2Car Communication Consortium (C2C-CC), which is an architecture using a geographic routing protocol [VANET-Geo-Routing]. Abrougui et al. presented a gateway discovery scheme for VANET, called Location-Aided Gateway Advertisement and Discovery (LAGAD) mechanism [LAGAD].

4.1.4. Mobility Management

For mobility management, Chen et al. tackled the issue of network fragmentation in VANET environments [IP-Passing-Protocol] by proposing a protocol that can postpone the time to release IP addresses to the DHCP server and select a faster way to get the vehicle's new IP address, when the vehicle density is low or the speeds of vehicles are highly variable. Nguyen et al. proposed a hybrid centralized-distributed mobility management called H-DMM to support highly mobile vehicles [H-DMM]. [NEMO-LMS] proposed an architecture to enable IP mobility for moving networks using a network-based mobility scheme based on PMIPv6. Chen et al. proposed a network mobility protocol to reduce handoff delay and maintain Internet connectivity to moving vehicles in a highway [NEMO-VANET]. Lee et al. proposed P-NEMO, which is a PMIPv6-based IP mobility management scheme to maintain the Internet connectivity at the vehicle as a mobile network, and provides a make-before-break mechanism when vehicles switch to a new access network [PMIP-NEMO-Analysis]. Peng et al. proposed a novel mobility management scheme for integration of VANET and fixed IP networks [VNET-MM]. Nguyen et al. extended their previous works on a vehicular adapted DMM considering a Software-Defined Networking (SDN) architecture [SDN-DMM].

4.1.5. DNS Naming Service

For DNS naming service, Multicast DNS (mDNS) [RFC6762] allows devices in one-hop communication range to resolve each other's DNS name into the corresponding IP address in multicast. DNS Name Autoconfiguration (DNSNA) [ID-DNSNA] proposes a DNS naming service for Internet-of-Things (IoT) devices in a large-scale network.

4.1.6. Service Discovery

To discover instances of a demanded service in vehicular networks, DNS-based Service Discovery (DNS-SD) [RFC6763] with either DNSNA [ID-DNSNA] or mDNS [RFC6762] provides vehicles with service discovery by using standard DNS queries. Vehicular ND [ID-Vehicular-ND]

proposes an extension of IPv6 ND for the prefix and service discovery. Note that a DNS query for service discovery is unicasted in DNSNA, but it is multicasted in both mDNS and Vehicular ND.

4.1.7. Security and Privacy

For security and privacy, Fernandez et al. proposed a secure vehicular IPv6 communication scheme using Internet Key Exchange version 2 (IKEv2) and Internet Protocol Security (IPsec) [Securing-VCOMM]. Moustafa et al. proposed a security scheme providing authentication, authorization, and accounting (AAA) services in vehicular networks [VNET-AAA].

```
                            *-------------*
                           *               *         +-------+
                          * Vehicular Cloud *<------>|  TCC  |
                           *               *         +_______+
                            *-------------*
                           ^               ^
                           |               |
                           | V2I       V2I |
                           v               v
                   +--------+             +--------+
                   |  RSU1  |<----------->|  RSU2  |
                   +________+             +________+
                   ^        ^                  ^
                   :        :                  :
                   :        :                  :
                   v        v                  v
           +--------+      +--------+      +--------+
           |Vehicle1|=>    |Vehicle2|=>    |Vehicle3|=>
           |        |<....>|        |<....>|        |
           +________+ V2V  +________+ V2V  +________+


   <----> Wired Link   <....> Wireless Link   => Moving Direction
```

Figure 1: A Vehicular Network Architecture for V2I and V2V Networking

4.2. General Problems

This section describes a possible vehicular network architecture for V2V, V2I, and V2X communications. Then it analyzes the limitations of the current protocols for vehicular networking.

4.2.1. Vehicular Network Architecture

Figure 1 shows a possible architecture for V2I and V2V networking in a road network. It is assumed that RSUs as routers and vehicles with OBU have wireless media interfaces (e.g., IEEE 802.11-OCB, LTE Uu and Device-to-Device (D2D) (also known as PC5 [TS-23.285-3GPP]), Bluetooth, and Light Fidelity (Li-Fi)) for V2I and V2V communication. Also, it is assumed that such 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. The two RSUs (RSU1 and RSU2) are deployed in the road network and are connected to a Vehicular Cloud through the Internet. TCC is connected to the Vehicular Cloud and the two vehicles (Vehicle1 and Vehicle2) are wirelessly connected to RSU1, and the last vehicle (Vehicle3) is wirelessly connected to RSU2. Vehicle1 can communicate with Vehicle2 via V2V communication, and Vehicle2 can communicate with Vehicle3 via V2V communication. Vehicle1 can communicate with Vehicle3 via RSU1 and RSU2 employing V2I (i.e., V2I2V) communication.

In vehicular networks, unidirectional links exist and must be considered for wireless communications. Also, in the vehicular networks, control plane must be separated from data plane for efficient mobility management and data forwarding using Software-Defined Networking (SDN) [SDN-DMM]. ID/Pseudonym change for privacy requires a lightweight DAD. IP tunneling over the wireless link should be avoided for performance efficiency. The mobility information of a mobile (e.g., vehicle-mounted) device through a GPS receiver in its vehicle, such as trajectory, position, speed, and direction, can be used by the mobile device and infrastructure nodes (e.g., TCC and RSU) for the accommodation of mobility-aware proactive protocols. Vehicles can use the TCC as their Home Network having a home agent for mobility management as in MIPv6 [RFC6275] and Proxy Mobile IPv6 (PMIPv6) [RFC5213], so the TCC maintains the mobility information of vehicles for location management.

Cespedes et al. proposed a vehicular IP in WAVE called VIP-WAVE for I2V and V2I networking [VIP-WAVE]. The standard WAVE does not support both seamless communications for Internet services and multi-hop communications between a vehicle and an infrastructure node (e.g., RSU), either. To overcome these limitations of the standard WAVE, VIP-WAVE enhances the standard WAVE by the following three schemes: (i) an efficient mechanism for the IPv6 address assignment and DAD, (ii) on-demand IP mobility based on PMIPv6 [RFC5213], and (iii) one-hop and two-hop communications for I2V and V2I networking.

Baccelli et al. provided an analysis of the operation of IPv6 as it has been described by the IEEE WAVE standards 1609 [IPv6-WAVE]. This analysis confirms that the use of the standard IPv6 protocol stack in

WAVE is not sufficient. It recommends that the IPv6 addressing assignment should follow considerations for ad-hoc link models, defined in [RFC5889] for nodes' mobility and link variability.

Petrescu et al. proposed the joint IP networking and radio architecture for V2V and V2I communication in [Joint-IP-Networking]. The proposed architecture considers an IP topology in a similar way as a radio link topology, in the sense that an IP subnet would correspond to the range of 1-hop vehicular communication. This architecture defines three types of vehicles: Leaf Vehicle, Range Extending Vehicle, and Internet Vehicle.

```
                                                    +----------------+
                           (*)<........>(*)  +----->| Vehicular Cloud|
          2001:DB8:1:1::/64 |            |   |      +----------------+
   +------------------------------+  +---------------------------------+
   |                        v     |  |   v   v                         |
   | .-------. .------. .-------. |  | .-------. .------. .-------.    |
   | | Host1 | |RDNSS1| |Router1| |  | |Router3| |RDNSS2| | Host3 |    |
   | ._______. .______. ._______. |  | ._______. .______. ._______.    |
   |     ^        ^         ^     |  |     ^         ^        ^        |
   |     |        |         |     |  |     |         |        |        |
   |     v        v         v     |  |     v         v        v        |
   | ---------------------------- |  | ------------------------------- |
   | 2001:DB8:10:1::/64 ^         |  |     ^ 2001:DB8:20:1::/64        |
   |                    |         |  |     |                           |
   |                    v         |  |     v                           |
   | .-------.      .-------.     |  | .-------. .-------.   .-------. |
   | | Host2 |      |Router2|     |  | |Router4| |Server1|...|ServerN| |
   | ._______.      ._______.     |  | ._______. ._______.   ._______. |
   |     ^              ^         |  |     ^         ^           ^     |
   |     |              |         |  |     |         |           |     |
   |     v              v         |  |     v         v           v     |
   | ---------------------------- |  | ------------------------------- |
   |  2001:DB8:10:2::/64          |  |       2001:DB8:20:2::/64        |
   +______________________________+  +_________________________________+
      Vehicle1 (Moving Network1)            RSU1 (Fixed Network1)

      <----> Wired Link   <....> Wireless Link   (*) Antenna
```

Figure 2: Internetworking between Vehicle Network and RSU Network

4.2.1.1. V2I-based Internetworking

This section discusses the internetworking between a vehicle's moving network and an RSU's fixed network via V2I communication.

As shown in Figure 2, the vehicle's moving network and the RSU's fixed network are self-contained networks having multiple subnets and having an edge router for the communication with another vehicle or RSU. The method of prefix assignment for each subnet inside the vehicle's mobile network and the RSU's fixed network is out of scope for this document. Internetworking between two internal networks via V2I communication requires an exchange of network prefix and other parameters through a prefix discovery mechanism, such as ND-based prefix discovery [ID-Vehicular-ND]. For the ND-based prefix discovery, network prefixes and parameters should be registered into a vehicle's router and an RSU router with an external network interface in advance.

The network parameter discovery collects networking information for an IP communication between a vehicle and an RSU or between two neighboring vehicles, such as link layer, MAC layer, and IP layer information. The link layer information includes wireless link layer parameters, such as wireless media (e.g., IEEE 802.11-OCB, LTE Uu and D2D, Bluetooth, and LiFi) and a transmission power level. Note that LiFi is a technology for light-based wireless communication between devices in order to transmit both data and position. The MAC layer information includes the MAC address of an external network interface for the internetworking with another vehicle or RSU. The IP layer information includes the IP address and prefix of an external network interface for the internetworking with another vehicle or RSU.

Once the network parameter discovery and prefix exchange operations have been performed, packets can be transmitted between the vehicle's moving network and the RSU's fixed network. DNS services should be supported to enable name resolution for hosts or servers residing either in the vehicle's moving network or the RSU's fixed network. It is assumed that the DNS names of in-vehicle devices and their service names are registered into a DNS server (i.e., recursive DNS server called RDNSS) in a vehicle or an RSU, as shown in Figure 2. For service discovery, those DNS names and service names can be advertised to neighboring vehicles through either DNS-based service discovery mechanisms [RFC6762][RFC6763][ID-DNSNA] and ND-based service discovery [ID-Vehicular-ND]. For the ND-based service discovery, service names should be registered into a vehicle's router and an RSU router with an external network interface in advance. Refer to Section 4.1.5 and Section 4.1.6 for detailed information. For these DNS services, an RDNSS within each internal network of a vehicle or RSU can be used for the hosts or servers.

Figure 2 shows internetworking between the vehicle's moving network and the RSU's fixed network. There exists an internal network (Moving Network1) inside Vehicle1. Vehicle1 has the DNS Server (RDNSS1), the two hosts (Host1 and Host2), and the two routers

(Router1 and Router2). There exists another internal network (Fixed Network1) inside RSU1. RSU1 has the DNS Server (RDNSS2), one host (Host3), the two routers (Router3 and Router4), and the collection of servers (Server1 to ServerN) for various services in the road networks, such as the emergency notification and navigation. Vehicle1's Router1 (called mobile router) and RSU1's Router3 (called fixed router) use 2001:DB8:1:1::/64 for an external link (e.g., DSRC) for I2V networking.

```
                           (*)<..........>(*)
          2001:DB8:1:1::/64 |              |
   +------------------------------+  +---------------------------------+
   |                        v     |  |     v                           |
   | .-------. .------. .-------. |  | .-------. .------. .-------.    |
   | | Host1 | |RDNSS1| |Router1| |  | |Router5| |RDNSS3| | Host4 |    |
   | ._______. .______. ._______. |  | ._______. .______. ._______.    |
   |     ^        ^         ^     |  |     ^         ^        ^        |
   |     |        |         |     |  |     |         |        |        |
   |     v        v         v     |  |     v         v        v        |
   | ---------------------------- |  | ------------------------------- |
   | 2001:DB8:10:1::/64 ^         |  |     ^ 2001:DB8:30:1::/64        |
   |                    |         |  |     |                           |
   |                    v         |  |     v                           |
   | .-------.      .-------.     |  | .-------.      .-------.        |
   | | Host2 |      |Router2|     |  | |Router6|      | Host5 |        |
   | ._______.      ._______.     |  | ._______.      ._______.        |
   |     ^              ^         |  |     ^              ^            |
   |     |              |         |  |     |              |            |
   |     v              v         |  |     v              v            |
   | ---------------------------- |  | ------------------------------- |
   |  2001:DB8:10:2::/64          |  |       2001:DB8:30:2::/64        |
   +______________________________+  +_________________________________+
      Vehicle1 (Moving Network1)        Vehicle2 (Moving Network2)

      <----> Wired Link   <....> Wireless Link   (*) Antenna
```

Figure 3: Internetworking between Two Vehicle Networks

4.2.1.2. V2V-based Internetworking

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

Figure 3 shows internetworking between the moving networks of two neighboring vehicles. There exists an internal network (Moving Network1) inside Vehicle1. Vehicle1 has the DNS Server (RDNSS1), the two hosts (Host1 and Host2), and the two routers (Router1 and Router2). There exists another internal network (Moving Network2)

inside Vehicle2. Vehicle2 has the DNS Server (RDNSS2), the two hosts (Host3 and Host4), and the two routers (Router3 and Router4). Vehicle1's Router1 (called mobile router) and Vehicle2's Router3 (called mobile router) use 2001:DB8:1:1::/64 for an external link (e.g., DSRC) for V2V networking.

The differences between IPWAVE (including Vehicular Ad Hoc Networks (VANET)) and Mobile Ad Hoc Networks (MANET) are as follows:

o IPWAVE is not power-constrained operation;

o Traffic can be sourced or sinked outside of IPWAVE;

o IPWAVE shall support both distributed and centralized operations;

o No "sleep" period operation is required for energy saving.

4.2.2. Latency

The communication delay (i.e., latency) between two vehicular nodes (vehicle and RSU) should be bounded to a certain threshold. For IP-based safety applications (e.g., context-aware navigation, adaptive cruise control, and platooning) in vehicular network, this bounded data delivery is critical. The real implementations for such applications are not available, so the feasibility of IP-based safety applications is not tested yet.

4.2.3. Security

Strong security measures shall protect vehicles roaming in road networks from the attacks of malicious nodes, which are controlled by hackers. For safety applications, the cooperation among vehicles is assumed. Malicious nodes may disseminate wrong driving information (e.g., location, speed, and direction) to make driving be unsafe. Sybil attack, which tries to illude a vehicle with multiple false identities, disturbs a vehicle in taking a safe maneuver. Applications on IP-based vehicular networking, which are resilient to such a sybil attack, are not developed and tested yet.

4.2.4. Pseudonym Handling

For the protection of drivers' privacy, pseudonym for a vehicle's network interface should be used, with the help of which the interface's identifier can be changed periodically. Such a pseudonym affects an IPv6 address based on the network interface's identifier, and a transport-layer (e.g., TCP) session with an IPv6 address pair. The pseudonym handling is not implemented and tested yet for applications on IP-based vehicular networking.

5. Problem Exploration

This section discusses key topics for IPWAVE WG, such as neighbor discovery, mobility management, and security & privacy.

5.1. Neighbor Discovery

Neighbor Discovery (ND) [RFC4861] is a core part of the IPv6 protocol suite. This section discusses the need for modifying ND for use with vehicular networking (e.g., V2V, V2I, and V2X). The vehicles are moving fast within the communication coverage of a vehicular node (e.g., vehicle and RSU). The external wireless link between two vehicular nodes can be used for vehicular networking, as shown in Figure 2 and Figure 3.

ND time-related parameters such as router lifetime and Neighbor Advertisement (NA) interval should be adjusted for high-speed vehicles and vehicle density. As vehicles move faster, the NA interval should decrease for the NA messages to reach the neighboring vehicles promptly. Also, as vehicle density is higher, the NA interval should increase for the NA messages to reduce collision probability with other NA messages.

5.1.1. Link Model

IPv6 protocols work under certain assumptions for the link model that do not necessarily hold in WAVE [IPv6-WAVE]. For instance, some IPv6 protocols assume symmetry in the connectivity among neighboring interfaces. However, interference and different levels of transmission power may cause unidirectional links to appear in a WAVE link model.

There is a relationship between a link and 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 IP link or extended IP links via ND proxy. Note that a subnet prefix can be used by spanning multiple links as a multi-link subnet [RFC6775]. Also, note that IPv6 Stateless Address Autoconfiguration can be performed in the multiple links where each of them is not assigned with a unique subnet prefix, that is, all of them are configured with the same subnet prefix [RFC4861][RFC4862]. A WAVE link model needs to consider a multi-hop VANET over a multi-link subnet. Such a VANET is usually a multi-link subnet consisting of multiple vehicles interconnected by wireless communication range. Such a subnet has a highly dynamic topology over time due to node mobility.

Thus, IPv6 ND should be extended to support the concept of an IPv6 link corresponding to an IPv6 prefix even in a multi-link subnet consisting of multiple vehicles and RSUs that are interconnected with wireless communication range in vehicular networks.

5.1.2. MAC Address Pseudonym

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 should be updated. For the continuity of an end-to-end (E2E) transport-layer (e.g., TCP, UDP, and SCTP) session, the new IP addresses of the transport-layer session should be notified to both the end points and the packets of the session should be forwarded to their destinations with the changed network interface identifier and IPv6 address.

5.1.3. Prefix Dissemination/Exchange

A vehicle and an RSU can have their internal network, as shown in Figure 2 and Figure 3. In this case, nodes in within the internal networks of two vehicular nodes (e.g., vehicle and RSU) want to communicate with each other. For this communication on the wireless link, the network prefix dissemination or exchange is required. It is assumed that a vehicular node has an external network interface and its internal network. The standard IPv6 ND needs to be extended for the communication between the internal-network vehicular nodes by letting each of them know the other side's prefix with a new ND option [ID-Vehicular-ND]. Thus, this ND extension for routing functionality can reduce control traffic for routing in vehicular networks.

5.1.4. Routing

For Neighbor Discovery in vehicular networks (called vehicular ND), Ad Hoc routing is required for either unicast or multicast in the links in a connected VANET with the same IPv6 prefix [GeoSAC]. Also, a rapid DAD should be supported to prevent or reduce IPv6 address conflicts in a multi-link subnet for both V2V and V2I by using a DAD optimization [RFC6775].

5.2. Mobility Management

The seamless connectivity and timely data exchange between two end points requires an efficient mobility management including location management and handover. Most of vehicles are equipped with a GPS

receiver as part of a dedicated navigation system or a corresponding smartphone App. In the case where the provided location information is precise enough, well-known temporary degradations in precision may occur due to system configuration or the adverse local environment. This precision is improved thanks to assistance by the RSUs or a cellular system with this navigation system. With this GPS navigator, an efficient mobility management is possible by vehicles periodically reporting their current position and trajectory (i.e., navigation path) to TCC. TCC can predict the future positions of the vehicles with their mobility information (i.e., the current position, speed, direction, and trajectory) for location management.

With the prediction of the vehicle mobility, TCC can support RSUs to perform DAD, data packet routing, 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 a proactive manner. When it is assigned a new IPv6 address belonging to a different subnet, a vehicle can skip the DAD operation, reducing IPv6 control traffic overhead. RSUs can efficiently forward data packets from the wired network to a moving destination vehicle along its trajectory. RSUs can smoothly perform handover for the sake of a moving vehicle along its trajectory.

5.3. Security and Privacy

Security and privacy are paramount in the V2I, V2V, and V2X networking in vehicular networks. Only authorized vehicles should be allowed to use vehicular networking. Also, in-vehicle devices and mobile devices in a vehicle need to communicate with other in-vehicle devices and mobile devices in another vehicle, and other servers in an RSU in a secure way.

A Vehicle Identification Number (VIN) and a user certificate along with in-vehicle device's identifier generation can be used to efficiently authenticate a vehicle or a user through a road infrastructure node (e.g., RSU) connected to an authentication server in TCC. Also, Transport Layer Security (TLS) certificates can be used for secure E2E vehicle communications.

For secure V2I communication, a secure channel between a mobile router in a vehicle and a fixed router in an RSU should be established, as shown in Figure 2. Also, for secure V2V communication, a secure channel between a mobile router in a vehicle and a mobile router in another vehicle should be established, as shown in Figure 3.

To prevent an adversary from tracking a vehicle with its MAC address or IPv6 address, MAC address pseudonym should be provided to the

vehicle; that is, each vehicle should periodically update its MAC address and the corresponding IPv6 address as suggested in [RFC4086][RFC4941]. Such an update of the MAC and IPv6 addresses should not interrupt the E2E communications between two vehicular nodes (e.g., vehicle and RSU) in terms of transport layer for a long-living higher-layer session. However, if this pseudonym is performed without strong E2E confidentiality, there will be no privacy benefit from changing MAC and IP addresses, because an adversary can see the change of the MAC and IP addresses and track the vehicle with those addresses.

6. Security Considerations

This document discussed security and privacy for IP-based vehicular networking.

The security and privacy for key components in IP-based vehicular networking, such as neighbor discovery and mobility management, need to be analyzed in depth.

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Appendix A. Relevant Topics to IPWAVE Working Group

This section discusses topics relevant to IPWAVE WG: (i) vehicle identity management; (ii) multihop V2X; (iii) multicast; (iv) DNS naming services and service discovery; (v) IPv6 over cellular networks.

A.1. Vehicle Identity Management

A vehicle can have multiple network interfaces using different access network technologies [Identity-Management]. These multiple network interfaces mean multiple identities. To identify a vehicle with multiple indenties, a Vehicle Identification Number (VIN) can be used as a globally unique vehicle identifier.

To support the seamless connectivity over the multiple identities, a cross-layer network architecture is required with vertical handover functionality [Identity-Management]. Also, an AAA service for multiple identities should be provided to vehicles in an efficient way to allow horizontal handover as well as vertical handover; note that AAA stands for Authentication, Authorization, and Accounting.

A.2. Multihop V2X

Multihop packet forwarding among vehicles in 802.11-OCB mode shows an unfavorable performance due to the common known broadcast-storm problem [Broadcast-Storm]. This broadcast-storm problem can be mitigated by the coordination (or scheduling) of a cluster head in a connected VANET or an RSU in an intersection area, where the cluster head can work as a coodinator for the access to wireless channels.

A.3. Multicast

IP multicast in vehicular network environments is especially useful for various services. For instance, an automobile manufacturer can multicast a particular group/class/type of vehicles for service notification. As another example, a vehicle or an RSU can disseminate alert messages in a particular area [Multicast-Alert].

In general IEEE 802 wireless media, some performance issues about multicast are found in [Multicast-802]. Since several procedures and functions based on IPv6 use multicast for control-plane messages, such as Neighbor Discovery (ND) and Service Discovery, [Multicast-802] describes that the ND process may fail due to unreliable wireless link, causing failure of the DAD process. Also, the Router Advertisement messages can be lost in multicasting.

A.4. DNS Naming Services and Service Discovery

When two vehicular nodes communicate with each other using the DNS name of the partner node, DNS naming service (i.e., DNS name resolution) is required. As shown in Figure 2 and Figure 3, a recursive DNS server (RDNSS) within an internal network can perform such DNS name resolution for the sake of other vehicular nodes.

A service discovery service is required for an application in a vehicular node to search for another application or server in another vehicular node, which resides in either the same internal network or the other internal network. In V2I or V2V networking, as shown in Figure 2 and Figure 3, such a service discovery service can be provided by either DNS-based Service Discovery (DNS-SD) [RFC6763] with mDNS [RFC6762] or the vehicular ND with a new option for service discovery [ID-Vehicular-ND].

A.5. IPv6 over Cellular Networks

Recently, 3GPP has announced a set of new technical specifications, such as Release 14 (3GPP-R14), which proposes an architecture enhancements for V2X services using the modified sidelink interface that originally is designed for the LTE-D2D communications. 3GPP-R14 specifies that the V2X services only support IPv6 implementation. 3GPP is also investigating and discussing the evolved V2X services in the next generation cellular networks, i.e., 5G new radio (5G-NR), for advanced V2X communications and automated vehicles' applications.

A.5.1. Cellular V2X (C-V2X) Using 4G-LTE

Before 3GPP-R14, some researchers have studied the potential usage of C-V2X communications. For example, [VMaSC-LTE] explores a multihop cluster-based hybrid architecture using both DSRC and LTE for safety message dissemination. Most of the research considers a short message service for safety instead of IP datagram forwarding. In other C-V2X research, the standard IPv6 is assumed.

The 3GPP technical specification [TS-23.285-3GPP] states that both IP based and non-IP based V2X messages are supported, and only IPv6 is supported for IP based messages. Moreover, [TS-23.285-3GPP] instructs that a UE autoconfigures a link-local IPv6 address by following [RFC4862], but without sending Neighbor Solicitation and Neighbor Advertisement messages for DAD. This is because a unique prefix is allocated to each node by the 3GPP network, so the IPv6 addresses cannot be duplicate.

A.5.2. Cellular V2X (C-V2X) Using 5G

The emerging services, functions, and applications, which are developped in automotive industry, demand reliable and efficient communication infrastructure for road networks. Correspondingly, the support of enhanced V2X (eV2X)-based services by future converged and interoperable 5G systems is required. The 3GPP Technical Report [TR-22.886-3GPP] is studying new use cases and the corresponding service requirements for V2X (including V2V and V2I) using 5G in both infrastructure mode and the sidelink variations in the future.

Appendix B. Changes from draft-ietf-ipwave-vehicular-networking-04

The following changes are made from draft-ietf-ipwave-vehicular-networking-04:

- In Section 1, the explanation about Geographic routing is added.

- In Section 4.2.1, an assumption is added for a wireless media interface of a vehicle and an RSU for V2V and V2I communication.

- In Section 5.1.1, a WAVE link model is clarified through the comparison with the legacy IPv6 link model.

- Many places are corrected for better explanation along with typo correction.

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