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Transmission of IPv6 Packets over IEEE 802.11 Networks operating in mode Outside the Context of a Basic Service Set (IPv6-over-80211-OCB) draft-ietf-ipwave-ipv6-over-80211ocb-30

Abstract

In order to transmit IPv6 packets on IEEE 802.11 networks running outside the context of a basic service set (OCB, earlier "802.11p") there is a need to define a few parameters such as the supported Maximum Transmission Unit size on the 802.11-OCB link, the header format preceding the IPv6 header, the Type value within it, and others. This document describes these parameters for IPv6 and IEEE 802.11-OCB networks; it portrays the layering of IPv6 on 802.11-OCB similarly to other known 802.11 and Ethernet layers - by using an Ethernet Adaptation Layer.

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1. Introduction

This document describes the transmission of IPv6 packets on IEEE Std 802.11-OCB networks [IEEE-802.11-2016] (a.k.a "802.11p" see Appendix B, Appendix C and Appendix D). This involves the layering of IPv6 networking on top of the IEEE 802.11 MAC layer, with an LLC layer. Compared to running IPv6 over the Ethernet MAC layer, there is no modification expected to IEEE Std 802.11 MAC and Logical Link sublayers: IPv6 works fine directly over 802.11-OCB too, with an LLC layer.

The IPv6 network layer operates on 802.11-OCB in the same manner as operating on Ethernet, but there are two kinds of exceptions:

- Exceptions due to different operation of IPv6 network layer on 802.11 than on Ethernet. To satisfy these exceptions, this document describes an Ethernet Adaptation Layer between Ethernet headers and 802.11 headers. The Ethernet Adaptation Layer is described Section 4.3.1. The operation of IP on Ethernet is described in [RFC1042], [RFC2464] and [I-D.hinden-6man-rfc2464bis].

- Exceptions due to the OCB nature of 802.11-OCB compared to 802.11. This has impacts on security, privacy, subnet structure and handover behaviour. For security and privacy recommendations see Section 5 and Section 4.6. The subnet structure is described in Section 4.7. The handover behaviour on OCB links is not described in this document.

The Security Considerations section describes security and privacy aspects of 802.11-OCB.

In the published literature, many documents describe aspects and problems related to running IPv6 over 802.11-OCB: [I-D.ietf-ipwave-vehicular-networking-survey].

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

IP-OBU (Internet Protocol On-Board Unit): an IP-OBU is a computer situated in a vehicle such as an automobile, bicycle, or similar. It has at least one IP interface that runs in mode OCB of 802.11, and that has an "OBU" transceiver. See the definition of the term "OBU" in section Appendix I.

IP-RSU (IP Road-Side 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 in the vehicle over 802.11 wireless link operating in OCB mode. An IP-RSU is similar to an Access Network Router (ANR) defined in [RFC3753], and a Wireless Termination Point (WTP) defined in [RFC5415].

OCB (outside the context of a basic service set - BSS): A mode of operation in which a STA is not a member of a BSS and does not utilize IEEE Std 802.11 authentication, association, or data confidentiality.

802.11-OCB: mode specified in IEEE Std 802.11-2016 when the MIB attribute dot11OCBActivited is true. Note: compliance with standards and regulations set in different countries when using the 5.9GHz frequency band is required.

3. Communication Scenarios where IEEE 802.11-OCB Links are Used

The IEEE 802.11-OCB Networks are used for vehicular communications, as 'Wireless Access in Vehicular Environments'. The IP communication scenarios for these environments have been described in several documents; in particular, we refer the reader to [I-D.ietf-ipwave-vehicular-networking-survey], that lists some scenarios and requirements for IP in Intelligent Transportation Systems.

The link model is the following: STA --- 802.11-OCB --- STA. In vehicular networks, STAs can be IP-RSUs and/or IP-OBUs. While 802.11-OCB is clearly specified, and the use of IPv6 over such link is not radically new, the operating environment (vehicular networks) brings in new perspectives.

The mechanisms for forming and terminating, discovering, peering and mobility management for 802.11-OCB links are not described in this document.

4. IPv6 over 802.11-OCB

4.1. Pseudonym Handling

Pseudonym.

4.2. Maximum Transmission Unit (MTU)

The default MTU for IP packets on 802.11-OCB MUST be 1500 octets. It is the same value as IPv6 packets on Ethernet links, as specified in [RFC2464]. This value of the MTU respects the recommendation that every link on the Internet must have a minimum MTU of 1280 octets (stated in [RFC8200], and the recommendations therein, especially with respect to fragmentation).

4.3. Frame Format

IP packets MUST be transmitted over 802.11-OCB media as QoS Data frames whose format is specified in IEEE Std 802.11.

The IPv6 packet transmitted on 802.11-OCB MUST be immediately preceded by a Logical Link Control (LLC) header and an 802.11 header. In the LLC header, and in accordance with the EtherType Protocol Discrimination (EPD), the value of the Type field MUST be set to 0x86DD (IPv6). In the 802.11 header, the value of the Subtype sub-field in the Frame Control field MUST be set to 8 (i.e. 'QoS Data'); the value of the Traffic Identifier (TID) sub-field of the QoS Control field of the 802.11 header MUST be set to binary 001 (i.e. User Priority 'Background', QoS Access Category 'AC_BK').

To simplify the Application Programming Interface (API) between the operating system and the 802.11-OCB media, device drivers MAY implement an Ethernet Adaptation Layer that translates Ethernet II frames to the 802.11 format and vice versa. An Ethernet Adaptation Layer is described in Section 4.3.1.

4.3.1. Ethernet Adaptation Layer

An 'adaptation' layer is inserted between a MAC layer and the Networking layer. This is used to transform some parameters between their form expected by the IP stack and the form provided by the MAC layer.

An Ethernet Adaptation Layer makes an 802.11 MAC look to IP Networking layer as a more traditional Ethernet layer. At reception, this layer takes as input the IEEE 802.11 header and the Logical-Link Layer Control Header and produces an Ethernet II Header. At sending, the reverse operation is performed.

The operation of the Ethernet Adaptation Layer is depicted by the double arrow in Figure 1.

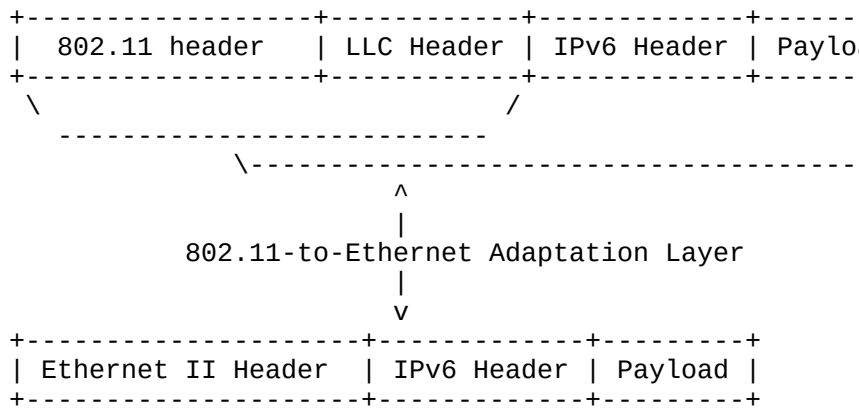

Figure 1: Operation of the Ethernet Adaptation Layer

The Receiver and Transmitter Address fields in the 802.11 header MUST contain the same values as the Destination and the Source Address fields in the Ethernet II Header, respectively. The value of the Type field in the LLC Header MUST be the same as the value of the Type field in the Ethernet II Header. That value MUST be set to 0x86DD (IPv6).

The ".11 Trailer" contains solely a 4-byte Frame Check Sequence.

The placement of IPv6 networking layer on Ethernet Adaptation Layer is illustrated in Figure 2.

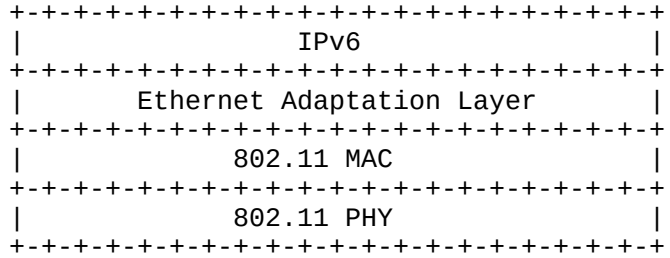

Figure 2: Ethernet Adaptation Layer stacked with other layers

(in the above figure, a 802.11 profile is represented; this is used also for 802.11-OCB profile.)

4.4. Link-Local Addresses

There are several types of IPv6 addresses [RFC4291], [RFC4193], that MAY be assigned to an 802.11-OCB interface. Among these types of addresses only the IPv6 link-local addresses MAY be formed using an EUI-64 identifier.

If the IPv6 link-local address is formed using an EUI-64 identifier, then the mechanism of forming that address is the same mechanism as used to form an IPv6 link-local address on Ethernet links. This mechanism is described in section 5 of [RFC2464].

For privacy, the link-local address MAY be formed according to the mechanisms described in Section 5.2.

4.5. Address Mapping

Unicast and multicast address mapping MUST follow the procedures specified for Ethernet interfaces in sections 6 and 7 of [RFC2464].

4.5.1. Address Mapping -- Unicast

The procedure for mapping IPv6 unicast addresses into Ethernet link-layer addresses is described in [RFC4861].

4.5.2. Address Mapping -- Multicast

The multicast address mapping is performed according to the method specified in section 7 of [RFC2464]. The meaning of the value "3333" mentioned in that section 7 of [RFC2464] is defined in section 2.3.1 of [RFC7042].

Transmitting IPv6 packets to multicast destinations over 802.11 links proved to have some performance issues [I-D.perkins-intarea-multicast-ieee802]. These issues may be exacerbated in OCB mode. Solutions for these problems should consider the OCB mode of operation.

4.6. Stateless Autoconfiguration

There are several types of IPv6 addresses [RFC4291], [RFC4193], that MAY be assigned to an 802.11-OCB interface. This section describes the formation of Interface Identifiers for IPv6 addresses of type ’Global’ or ’Unique Local’. For Interface Identifiers for IPv6 address of type ’Link-Local’ see Section 4.4.

The Interface Identifier for an 802.11-OCB interface is formed using the same rules as the Interface Identifier for an Ethernet interface; the RECOMMENDED method for forming stable Interface Identifiers (IIDs) is described in [RFC8064]. The method of forming IIDs described in section 4 of [RFC2464] MAY be used during transition time.

The bits in the Interface Identifier have no generic meaning and the identifier should be treated as an opaque value. The bits 'Universal' and 'Group' in the identifier of an 802.11-OCB interface are significant, as this is an IEEE link-layer address. The details of this significance are described in [RFC7136]. If semantically opaque Interface Identifiers are needed, a potential method for generating semantically opaque Interface Identifiers with IPv6 Stateless Address Autoconfiguration is given in [RFC7217].

Semantically opaque Interface Identifiers, instead of meaningful Interface Identifiers derived from a valid and meaningful MAC address ([RFC2464], section 4), MAY be needed in order to avoid certain privacy risks.

A valid MAC address includes a unique identifier pointing to a company together with its postal address, and a unique number within that company MAC space (see the oui.txt file). The calculation operation of the MAC address back from a given meaningful Interface Identifier is straightforward ([RFC2464], section 4). The Interface Identifier is part of an IPv6 address that is stored in IPv6 packets. The IPv6 packets can be captured in the Internet easily. For these reasons, an attacker may realize many attacks on privacy. One such attack on 802.11-OCB is to capture, store and correlate Company ID information of many cars in public areas (e.g. listen for Router Advertisements, or other IPv6 application data packets, and record the value of the source address in these packets). Further correlation of this information with other data captured by other means, or other visual information (car color, others) MAY constitute privacy risks.

In order to avoid these risks, opaque Interface Identifiers MAY be formed according to rules described in [RFC7217]. These opaque Interface Identifiers are formed starting from identifiers different than the MAC addresses, and from cryptographically strong material. Thus, privacy sensitive information is absent from Interface IDs, and it is impossible to calculate the initial value from which the Interface ID was calculated.

Some applications that use IPv6 packets on 802.11-OCB links (among other link types) may benefit from IPv6 addresses whose Interface Identifiers don't change too often. It is RECOMMENDED to use the

mechanisms described in RFC 7217 to permit the use of Stable Interface Identifiers that do not change within one subnet prefix. A possible source for the Net-Iface Parameter is a virtual interface name, or logical interface name, that is decided by a local administrator.

The way Interface Identifiers are used MAY involve risks to privacy, as described in Section 5.1.

4.7. Subnet Structure

A subnet is formed by the external 802.11-OCB interfaces of vehicles that are in close range (not by their in-vehicle interfaces). This subnet MUST use at least the link-local prefix fe80::/10 and the interfaces MUST be assigned IPv6 addresses of type link-local. This subnet MAY NOT have any other prefix than the link-local prefix.

The structure of this subnet is ephemeral, in that it is strongly influenced by the mobility of vehicles: the 802.11 hidden node effects appear; the 802.11 networks in OCB mode may be considered as 'ad-hoc' networks with an addressing model as described in [RFC5889]. On another hand, the structure of the internal subnets in each car is relatively stable.

As recommended in [RFC5889], when the timing requirements are very strict (e.g. fast drive through IP-RSU coverage), no on-link subnet prefix should be configured on an 802.11-OCB interface. In such cases, the exclusive use of IPv6 link-local addresses is RECOMMENDED.

Additionally, even if the timing requirements are not very strict (e.g. the moving subnet formed by two following vehicles is stable, a fixed IP-RSU is absent), the subnet is disconnected from the Internet (a default route is absent), and the addressing peers are equally qualified (impossible to determine that some vehicle owns and distributes addresses to others) the use of link-local addresses is RECOMMENDED.

The Neighbor Discovery protocol (ND) [RFC4861] is used over 802.11-OCB links. The reliability of the ND protocol over 802.11-OCB is the reliability of the delivery of ND multicast messages. This reliability is the same as the reliability of delivery of ND multicast messages over 802.11 links operated with a BSS ID.

The operation of the Mobile IPv6 protocol over 802.11-OCB links is different than on other links. The Movement Detection operation (section 11.5.1 of [RFC6275]) can not rely on Neighbor Unreachability Detection operation of the Neighbor Discovery protocol, for the reason mentioned in the previous paragraph. Also, the 802.11-OCB

link layer is not a lower layer that can provide an indication that a link layer handover has occured. The operation of the Mobile IPv6 protocol over 802.11-OCB is not specified in this document.

5. Security Considerations

Any security mechanism at the IP layer or above that may be carried out for the general case of IPv6 may also be carried out for IPv6 operating over 802.11-OCB.

The OCB operation is stripped off of all existing 802.11 link-layer security mechanisms. There is no encryption applied below the network layer running on 802.11-OCB. At application layer, the IEEE 1609.2 document [IEEE-1609.2] does provide security services for certain applications to use; application-layer mechanisms are out-of-scope of this document. On another hand, a security mechanism provided at networking layer, such as IPsec [RFC4301], may provide data security protection to a wider range of applications.

802.11-OCB does not provide any cryptographic protection, because it operates outside the context of a BSS (no Association Request/ Response, no Challenge messages). Any attacker can therefore just sit in the near range of vehicles, sniff the network (just set the interface card’s frequency to the proper range) and perform attacks without needing to physically break any wall. Such a link is less protected than commonly used links (wired link or protected 802.11).

The potential attack vectors are: MAC address spoofing, IP address and session hijacking, and privacy violation Section 5.1.

Within the IPsec Security Architecture [RFC4301], the IPsec AH and ESP headers [RFC4302] and [RFC4303] respectively, its multicast extensions [RFC5374], HTTPS [RFC2818] and SeND [RFC3971] protocols can be used to protect communications. Further, the assistance of proper Public Key Infrastructure (PKI) protocols [RFC4210] is necessary to establish credentials. More IETF protocols are available in the toolbox of the IP security protocol designer. Certain ETSI protocols related to security protocols in Intelligent Transportation Systems are described in [ETSI-sec-archi].

5.1. Privacy Considerations

As with all Ethernet and 802.11 interface identifiers ([RFC7721]), the identifier of an 802.11-OCB interface may involve privacy, MAC address spoofing and IP address hijacking risks. A vehicle embarking an IP-OBU whose egress interface is 802.11-OCB may expose itself to eavesdropping and subsequent correlation of data; this may reveal data considered private by the vehicle owner; there is a risk of

being tracked. In outdoors public environments, where vehicles typically circulate, the privacy risks are more important than in indoors settings. It is highly likely that attacker sniffers are deployed along routes which listen for IEEE frames, including IP packets, of vehicles passing by. For this reason, in the 802.11-OCB deployments, there is a strong necessity to use protection tools such as dynamically changing MAC addresses Section 5.2, semantically opaque Interface Identifiers and stable Interface Identifiers Section 4.6. This may help mitigate privacy risks to a certain level.

5.2. MAC Address and Interface ID Generation

In 802.11-OCB networks, the MAC addresses MAY change during well defined renumbering events. In the moment the MAC address is changed on an 802.11-OCB interface all the Interface Identifiers of IPv6 addresses assigned to that interface MUST change.

The policy dictating when the MAC address is changed on the 802.11-OCB interface is to-be-determined. For more information on the motivation of this policy please refer to the privacy discussion in Appendix C.

A ’randomized’ MAC address has the following characteristics:

- Bit "Local/Global" set to "locally admninistered".
- Bit "Unicast/Multicast" set to "Unicast".
- The 46 remaining bits are set to a random value, using a random number generator that meets the requirements of [RFC4086].

To meet the randomization requirements for the 46 remaining bits, a hash function may be used. For example, the SHA256 hash function may be used with input a 256 bit local secret, the ’nominal’ MAC Address of the interface, and a representation of the date and time of the renumbering event.

A randomized Interface ID has the same characteristics of a randomized MAC address, except the length in bits. A MAC address SHOULD be of length 48 decimal. An Interface ID SHOULD be of length 64 decimal for all types of IPv6 addresses. In the particular case of IPv6 link-local addresses, the length of the Interface ID MAY be 118 decimal.

6. IANA Considerations

No request to IANA.

7. Contributors

Christian Huitema, Tony Li.

Romain Kuntz contributed extensively about IPv6 handovers between links running outside the context of a BSS (802.11-OCB links).

Tim Leinmueller contributed the idea of the use of IPv6 over 802.11-OCB for distribution of certificates.

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Human Rights Protocol Considerations review by Amelia Andersdotter.

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"IEEE Standard 802.11-2016 - IEEE Standard for Information Technology - Telecommunications and information exchange between systems Local and metropolitan area networks - Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications. Status - Active Standard. Description retrieved freely on September 12th, 2017, at URL https://standards.ieee.org/findstds/standard/802.11-2016.html".

[IEEE-802.11p-2010]
"IEEE Std 802.11p (TM)-2010, IEEE Standard for Information Technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 6: Wireless Access in Vehicular Environments; document freely available at URL http://standards.ieee.org/getieee802/download/802.11p-2010.pdf retrieved on September 20th, 2013.".

Appendix A. ChangeLog

The changes are listed in reverse chronological order, most recent changes appearing at the top of the list.

-30: a clarification on the reliability of ND over OCB and over 802.11.

-29:

o

-28:

- Created a new section ’Pseudonym Handling’.
- removed the ’Vehicle ID’ appendix.
- improved the address generation from random MAC address.
- shortened Term IP-RSU definition.
- removed refs to two detail Clauses in IEEE documents, kept just these latter.

-27: part 1 of addressing Human Rights review from IRTF. Removed appendices F.2 and F.3. Shortened definition of IP-RSU. Removed reference to 1609.4. A few other small changes, see diff.

-26: moved text from SLAAC section and from Design Considerations appendix about privacy into a new Privacy Condiderations subsection of the Security section; reformulated the SLAAC and IID sections to stress only LLs can use EUI-64; removed the "GeoIP" wireshark explanation; reformulated SLAAC and LL sections; added brief mention of need of use LLs; clarified text about MAC address changes; dropped pseudonym discussion; changed title of section describing examples of packet formats.

-25: added a reference to ’IEEE Management Information Base’, instead of just ’Management Information Base’; added ref to further appendices in the introductory phrases; improved text for IID formation for SLAAC, inserting recommendation for RFC8064 before RFC2464.

From draft-ietf-ipwave-ipv6-over-80211ocb-23 to draft-ietf-ipwave-ipv6-over-80211ocb-24

- Nit: wrote "IPWAVE Working Group" on the front page, instead of "Network Working Group".

- Addressed the comments on 6MAN: replaced a sentence about ND problem with "is used over 802.11-OCB".

From draft-ietf-ipwave-ipv6-over-80211ocb-22 to draft-ietf-ipwave-ipv6-over-80211ocb-23

- No content modifications, but check the entire draft chain on IPv6-only: xml2rfc, submission on tools.ietf.org and datatracker.

From draft-ietf-ipwave-ipv6-over-80211ocb-21 to draft-ietf-ipwave-ipv6-over-80211ocb-22

- Corrected typo, use dash in "802.11-OCB" instead of space.

- Improved the Frame Format section: MUST use QoSData, specify the values within; clarified the Ethernet Adaptation Layer text.

From draft-ietf-ipwave-ipv6-over-80211ocb-20 to draft-ietf-ipwave-ipv6-over-80211ocb-21

- Corrected a few nits and added names in Acknowledgments section.

- Removed unused reference to old Internet Draft tsvwg about QoS.

From draft-ietf-ipwave-ipv6-over-80211ocb-19 to draft-ietf-ipwave-ipv6-over-80211ocb-20

- Reduced the definition of term "802.11-OCB".

- Left out of this specification which 802.11 header to use to transmit IP packets in OCB mode (QoS Data header, Data header, or any other).

- Added ’MUST’ use an Ethernet Adaptation Layer, instead of ’is using’ an Ethernet Adaptation Layer.

From draft-ietf-ipwave-ipv6-over-80211ocb-18 to draft-ietf-ipwave-ipv6-over-80211ocb-19

- Removed the text about fragmentation.

- Removed the mentioning of WSMP and GeoNetworking.

- Removed the explanation of the binary representation of the EtherType.

- Rendered normative the paragraph about unicast and multicast address mapping.

- Removed paragraph about addressing model, subnet structure and easiness of using LLs.

- Clarified the Type/Subtype field in the 802.11 Header.

- Used RECOMMENDED instead of recommended, for the stable interface identifiers.

From draft-ietf-ipwave-ipv6-over-80211ocb-17 to draft-ietf-ipwave-ipv6-over-80211ocb-18

- Improved the MTU and fragmentation paragraph.

From draft-ietf-ipwave-ipv6-over-80211ocb-16 to draft-ietf-ipwave-ipv6-over-80211ocb-17

- Susbtituted "MUST be increased" to "is increased" in the MTU section, about fragmentation.

From draft-ietf-ipwave-ipv6-over-80211ocb-15 to draft-ietf-ipwave-ipv6-over-80211ocb-16

- Removed the definition of the 'WiFi' term and its occurences. Clarified a phrase that used it in Appendix C "Aspects introduced by the OCB mode to 802.11".

- Added more normative words: MUST be 0x86DD, MUST fragment if size larger than MTU, Sequence number in 802.11 Data header MUST be increased.

From draft-ietf-ipwave-ipv6-over-80211ocb-14 to draft-ietf-ipwave-ipv6-over-80211ocb-15

- Added normative term MUST in two places in section "Ethernet Adaptation Layer".

From draft-ietf-ipwave-ipv6-over-80211ocb-13 to draft-ietf-ipwave-ipv6-over-80211ocb-14

- Created a new Appendix titled "Extra Terminology" that contains terms DSRC, DSRCS, OBU, RSU as defined outside IETF. Some of them are used in the main Terminology section.

- Added two paragraphs explaining that ND and Mobile IPv6 have problems working over 802.11-OCB, yet their adaptations is not specified in this document.

From draft-ietf-ipwave-ipv6-over-80211ocb-12 to draft-ietf-ipwave-ipv6-over-80211ocb-13

- Substituted "IP-OBU" for "OBRU", and "IP-RSU" for "RSRU" throughout and improved OBU-related definitions in the Terminology section.

From draft-ietf-ipwave-ipv6-over-80211ocb-11 to draft-ietf-ipwave-ipv6-over-80211ocb-12

- Improved the appendix about "MAC Address Generation" by expressing the technique to be an optional suggestion, not a mandatory mechanism.

From draft-ietf-ipwave-ipv6-over-80211ocb-10 to draft-ietf-ipwave-ipv6-over-80211ocb-11

- Shortened the paragraph on forming/terminating 802.11-OCB links.

- Moved the draft tsvwg-ieee-802-11 to Informative References.

From draft-ietf-ipwave-ipv6-over-80211ocb-09 to draft-ietf-ipwave-ipv6-over-80211ocb-10

- Removed text requesting a new Group ID for multicast for OCB.

- Added a clarification of the meaning of value "3333" in the section Address Mapping -- Multicast.

- Added note clarifying that in Europe the regional authority is not ETSI, but "ECC/CEPT based on ENs from ETSI".

- Added note stating that the manner in which two STAtions set their communication channel is not described in this document.

- Added a time qualifier to state that the "each node is represented uniquely at a certain point in time."

- Removed text "This section may need to be moved" (the "Reliability Requirements" section). This section stays there at this time.

- In the term definition "802.11-OCB" added a note stating that "any implementation should comply with standards and regulations set in the different countries for using that frequency band."

- In the RSU term definition, added a sentence explaining the difference between RSU and RSRU: in terms of number of interfaces and IP forwarding.
- Replaced "with at least two IP interfaces" with "with at least two real or virtual IP interfaces".
- Added a term in the Terminology for "OBU". However the definition is left empty, as this term is defined outside IETF.
- Added a clarification that it is an OBU or an OBRU in this phrase "A vehicle embarking an OBU or an OBRU".
- Checked the entire document for a consistent use of terms OBU and OBRU.
- Added note saying that "'p' is a letter identifying the Ammendment".
- Substituted lower case for capitals SHALL or MUST in the Appendices.
- Added reference to RFC7042, helpful in the 3333 explanation. Removed reference to individual submission draft-petrescu-its-scenario-reqs and added reference to draft-ietf-ipwave-vehicular-networking-survey.
- Added figure captions, figure numbers, and references to figure numbers instead of 'below'. Replaced "section Section" with "section" throughout.
- Minor typographical errors.

From draft-ietf-ipwave-ipv6-over-80211ocb-08 to draft-ietf-ipwave-ipv6-over-80211ocb-09

- Significantly shortened the Address Mapping sections, by text copied from RFC2464, and rather referring to it.
- Moved the EPD description to an Appendix on its own.
- Shortened the Introduction and the Abstract.
- Moved the tutorial section of OCB mode introduced to .11, into an appendix.
- Removed the statement that suggests that for routing purposes a prefix exchange mechanism could be needed.

- Removed refs to RFC3963, RFC4429 and RFC6775; these are about ND, MIP/NEMO and oDAD; they were referred in the handover discussion section, which is out.

- Updated a reference from individual submission to now a WG item in IPWAVE: the survey document.

- Added term definition for WiFi.

- Updated the authorship and expanded the Contributors section.

- Corrected typographical errors.

From draft-ietf-ipwave-ipv6-over-80211ocb-07 to draft-ietf-ipwave-ipv6-over-80211ocb-08

- Removed the per-channel IPv6 prohibition text.

- Corrected typographical errors.

From draft-ietf-ipwave-ipv6-over-80211ocb-06 to draft-ietf-ipwave-ipv6-over-80211ocb-07

- Added new terms: OBRU and RSRU ('R' for Router). Refined the existing terms RSU and OBU, which are no longer used throughout the document.

- Improved definition of term "802.11-OCB".

- Clarified that OCB does not "strip" security, but that the operation in OCB mode is "stripped off of all .11 security".

- Clarified that theoretical OCB bandwidth speed is 54mbits, but that a commonly observed bandwidth in IP-over-OCB is 12mbit/s.

- Corrected typographical errors, and improved some phrasing.

From draft-ietf-ipwave-ipv6-over-80211ocb-05 to draft-ietf-ipwave-ipv6-over-80211ocb-06

- Updated references of 802.11-OCB document from -2012 to the IEEE 802.11-2016.

- In the LL address section, and in SLAAC section, added references to 7217 opaque IIDs and 8064 stable IIDs.

From draft-ietf-ipwave-ipv6-over-80211ocb-04 to draft-ietf-ipwave-ipv6-over-80211ocb-05

- Lengthened the title and cleanded the abstract.
- Added text suggesting LLs may be easy to use on OCB, rather than GUAs based on received prefix.
- Added the risks of spoofing and hijacking.
- Removed the text speculation on adoption of the TSA message.
- Clarified that the ND protocol is used.
- Clarified what it means "No association needed".
- Added some text about how two STAs discover each other.
- Added mention of external (OCB) and internal network (stable), in the subnet structure section.
- Added phrase explaining that both .11 Data and .11 QoS Data headers are currently being used, and may be used in the future.
- Moved the packet capture example into an Appendix Implementation Status.
- Suggested moving the reliability requirements appendix out into another document.
- Added a IANA Consiserations section, with content, requesting for a new multicast group "all OCB interfaces".
- Added new OBU term, improved the RSU term definition, removed the ETTC term, replaced more occurences of 802.11p, 802.11-OCB with 802.11-OCB.
- References:
  * Added an informational reference to ETSI’s IPv6-over-GeoNetworking.
  * Added more references to IETF and ETSI security protocols.
  * Updated some references from I-D to RFC, and from old RFC to new RFC numbers.
  * Added reference to multicast extensions to IPsec architecture RFC.
  * Added a reference to 2464-bis.

    * Removed FCC informative references, because not used.

- Updated the affiliation of one author.

- Reformulation of some phrases for better readability, and correction of typographical errors.

From draft-ietf-ipwave-ipv6-over-80211ocb-03 to draft-ietf-ipwave-ipv6-over-80211ocb-04

- Removed a few informative references pointing to Dx draft IEEE 1609 documents.

- Removed outdated informative references to ETSI documents.

- Added citations to IEEE 1609.2, .3 and .4-2016.

- Minor textual issues.

From draft-ietf-ipwave-ipv6-over-80211ocb-02 to draft-ietf-ipwave-ipv6-over-80211ocb-03

- Keep the previous text on multiple addresses, so remove talk about MIP6, NEMOv6 and MCoA.

- Clarified that a 'Beacon' is an IEEE 802.11 frame Beacon.

- Clarified the figure showing Infrastructure mode and OCB mode side by side.

- Added a reference to the IP Security Architecture RFC.

- Detailed the IPv6-per-channel prohibition paragraph which reflects the discussion at the last IETF IPWAVE WG meeting.

- Added section "Address Mapping -- Unicast".

- Added the ".11 Trailer" to pictures of 802.11 frames.

- Added text about SNAP carrying the Ethertype.

- New RSU definition allowing for it be both a Router and not necessarily a Router some times.

- Minor textual issues.

From draft-ietf-ipwave-ipv6-over-80211ocb-01 to draft-ietf-ipwave-ipv6-over-80211ocb-02

- Replaced almost all occurences of 802.11p with 802.11-OCB, leaving only when explanation of evolution was necessary.
- Shortened by removing parameter details from a paragraph in the Introduction.
- Moved a reference from Normative to Informative.
- Added text in intro clarifying there is no handover spec at IEEE, and that 1609.2 does provide security services.
- Named the contents the fields of the EthernetII header (including the Ethertype bitstring).
- Improved relationship between two paragraphs describing the increase of the Sequence Number in 802.11 header upon IP fragmentation.
- Added brief clarification of "tracking".

From draft-ietf-ipwave-ipv6-over-80211ocb-00 to draft-ietf-ipwave-ipv6-over-80211ocb-01

- Introduced message exchange diagram illustrating differences between 802.11 and 802.11 in OCB mode.
- Introduced an appendix listing for information the set of 802.11 messages that may be transmitted in OCB mode.
- Removed appendix sections "Privacy Requirements", "Authentication Requirements" and "Security Certificate Generation".
- Removed appendix section "Non IP Communications".
- Introductory phrase in the Security Considerations section.
- Improved the definition of "OCB".
- Introduced theoretical stacked layers about IPv6 and IEEE layers including EPD.
- Removed the appendix describing the details of prohibiting IPv6 on certain channels relevant to 802.11-OCB.
- Added a brief reference in the privacy text about a precise clause in IEEE 1609.3 and .4.
- Clarified the definition of a Road Side Unit.

- Removed the discussion about security of WSA (because is non-IP).
- Removed mentioning of the GeoNetworking discussion.
- Moved references to scientific articles to a separate 'overview' draft, and referred to it.

Appendix B. 802.11p

The term "802.11p" is an earlier definition. The behaviour of "802.11p" networks is rolled in the document IEEE Std 802.11-2016. In that document the term 802.11p disappears. Instead, each 802.11p feature is conditioned by the IEEE Management Information Base (MIB) attribute "OCBActivated" [IEEE-802.11-2016]. Whenever OCBActivated is set to true the IEEE Std 802.11-OCB state is activated. For example, an 802.11 STAtion operating outside the context of a basic service set has the OCBActivated flag set. Such a station, when it has the flag set, uses a BSS identifier equal to ff:ff:ff:ff:ff:ff.

Appendix C. Aspects introduced by the OCB mode to 802.11

In the IEEE 802.11-OCB mode, all nodes in the wireless range can directly communicate with each other without involving authentication or association procedures. At link layer, it is necessary to set the same channel number (or frequency) on two stations that need to communicate with each other. The manner in which stations set their channel number is not specified in this document. Stations STA1 and STA2 can exchange IP packets if they are set on the same channel. At IP layer, they then discover each other by using the IPv6 Neighbor Discovery protocol.

Briefly, the IEEE 802.11-OCB mode has the following properties:

- The use by each node of a 'wildcard' BSSID (i.e., each bit of the BSSID is set to 1)
- No IEEE 802.11 Beacon frames are transmitted
- No authentication is required in order to be able to communicate
- No association is needed in order to be able to communicate
- No encryption is provided in order to be able to communicate
- Flag dot11OCBActivated is set to true

All the nodes in the radio communication range (IP-OBU and IP-RSU) receive all the messages transmitted (IP-OBU and IP-RSU) within the

radio communications range. The eventual conflict(s) are resolved by the MAC CDMA function.

The message exchange diagram in Figure 3 illustrates a comparison between traditional 802.11 and 802.11 in OCB mode. The 'Data' messages can be IP packets such as HTTP or others. Other 802.11 management and control frames (non IP) may be transmitted, as specified in the 802.11 standard. For information, the names of these messages as currently specified by the 802.11 standard are listed in Appendix G.

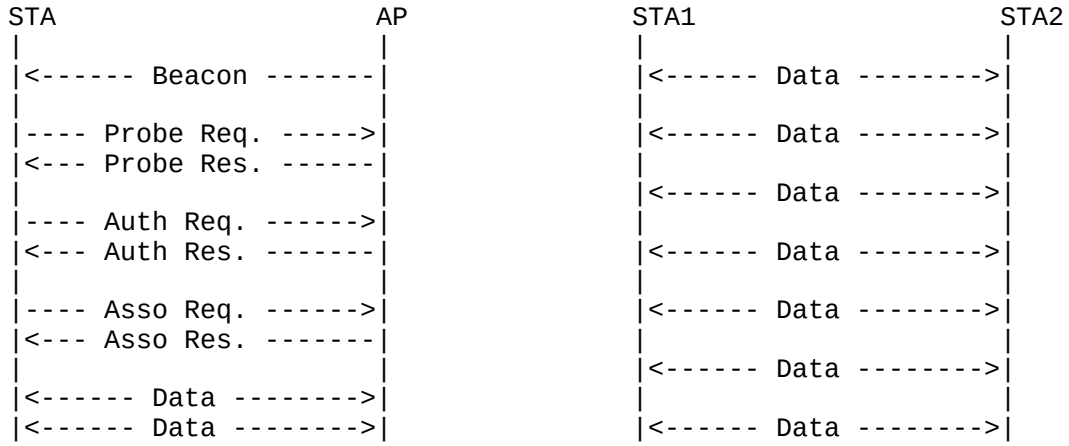


Figure 3: Difference between messages exchanged on 802.11 (left) and 802.11-OCB (right)

The interface 802.11-OCB was specified in IEEE Std 802.11p (TM) -2010 [IEEE-802.11p-2010] as an amendment to IEEE Std 802.11 (TM) -2007, titled "Amendment 6: Wireless Access in Vehicular Environments". Since then, this amendment has been integrated in IEEE 802.11(TM) -2012 and -2016 [IEEE-802.11-2016].

In document 802.11-2016, anything qualified specifically as "OCBActivated", or "outside the context of a basic service" set to be true, then it is actually referring to OCB aspects introduced to 802.11.

In order to delineate the aspects introduced by 802.11-OCB to 802.11, we refer to the earlier [IEEE-802.11p-2010]. The amendment is concerned with vehicular communications, where the wireless link is

similar to that of Wireless LAN (using a PHY layer specified by 802.11a/b/g/n), but which needs to cope with the high mobility factor inherent in scenarios of communications between moving vehicles, and between vehicles and fixed infrastructure deployed along roads. While 'p' is a letter identifying the Ammendment, just like 'a, b, g' and 'n' are, 'p' is concerned more with MAC modifications, and a little with PHY modifications; the others are mainly about PHY modifications. It is possible in practice to combine a 'p' MAC with an 'a' PHY by operating outside the context of a BSS with OFDM at 5.4GHz and 5.9GHz.

The 802.11-OCB links are specified to be compatible as much as possible with the behaviour of 802.11a/b/g/n and future generation IEEE WLAN links. From the IP perspective, an 802.11-OCB MAC layer offers practically the same interface to IP as the 802.11a/b/g/n and 802.3. A packet sent by an IP-OBU may be received by one or multiple IP-RSUs. The link-layer resolution is performed by using the IPv6 Neighbor Discovery protocol.

To support this similarity statement (IPv6 is layered on top of LLC on top of 802.11-OCB, in the same way that IPv6 is layered on top of LLC on top of 802.11a/b/g/n (for WLAN) or layered on top of LLC on top of 802.3 (for Ethernet)) it is useful to analyze the differences between 802.11-OCB and 802.11 specifications. During this analysis, we note that whereas 802.11-OCB lists relatively complex and numerous changes to the MAC layer (and very little to the PHY layer), there are only a few characteristics which may be important for an implementation transmitting IPv6 packets on 802.11-OCB links.

The most important 802.11-OCB point which influences the IPv6 functioning is the OCB characteristic; an additional, less direct influence, is the maximum bandwidth afforded by the PHY modulation/ demodulation methods and channel access specified by 802.11-OCB. The maximum bandwidth theoretically possible in 802.11-OCB is 54 Mbit/s (when using, for example, the following parameters: 20 MHz channel; modulation 64-QAM; coding rate R is 3/4); in practice of IP-over-802.11-OCB a commonly observed figure is 12Mbit/s; this bandwidth allows the operation of a wide range of protocols relying on IPv6.

- Operation Outside the Context of a BSS (OCB): the (earlier 802.11p) 802.11-OCB links are operated without a Basic Service Set (BSS). This means that the frames IEEE 802.11 Beacon, Association Request/Response, Authentication Request/Response, and similar, are not used. The used identifier of BSS (BSSID) has a hexadecimal value always 0xffffffffffff (48 '1' bits, represented as MAC address ff:ff:ff:ff:ff:ff, or otherwise the 'wildcard' BSSID), as opposed to an arbitrary BSSID value set by administrator (e.g. 'My-Home-AccessPoint'). The OCB operation -

namely the lack of beacon-based scanning and lack of authentication - should be taken into account when the Mobile IPv6 protocol [RFC6275] and the protocols for IP layer security [RFC4301] are used. The way these protocols adapt to OCB is not described in this document.

- Timing Advertisement: is a new message defined in 802.11-OCB, which does not exist in 802.11a/b/g/n. This message is used by stations to inform other stations about the value of time. It is similar to the time as delivered by a GNSS system (Galileo, GPS, ...) or by a cellular system. This message is optional for implementation.

- Frequency range: this is a characteristic of the PHY layer, with almost no impact on the interface between MAC and IP. However, it is worth considering that the frequency range is regulated by a regional authority (ARCEP, ECC/CEPT based on ENs from ETSI, FCC, etc.); as part of the regulation process, specific applications are associated with specific frequency ranges. In the case of 802.11-OCB, the regulator associates a set of frequency ranges, or slots within a band, to the use of applications of vehicular communications, in a band known as "5.9GHz". The 5.9GHz band is different from the 2.4GHz and 5GHz bands used by Wireless LAN. However, as with Wireless LAN, the operation of 802.11-OCB in "5.9GHz" bands is exempt from owning a license in EU (in US the 5.9GHz is a licensed band of spectrum; for the fixed infrastructure an explicit FCC authorization is required; for an on-board device a 'licensed-by-rule' concept applies: rule certification conformity is required.) Technical conditions are different than those of the bands "2.4GHz" or "5GHz". The allowed power levels, and implicitly the maximum allowed distance between vehicles, is of 33dBm for 802.11-OCB (in Europe), compared to 20 dBm for Wireless LAN 802.11a/b/g/n; this leads to a maximum distance of approximately 1km, compared to approximately 50m. Additionally, specific conditions related to congestion avoidance, jamming avoidance, and radar detection are imposed on the use of DSRC (in US) and on the use of frequencies for Intelligent Transportation Systems (in EU), compared to Wireless LAN (802.11a/b/g/n).

- 'Half-rate' encoding: as the frequency range, this parameter is related to PHY, and thus has not much impact on the interface between the IP layer and the MAC layer.

- In vehicular communications using 802.11-OCB links, there are strong privacy requirements with respect to addressing. While the 802.11-OCB standard does not specify anything in particular with respect to MAC addresses, in these settings there exists a strong

need for dynamic change of these addresses (as opposed to the non-vehicular settings - real wall protection - where fixed MAC addresses do not currently pose some privacy risks). This is further described in Section 5. A relevant function is described in documents IEEE 1609.3-2016 [IEEE-1609.3] and IEEE 1609.4-2016 [IEEE-1609.4].

Appendix D. Changes Needed on a software driver 802.11a to become a 802.11-OCB driver

The 802.11p amendment modifies both the 802.11 stack's physical and MAC layers but all the induced modifications can be quite easily obtained by modifying an existing 802.11a ad-hoc stack.

Conditions for a 802.11a hardware to be 802.11-OCB compliant:

- The PHY entity shall be an orthogonal frequency division multiplexing (OFDM) system. It must support the frequency bands on which the regulator recommends the use of ITS communications, for example using IEEE 802.11-OCB layer, in France: 5875MHz to 5925MHz.
- The OFDM system must provide a "half-clocked" operation using 10 MHz channel spacings.
- The chip transmit spectrum mask must be compliant to the "Transmit spectrum mask" from the IEEE 802.11p amendment (but experimental environments tolerate otherwise).
- The chip should be able to transmit up to 44.8 dBm when used by the US government in the United States, and up to 33 dBm in Europe; other regional conditions apply.

Changes needed on the network stack in OCB mode:

- Physical layer:
  - The chip must use the Orthogonal Frequency Multiple Access (OFDM) encoding mode.
  - The chip must be set in half-mode rate mode (the internal clock frequency is divided by two).
  - The chip must use dedicated channels and should allow the use of higher emission powers. This may require modifications to the local computer file that describes regulatory domains rules, if used by the kernel to enforce local specific

restrictions. Such modifications to the local computer file must respect the location-specific regulatory rules.

MAC layer:

* All management frames (beacons, join, leave, and others) emission and reception must be disabled except for frames of subtype Action and Timing Advertisement (defined below).

* No encryption key or method must be used.

* Packet emission and reception must be performed as in ad-hoc mode, using the wildcard BSSID (ff:ff:ff:ff:ff:ff).

* The functions related to joining a BSS (Association Request/ Response) and for authentication (Authentication Request/Reply, Challenge) are not called.

* The beacon interval is always set to 0 (zero).

* Timing Advertisement frames, defined in the amendment, should be supported. The upper layer should be able to trigger such frames emission and to retrieve information contained in received Timing Advertisements.

Appendix E. EtherType Protocol Discrimination (EPD)

A more theoretical and detailed view of layer stacking, and interfaces between the IP layer and 802.11-OCB layers, is illustrated in Figure 4. The IP layer operates on top of the EtherType Protocol Discrimination (EPD); this Discrimination layer is described in IEEE Std 802.3-2012; the interface between IPv6 and EPD is the LLC_SAP (Link Layer Control Service Access Point).

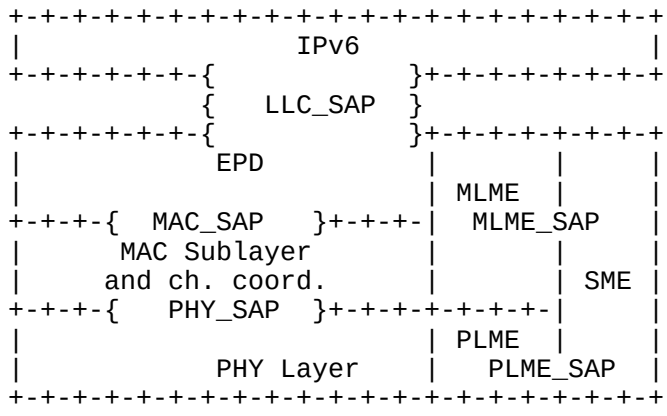


Figure 4: EtherType Protocol Discrimination

Appendix F. Design Considerations

The networks defined by 802.11-OCB are in many ways similar to other networks of the 802.11 family. In theory, the encapsulation of IPv6 over 802.11-OCB could be very similar to the operation of IPv6 over other networks of the 802.11 family. However, the high mobility, strong link asymmetry and very short connection makes the 802.11-OCB link significantly different from other 802.11 networks. Also, the automotive applications have specific requirements for reliability, security and privacy, which further add to the particularity of the 802.11-OCB link.

Appendix G. IEEE 802.11 Messages Transmitted in OCB mode

For information, at the time of writing, this is the list of IEEE 802.11 messages that may be transmitted in OCB mode, i.e. when dot11OCBActivated is true in a STA:

- The STA may send management frames of subtype Action and, if the STA maintains a TSF Timer, subtype Timing Advertisement;
- The STA may send control frames, except those of subtype PS-Poll, CF-End, and CF-End plus CFAck;
- The STA may send data frames of subtype Data, Null, QoS Data, and QoS Null.

Appendix H. Examples of Packet Formats

This section describes an example of an IPv6 Packet captured over a IEEE 802.11-OCB link.

By way of example we show that there is no modification in the headers when transmitted over 802.11-OCB networks - they are transmitted like any other 802.11 and Ethernet packets.

We describe an experiment of capturing an IPv6 packet on an 802.11-OCB link. In topology depicted in Figure 5, the packet is an IPv6 Router Advertisement. This packet is emitted by a Router on its 802.11-OCB interface. The packet is captured on the Host, using a network protocol analyzer (e.g. Wireshark); the capture is performed in two different modes: direct mode and 'monitor' mode. The topology used during the capture is depicted below.

The packet is captured on the Host. The Host is an IP-OBU containing an 802.11 interface in format PCI express (an ITRI product). The kernel runs the ath5k software driver with modifications for OCB mode. The capture tool is Wireshark. The file format for save and analyze is 'pcap'. The packet is generated by the Router. The Router is an IP-RSU (ITRI product).

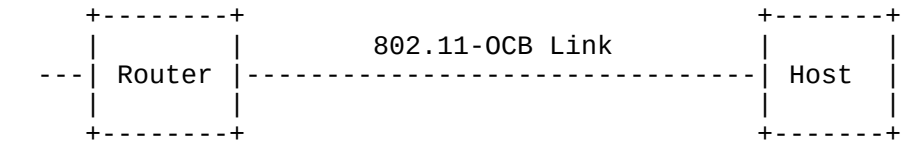


Figure 5: Topology for capturing IP packets on 802.11-OCB

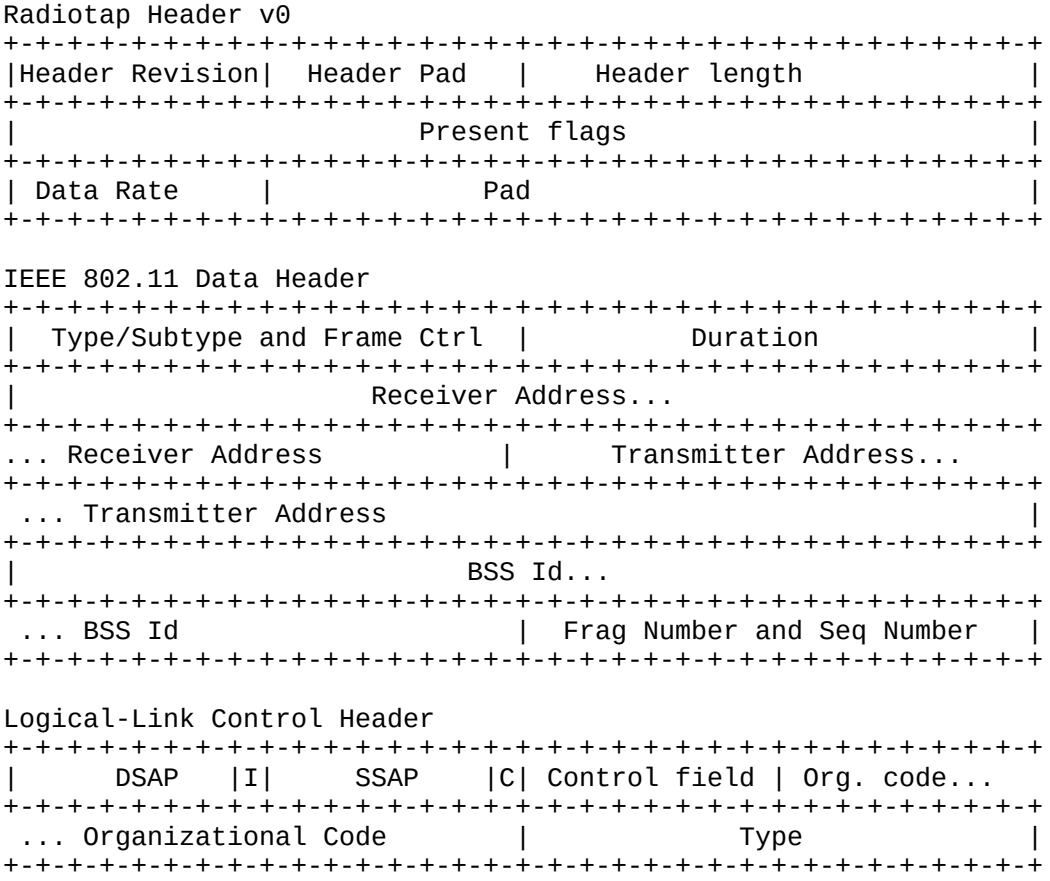
During several capture operations running from a few moments to several hours, no message relevant to the BSSID contexts were captured (no Association Request/Response, Authentication Req/Resp, Beacon). This shows that the operation of 802.11-OCB is outside the context of a BSSID.

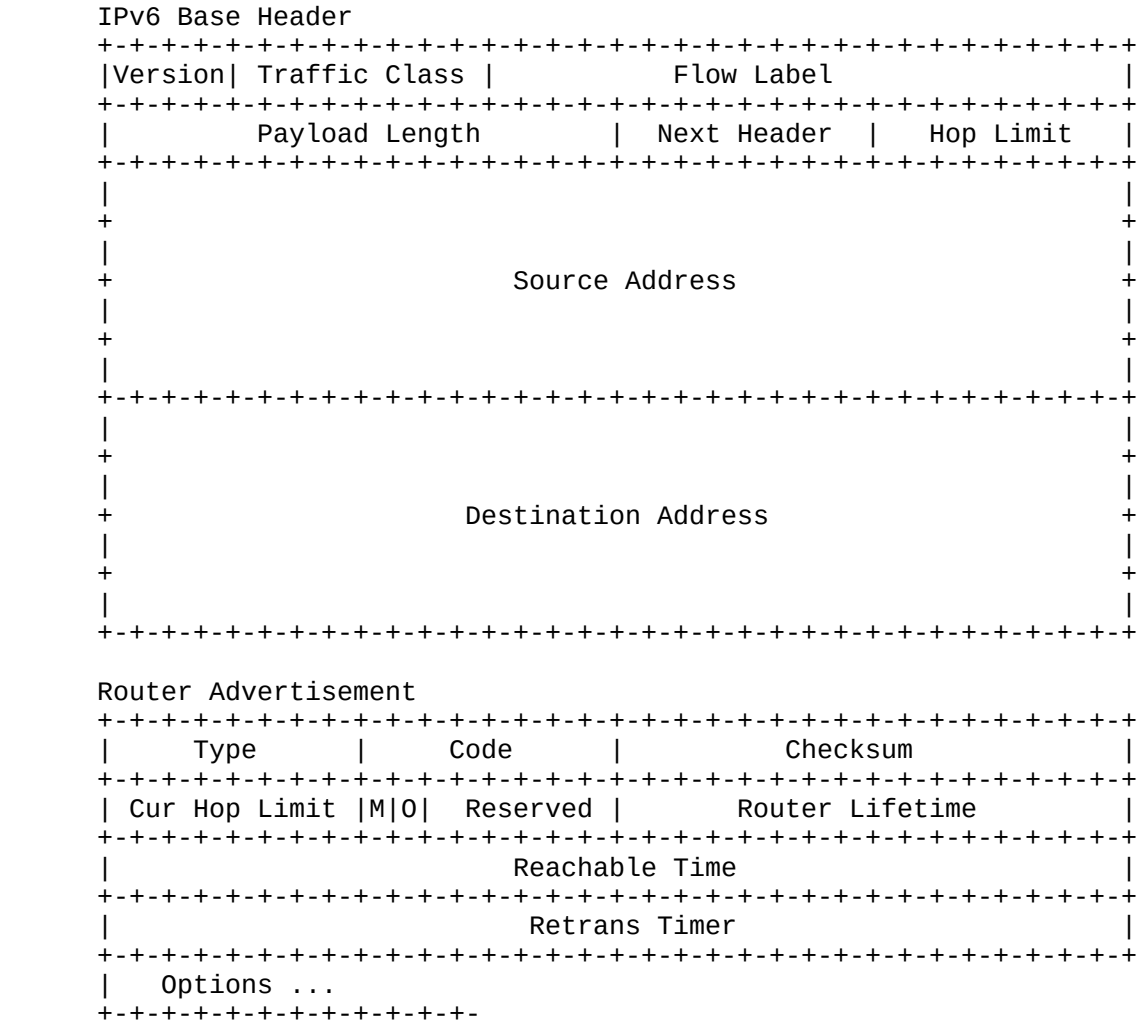
Overall, the captured message is identical with a capture of an IPv6 packet emitted on a 802.11b interface. The contents are precisely similar.

H.1. Capture in Monitor Mode

The IPv6 RA packet captured in monitor mode is illustrated below. The radio tap header provides more flexibility for reporting the characteristics of frames. The Radiotap Header is prepended by this particular stack and operating system on the Host machine to the RA packet received from the network (the Radiotap Header is not present on the air). The implementation-dependent Radiotap Header is useful for piggybacking PHY information from the chip's registers as data in a packet understandable by userland applications using Socket interfaces (the PHY interface can be, for example: power levels, data rate, ratio of signal to noise).

The packet present on the air is formed by IEEE 802.11 Data Header, Logical Link Control Header, IPv6 Base Header and ICMPv6 Header.





The value of the Data Rate field in the Radiotap header is set to 6 Mb/s. This indicates the rate at which this RA was received.

The value of the Transmitter address in the IEEE 802.11 Data Header is set to a 48bit value. The value of the destination address is 33:33:00:00:00:1 (all-nodes multicast address). The value of the BSS Id field is ff:ff:ff:ff:ff:ff, which is recognized by the network protocol analyzer as being "broadcast". The Fragment number and sequence number fields are together set to 0x90C6.

The value of the Organization Code field in the Logical-Link Control Header is set to 0x0, recognized as "Encapsulated Ethernet". The value of the Type field is 0x86DD (hexadecimal 86DD, or otherwise #86DD), recognized as "IPv6".

A Router Advertisement is periodically sent by the router to multicast group address ff02::1. It is an icmp packet type 134. The IPv6 Neighbor Discovery's Router Advertisement message contains an 8-bit field reserved for single-bit flags, as described in [RFC4861].

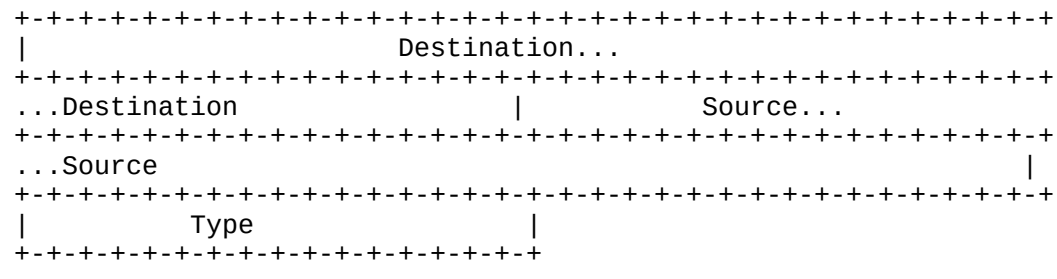
The IPv6 header contains the link local address of the router (source) configured via EUI-64 algorithm, and destination address set to ff02::1.

The Ethernet Type field in the logical-link control header is set to 0x86dd which indicates that the frame transports an IPv6 packet. In the IEEE 802.11 data, the destination address is 33:33:00:00:00:01 which is the corresponding multicast MAC address. The BSS id is a broadcast address of ff:ff:ff:ff:ff:ff. Due to the short link duration between vehicles and the roadside infrastructure, there is no need in IEEE 802.11-OCB to wait for the completion of association and authentication procedures before exchanging data. IEEE 802.11-OCB enabled nodes use the wildcard BSSID (a value of all 1s) and may start communicating as soon as they arrive on the communication channel.

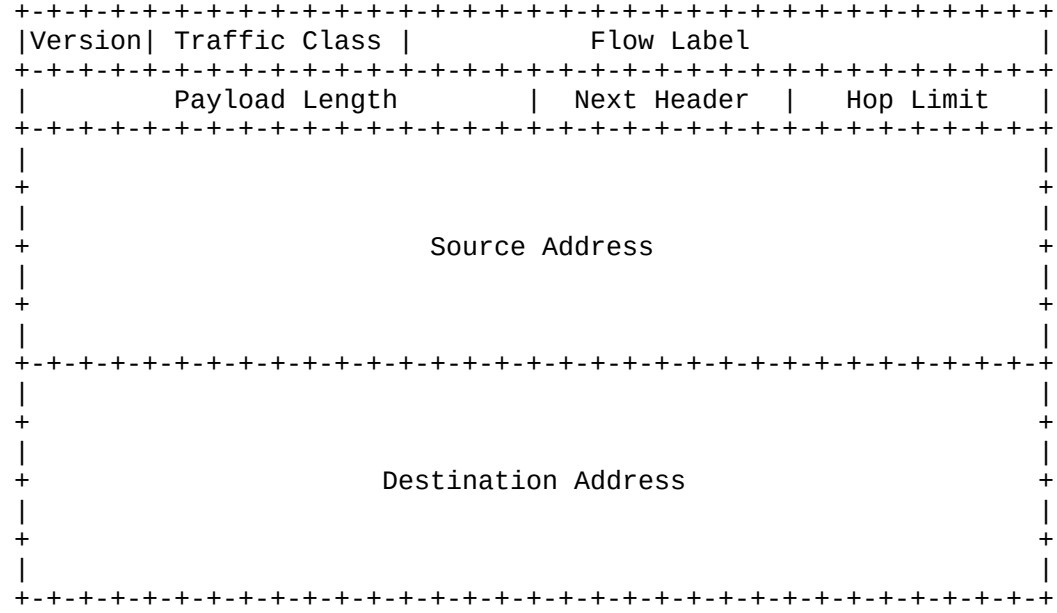
H.2. Capture in Normal Mode

The same IPv6 Router Advertisement packet described above (monitor mode) is captured on the Host, in the Normal mode, and depicted below.

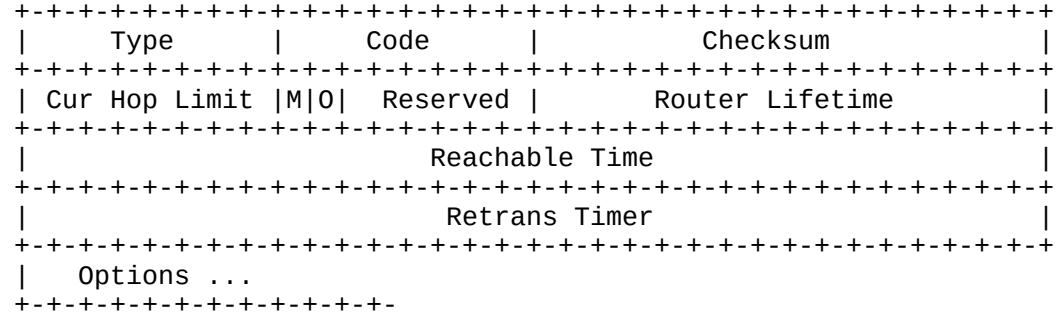
Ethernet II Header



IPv6 Base Header



Router Advertisement



One notices that the Radiotap Header, the IEEE 802.11 Data Header and the Logical-Link Control Headers are not present. On the other hand, a new header named Ethernet II Header is present.

The Destination and Source addresses in the Ethernet II header contain the same values as the fields Receiver Address and Transmitter Address present in the IEEE 802.11 Data Header in the "monitor" mode capture.

The value of the Type field in the Ethernet II header is 0x86DD (recognized as "IPv6"); this value is the same value as the value of the field Type in the Logical-Link Control Header in the "monitor" mode capture.

The knowledgeable experimenter will no doubt notice the similarity of this Ethernet II Header with a capture in normal mode on a pure Ethernet cable interface.

An Adaptation layer is inserted on top of a pure IEEE 802.11 MAC layer, in order to adapt packets, before delivering the payload data to the applications. It adapts 802.11 LLC/MAC headers to Ethernet II headers. In further detail, this adaptation consists in the elimination of the Radiotap, 802.11 and LLC headers, and in the insertion of the Ethernet II header. In this way, IPv6 runs straight over LLC over the 802.11-OCB MAC layer; this is further confirmed by the use of the unique Type 0x86DD.

Appendix I. Extra Terminology

The following terms are defined outside the IETF. They are used to define the main terms in the main terminology section Section 2.

DSRC (Dedicated Short Range Communication): a term defined outside the IETF. The US Federal Communications Commission (FCC) Dedicated Short Range Communication (DSRC) is defined in the Code of Federal Regulations (CFR) 47, Parts 90 and 95. This Code is referred in the definitions below. At the time of the writing of this Internet Draft, the last update of this Code was dated October 1st, 2010.

DSRCS (Dedicated Short-Range Communications Services): a term defined outside the IETF. The use of radio techniques to transfer data over short distances between roadside and mobile units, between mobile units, and between portable and mobile units to perform operations related to the improvement of traffic flow, traffic safety, and other intelligent transportation service applications in a variety of environments. DSRCS systems may also transmit status and instructional messages related to the units involve. [Ref. 47 CFR 90.7 - Definitions]

OBU (On-Board Unit): a term defined outside the IETF. An On-Board Unit is a DSRCS transceiver that is normally mounted in or on a vehicle, or which in some instances may be a portable unit. An OBU can be operational while a vehicle or person is either mobile or stationary. The OBUs receive and contend for time to transmit on one or more radio frequency (RF) channels. Except where specifically excluded, OBU operation is permitted wherever vehicle operation or human passage is permitted. The OBUs mounted in vehicles are licensed by rule under part 95 of the respective chapter and communicate with Roadside Units (RSUs) and other OBUs. Portable OBUs are also licensed by rule under part 95 of the respective chapter. OBU operations in the Unlicensed National Information Infrastructure (UNII) Bands follow the rules in those bands. - [CFR 90.7 - Definitions].

RSU (Road-Side Unit): a term defined outside of IETF. A Roadside Unit is a DSRC transceiver that is mounted along a road or pedestrian passageway. An RSU may also be mounted on a vehicle or is hand carried, but it may only operate when the vehicle or hand- carried unit is stationary. Furthermore, an RSU operating under the respectgive part is restricted to the location where it is licensed to operate. However, portable or hand-held RSUs are permitted to operate where they do not interfere with a site-licensed operation. A RSU broadcasts data to OBUs or exchanges data with OBUs in its communications zone. An RSU also provides channel assignments and operating instructions to OBUs in its communications zone, when required. - [CFR 90.7 - Definitions].

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Basic Support for IPv6 over IEEE Std 802.11 Networks Operating Outside the Context of a Basic Service Set
draft-ietf-ipwave-ipv6-over-80211ocb-52

Abstract

This document provides methods and settings, for using IPv6 to communicate among nodes within range of one another over a single IEEE 802.11-OCB link. Support for these methods and settings require minimal changes to existing stacks. This document also describes limitations associated with using these methods. Optimizations and usage of IPv6 over more complex scenarios is not covered in this specification and is subject of future work.

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Table of Contents

1. Introduction

This document provides a baseline for using IPv6 to communicate among nodes in range of one another over a single IEEE 802.11-OCB link [IEEE-802.11-2016] (a.k.a., "802.11p" see Appendix A, Appendix B and Appendix C) with minimal changes to existing stacks. Moreover, the document identifies limitations of such usage. Concretely, the document describes the layering of IPv6 networking on top of the IEEE Std 802.11 MAC layer or an IEEE Std 802.3 MAC layer with a frame translation underneath. The resulting stack is derived from IPv6 over Ethernet [RFC2464], but operates over 802.11-OCB to provide at least P2P (Point to Point) connectivity using IPv6 ND and link-local addresses.

The IPv6 network layer operates on 802.11-OCB in the same manner as operating on Ethernet with the following exceptions:

- Exceptions due to different operation of IPv6 network layer on 802.11 than on Ethernet. The operation of IP on Ethernet is described in [RFC1042] and [RFC2464].

- Exceptions due to the OCB nature of 802.11-OCB compared to 802.11. This has impacts on security, privacy, subnet structure and movement detection. Security and privacy recommendations are discussed in Section 5 and Section 4.4. The subnet structure is described in Section 4.6. The movement detection on OCB links is not described in this document. Likewise, ND Extensions and IPWAVE optimizations for vehicular communications are not in scope. The expectation is that further specifications will be edited to cover more complex vehicular networking scenarios.

The reader may refer to [I-D.ietf-ipwave-vehicular-networking] for an overview of problems related to running IPv6 over 802.11-OCB. It is out of scope of this document to reiterate those.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

The document makes uses of the following terms: IP-OBU (Internet Protocol On-Board Unit): an IP-OBU denotes a computer situated in a vehicle such as a car, bicycle, or similar. It has at least one IP

interface that runs in mode OCB of 802.11, and that has an "OBU" transceiver. See the definition of the term "OBU" in section Appendix H.

IP-RSU (IP Road-Side 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 in the vehicle over 802.11 wireless link operating in OCB mode. An IP-RSU is similar to an Access Network Router (ANR) defined in [RFC3753], and a Wireless Termination Point (WTP) defined in [RFC5415].

OCB (outside the context of a basic service set - BSS): is a mode of operation in which a STA is not a member of a BSS and does not utilize IEEE Std 802.11 authentication, association, or data confidentiality.

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

3. Communication Scenarios where IEEE 802.11-OCB Links are Used

The IEEE 802.11-OCB networks are used for vehicular communications, as 'Wireless Access in Vehicular Environments'. In particular, we refer the reader to [I-D.ietf-ipwave-vehicular-networking], that lists some scenarios and requirements for IP in Intelligent Transportation Systems (ITS).

The link model is the following: STA --- 802.11-OCB --- STA. In vehicular networks, STAs can be IP-RSUs and/or IP-OBUs. All links are assumed to be P2P and multiple links can be on one radio interface. While 802.11-OCB is clearly specified, and a legacy IPv6 stack can operate on such links, the use of the operating environment (vehicular networks) brings in new perspectives.

4. IPv6 over 802.11-OCB

4.1. Maximum Transmission Unit (MTU)

The default MTU for IP packets on 802.11-OCB is inherited from [RFC2464] and is, as such, 1500 octets. As noted in [RFC8200], every link on the Internet must have a minimum MTU of 1280 octets, as well as follow the other recommendations, especially with regard to fragmentation.

4.2. Frame Format

IP packets MUST be transmitted over 802.11-OCB media as QoS Data frames whose format is specified in IEEE 802.11 spec [IEEE-802.11-2016].

The IPv6 packet transmitted on 802.11-OCB are immediately preceded by a Logical Link Control (LLC) header and an 802.11 header. In the LLC header, and in accordance with the EtherType Protocol Discrimination (EPD, see Appendix D), the value of the Type field MUST be set to 0x86DD (IPv6). The mapping to the 802.11 data service SHOULD use a 'priority' value of 1 (QoS with a 'Background' user priority), reserving higher priority values for safety-critical and time-sensitive traffic, including the ones listed in [ETSI-sec-archi].

To simplify the Application Programming Interface (API) between the operating system and the 802.11-OCB media, device drivers MAY implement IPv6-over-Ethernet as per [RFC2464] and then a frame translation from 802.3 to 802.11 in order to minimize the code changes.

4.3. Link-Local Addresses

There are several types of IPv6 addresses [RFC4291], [RFC4193], that may be assigned to an 802.11-OCB interface. Among these types of addresses only the IPv6 link-local addresses can be formed using an EUI-64 identifier, in particular during transition time, (the time spent before an interface starts using a different address than the LL one).

If the IPv6 link-local address is formed using an EUI-64 identifier, then the mechanism of forming that address is the same mechanism as used to form an IPv6 link-local address on Ethernet links. Moreover, whether or not the interface identifier is derived from the EUI-64 identifier, its length is 64 bits as is the case for Ethernet [RFC2464].

4.4. Stateless Autoconfiguration

The steps a host takes in deciding how to autoconfigure its interfaces in IPv6 are described in [RFC4862]. This section describes the formation of Interface Identifiers for IPv6 addresses of type 'Global' or 'Unique Local'. Interface Identifiers for IPv6 address of type 'Link-Local' are discussed in Section 4.3.

The RECOMMENDED method for forming stable Interface Identifiers (IIDs) is described in [RFC8064]. The method of forming IIDs described in Section 4 of [RFC2464] MAY be used during transition

time, in particular for IPv6 link-local addresses. Regardless of how to form the IID, its length is 64 bits, similarely to IPv6 over Ethernet [RFC2464].

The bits in the IID have no specific meaning and the identifier should be treated as an opaque value. The bits 'Universal' and 'Group' in the identifier of an 802.11-OCB interface are significant, as this is an IEEE link-layer address. The details of this significance are described in [RFC7136].

Semantically opaque IIDs, instead of meaningful IIDs derived from a valid and meaningful MAC address ([RFC2464], Section 4), help avoid certain privacy risks (see the risks mentioned in Section 5.1.1). If semantically opaque IIDs are needed, they may be generated using the method for generating semantically opaque IIDs with IPv6 Stateless Address Autoconfiguration given in [RFC7217]. Typically, an opaque IID is formed starting from identifiers different than the MAC addresses, and from cryptographically strong material. Thus, privacy sensitive information is absent from Interface IDs, because it is impossible to calculate back the initial value from which the Interface ID was first generated.

Some applications that use IPv6 packets on 802.11-OCB links (among other link types) may benefit from IPv6 addresses whose IIDs don't change too often. It is RECOMMENDED to use the mechanisms described in RFC 7217 to permit the use of Stable IIDs that do not change within one subnet prefix. A possible source for the Net-Iface Parameter is a virtual interface name, or logical interface name, that is decided by a local administrator.

4.5. Address Mapping

Unicast and multicast address mapping MUST follow the procedures specified for Ethernet interfaces specified in Sections 6 and 7 of [RFC2464].

4.5.1. Address Mapping -- Unicast

This document is scoped for Address Resolution (AR) and Duplicate Address Detection (DAD) per [RFC4862].

4.5.2. Address Mapping -- Multicast

The multicast address mapping is performed according to the method specified in section 7 of [RFC2464]. The meaning of the value "3333" mentioned there is defined in section 2.3.1 of [RFC7042].

Transmitting IPv6 packets to multicast destinations over 802.11 links proved to have some performance issues [I-D.ietf-mboned-ieee802-mcast-problems]. These issues may be exacerbated in OCB mode. A future improvement to this specification should consider solutions for these problems.

4.6. Subnet Structure

When vehicles are in close range, a subnet may be formed over 802.11-OCB interfaces (not by their in-vehicle interfaces). A Prefix List conceptual data structure ([RFC4861] Section 5.1) is maintained for each 802.11-OCB interface.

IPv6 Neighbor Discovery protocol (ND) requires reflexive properties (bidirectional connectivity) which is generally, though not always, the case for P2P OCB links. IPv6 ND also requires transitive properties for DAD and AR, so an IPv6 subnet can be mapped on an OCB network only if all nodes in the network share a single physical broadcast domain. The extension to IPv6 ND operating on a subnet that covers multiple OCB links and not fully overlapping (NBMA) is not in scope. Finally, IPv6 ND requires a permanent connectivity of all nodes in the subnet to defend their addresses, in other words very stable network conditions.

The structure of this subnet is ephemeral, in that it is strongly influenced by the mobility of vehicles: the hidden terminal effects appear; the 802.11 networks in OCB mode may be considered as 'ad-hoc' networks with an addressing model as described in [RFC5889]. On another hand, the structure of the internal subnets in each vehicle is relatively stable.

As recommended in [RFC5889], when the timing requirements are very strict (e.g., fast-drive-through IP-RSU coverage), no on-link subnet prefix should be configured on an 802.11-OCB interface. In such cases, the exclusive use of IPv6 link-local addresses is RECOMMENDED.

Additionally, even if the timing requirements are not very strict (e.g., the moving subnet formed by two following vehicles is stable, a fixed IP-RSU is absent), the subnet is disconnected from the Internet (i.e., a default route is absent), and the addressing peers are equally qualified (that is, it is impossible to determine that some vehicle owns and distributes addresses to others) the use of link-local addresses is RECOMMENDED.

The baseline ND protocol [RFC4861] MUST be supported over 802.11-OCB links. Transmitting ND packets may prove to have some performance issues as mentioned in Section 4.5.2, and Appendix I. These issues may be exacerbated in OCB mode. Solutions for these problems should

consider the OCB mode of operation. Future solutions to OCB should consider solutions for avoiding broadcast. The best of current knowledge indicates the kinds of issues that may arise with ND in OCB mode; they are described in Appendix I.

Protocols like Mobile IPv6 [RFC6275] , [RFC3963] and DNAv6 [RFC6059], which depend on a timely movement detection, might need additional tuning work to handle the lack of link-layer notifications during handover. This is for further study.

5. Security Considerations

Any security mechanism at the IP layer or above that may be carried out for the general case of IPv6 may also be carried out for IPv6 operating over 802.11-OCB.

The OCB operation does not use existing 802.11 link-layer security mechanisms. There is no encryption applied below the network layer running on 802.11-OCB. At the application layer, the IEEE 1609.2 document [IEEE-1609.2] provides security services for certain applications to use; application-layer mechanisms are out of scope of this document. On another hand, a security mechanism provided at networking layer, such as IPsec [RFC4301], may provide data security protection to a wider range of applications.

802.11-OCB does not provide any cryptographic protection, because it operates outside the context of a BSS (no Association Request/ Response, no Challenge messages). Therefore, an attacker can sniff or inject traffic while within range of a vehicle or IP-RSU (by setting an interface card's frequency to the proper range). Also, an attacker may not heed to legal limits for radio power and can use a very sensitive directional antenna; if attackers wishe to attack a given exchange they do not necessarily need to be in close physical proximity. Hence, such a link is less protected than commonly used links (wired link or aforementioned 802.11 links with link-layer security).

Therefore, any node can join a subnet, directly communicate with any nodes on the subset to include potentially impersonating another node. This design allows for a number of threats outlined in Section 3 of [RFC6959]. While not widely deployed, SeND [RFC3971], [RFC3972] is a solution that can address Spoof-Based Attack Vectors.

5.1. Privacy Considerations

As with all Ethernet and 802.11 interface identifiers ([RFC7721]), the identifier of an 802.11-OCB interface may involve privacy, MAC address spoofing and IP hijacking risks. A vehicle embarking an IP-

OBU whose egress interface is 802.11-OCB may expose itself to eavesdropping and subsequent correlation of data. This may reveal data considered private by the vehicle owner; there is a risk of being tracked. In outdoors public environments, where vehicles typically circulate, the privacy risks are more important than in indoors settings. It is highly likely that attacker sniffers are deployed along routes which listen for IEEE frames, including IP packets, of vehicles passing by. For this reason, in the 802.11-OCB deployments, there is a strong necessity to use protection tools such as dynamically changing MAC addresses Section 5.2, semantically opaque Interface Identifiers and stable Interface Identifiers Section 4.4. An example of change policy is to change the MAC address of the OCB interface each time the system boots up. This may help mitigate privacy risks to a certain level. Furthermore, for privacy concerns, ([RFC8065]) recommends using an address generation scheme rather than addresses generated from a fixed link-layer address. However, there are some specificities related to vehicles. Since roaming is an important characteristic of moving vehicles, the use of the same Link-Local Address over time can indicate the presence of the same vehicle in different places and thus leads to location tracking. Hence, a vehicle should get hints about a change of environment (e.g. , engine running, GPS, etc..) and renew the IID in its LLAs.

5.1.1. Privacy Risks of Meaningful info in Interface IDs

The privacy risks of using MAC addresses displayed in Interface Identifiers are important. The IPv6 packets can be captured easily in the Internet and on-link in public roads. For this reason, an attacker may realize many attacks on privacy. One such attack on 802.11-OCB is to capture, store and correlate Company ID information present in MAC addresses of many cars (e.g. listen for Router Advertisements, or other IPv6 application data packets, and record the value of the source address in these packets). Further correlation of this information with other data captured by other means, or other visual information (car color, others) may constitute privacy risks.

5.2. MAC Address and Interface ID Generation

In 802.11-OCB networks, the MAC addresses may change during well defined renumbering events. In the moment the MAC address is changed on an 802.11-OCB interface all the Interface Identifiers of IPv6 addresses assigned to that interface MUST change.

Implementations should use a policy dictating when the MAC address is changed on the 802.11-OCB interface. For more information on the

motivation of this policy please refer to the privacy discussion in Appendix B.

A 'randomized' MAC address has the following characteristics:

- Bit "Local/Global" set to "locally administered".
- Bit "Unicast/Multicast" set to "Unicast".
- The 46 remaining bits are set to a random value, using a random number generator that meets the requirements of [RFC4086].

To meet the randomization requirements for the 46 remaining bits, a hash function may be used. For example, the [SHA256] hash function may be used with input a 256 bit local secret, the 'nominal' MAC Address of the interface, and a representation of the date and time of the renumbering event.

A randomized Interface ID has the same characteristics of a randomized MAC address, except the length in bits.

5.3. Pseudonymization impact on confidentiality and trust

Vehicles 'and drivers' privacy relies on pseudonymization mechanisms such as the ones described in Section 5.2. This pseudonymization means that upper-layer protocols and applications SHOULD NOT rely on layer-2 or layer-3 addresses to assume that the other participant can be trusted.

6. IANA Considerations

No request to IANA.

7. Contributors

Christian Huitema, Tony Li.

Romain Kuntz contributed extensively about IPv6 handovers between links running outside the context of a BSS (802.11-OCB links).

Tim Leinmueller contributed the idea of the use of IPv6 over 802.11-OCB for distribution of certificates.

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Appendix A. 802.11p

The term "802.11p" is an earlier definition. The behaviour of "802.11p" networks is rolled in the document IEEE Std 802.11-2016. In that document the term 802.11p disappears. Instead, each 802.11p feature is conditioned by the IEEE Management Information Base (MIB) attribute "OCBActivated" [IEEE-802.11-2016]. Whenever OCBActivated is set to true the IEEE Std 802.11-OCB state is activated. For example, an 802.11 STAtion operating outside the context of a basic service set has the OCBActivated flag set. Such a station, when it has the flag set, uses a BSS identifier equal to ff:ff:ff:ff:ff:ff.

Appendix B. Aspects introduced by the OCB mode to 802.11

In the IEEE 802.11-OCB mode, all nodes in the wireless range can directly communicate with each other without involving authentication or association procedures. In OCB mode, the manner in which channels are selected and used is simplified compared to when in BSS mode. Contrary to BSS mode, at link layer, it is necessary to set statically the same channel number (or frequency) on two stations that need to communicate with each other (in BSS mode this channel set operation is performed automatically during 'scanning'). The manner in which stations set their channel number in OCB mode is not specified in this document. Stations STA1 and STA2 can exchange IP packets only if they are set on the same channel. At IP layer, they then discover each other by using the IPv6 Neighbor Discovery protocol. The allocation of a particular channel for a particular use is defined statically in standards authored by ETSI (in Europe), FCC in America, and similar organisations in South Korea, Japan and other parts of the world.

Briefly, the IEEE 802.11-OCB mode has the following properties:

- The use by each node of a 'wildcard' BSSID (i.e., each bit of the BSSID is set to 1)
- No IEEE 802.11 Beacon frames are transmitted
- No authentication is required in order to be able to communicate
- No association is needed in order to be able to communicate
- No encryption is provided in order to be able to communicate
- Flag dot11OCBActivated is set to true

All the nodes in the radio communication range (IP-OBU and IP-RSU) receive all the messages transmitted (IP-OBU and IP-RSU) within the radio communications range. The eventual conflict(s) are resolved by the MAC CDMA function.

The message exchange diagram in Figure 1 illustrates a comparison between traditional 802.11 and 802.11 in OCB mode. The 'Data' messages can be IP packets such as HTTP or others. Other 802.11 management and control frames (non IP) may be transmitted, as specified in the 802.11 standard. For information, the names of these messages as currently specified by the 802.11 standard are listed in Appendix F.

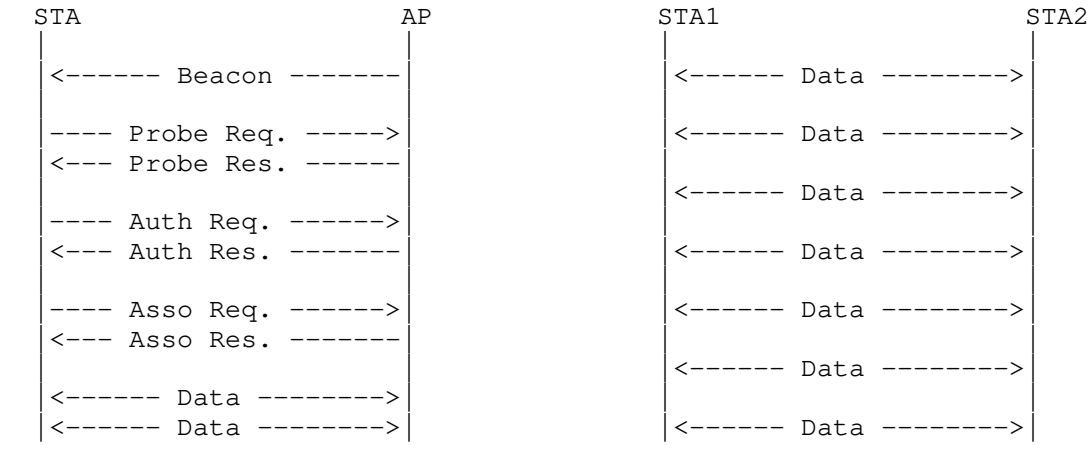


Figure 1: Difference between messages exchanged on 802.11 (left) and 802.11-OCB (right)

The interface 802.11-OCB was specified in IEEE Std 802.11p (TM) -2010 [IEEE-802.11p-2010] as an amendment to IEEE Std 802.11 (TM) -2007, titled "Amendment 6: Wireless Access in Vehicular Environments". Since then, this amendment has been integrated in IEEE 802.11(TM) -2012 and -2016 [IEEE-802.11-2016].

In document 802.11-2016, anything qualified specifically as "OCBActivated", or "outside the context of a basic service" set to be true, then it is actually referring to OCB aspects introduced to 802.11.

In order to delineate the aspects introduced by 802.11-OCB to 802.11, we refer to the earlier [IEEE-802.11p-2010]. The amendment is concerned with vehicular communications, where the wireless link is similar to that of Wireless LAN (using a PHY layer specified by 802.11a/b/g/n), but which needs to cope with the high mobility factor inherent in scenarios of communications between moving vehicles, and between vehicles and fixed infrastructure deployed along roads. While 'p' is a letter identifying the Amendment, just like 'a, b, g' and 'n' are, 'p' is concerned more with MAC modifications, and a little with PHY modifications; the others are mainly about PHY modifications. It is possible in practice to combine a 'p' MAC with an 'a' PHY by operating outside the context of a BSS with OFDM at 5.4GHz and 5.9GHz.

The 802.11-OCB links are specified to be compatible as much as possible with the behaviour of 802.11a/b/g/n and future generation IEEE WLAN links. From the IP perspective, an 802.11-OCB MAC layer offers practically the same interface to IP as the 802.11a/b/g/n and 802.3. A packet sent by an IP-OBU may be received by one or multiple IP-RSUs. The link-layer resolution is performed by using the IPv6 Neighbor Discovery protocol.

To support this similarity statement (IPv6 is layered on top of LLC on top of 802.11-OCB, in the same way that IPv6 is layered on top of LLC on top of 802.11a/b/g/n (for WLAN) or layered on top of LLC on top of 802.3 (for Ethernet)) it is useful to analyze the differences between 802.11-OCB and 802.11 specifications. During this analysis, we note that whereas 802.11-OCB lists relatively complex and numerous changes to the MAC layer (and very little to the PHY layer), there are only a few characteristics which may be important for an implementation transmitting IPv6 packets on 802.11-OCB links.

The most important 802.11-OCB point which influences the IPv6 functioning is the OCB characteristic; an additional, less direct influence, is the maximum bandwidth afforded by the PHY modulation/ demodulation methods and channel access specified by 802.11-OCB. The maximum bandwidth theoretically possible in 802.11-OCB is 54 Mbit/s

(when using, for example, the following parameters: 20 MHz channel; modulation 64-QAM; coding rate R is 3/4); in practice of IP-over-802.11-OCB a commonly observed figure is 12Mbit/s; this bandwidth allows the operation of a wide range of protocols relying on IPv6.

- Operation Outside the Context of a BSS (OCB): the (earlier 802.11p) 802.11-OCB links are operated without a Basic Service Set (BSS). This means that the frames IEEE 802.11 Beacon, Association Request/Response, Authentication Request/Response, and similar, are not used. The used identifier of BSS (BSSID) has a hexadecimal value always 0xffffffffffff (48 '1' bits, represented as MAC address ff:ff:ff:ff:ff:ff, or otherwise the 'wildcard' BSSID), as opposed to an arbitrary BSSID value set by administrator (e.g. 'My-Home-AccessPoint'). The OCB operation - namely the lack of beacon-based scanning and lack of authentication - should be taken into account when the Mobile IPv6 protocol [RFC6275] and the protocols for IP layer security [RFC4301] are used. The way these protocols adapt to OCB is not described in this document.

- Timing Advertisement: is a new message defined in 802.11-OCB, which does not exist in 802.11a/b/g/n. This message is used by stations to inform other stations about the value of time. It is similar to the time as delivered by a GNSS system (Galileo, GPS, ...) or by a cellular system. This message is optional for implementation.

- Frequency range: this is a characteristic of the PHY layer, with almost no impact on the interface between MAC and IP. However, it is worth considering that the frequency range is regulated by a regional authority (ARCEP, ECC/CEPT based on ENs from ETSI, FCC, etc.); as part of the regulation process, specific applications are associated with specific frequency ranges. In the case of 802.11-OCB, the regulator associates a set of frequency ranges, or slots within a band, to the use of applications of vehicular communications, in a band known as "5.9GHz". The 5.9GHz band is different from the 2.4GHz and 5GHz bands used by Wireless LAN. However, as with Wireless LAN, the operation of 802.11-OCB in "5.9GHz" bands is exempt from owning a license in EU (in US the 5.9GHz is a licensed band of spectrum; for the fixed infrastructure an explicit FCC authorization is required; for an on-board device a 'licensed-by-rule' concept applies: rule certification conformity is required.) Technical conditions are different than those of the bands "2.4GHz" or "5GHz". The allowed power levels, and implicitly the maximum allowed distance between vehicles, is of 33dBm for 802.11-OCB (in Europe), compared to 20 dBm for Wireless LAN 802.11a/b/g/n; this leads to a maximum distance of approximately 1km, compared to approximately 50m.

Additionally, specific conditions related to congestion avoidance, jamming avoidance, and radar detection are imposed on the use of DSRC (in US) and on the use of frequencies for Intelligent Transportation Systems (in EU), compared to Wireless LAN (802.11a/b/g/n).

- 'Half-rate' encoding: as the frequency range, this parameter is related to PHY, and thus has not much impact on the interface between the IP layer and the MAC layer.

- In vehicular communications using 802.11-OCB links, there are strong privacy requirements with respect to addressing. While the 802.11-OCB standard does not specify anything in particular with respect to MAC addresses, in these settings there exists a strong need for dynamic change of these addresses (as opposed to the non-vehicular settings - real wall protection - where fixed MAC addresses do not currently pose some privacy risks). This is further described in Section 5. A relevant function is described in documents IEEE 1609.3-2016 [IEEE-1609.3] and IEEE 1609.4-2016 [IEEE-1609.4].

Appendix C. Changes Needed on a software driver 802.11a to become a 802.11-OCB driver

The 802.11p amendment modifies both the 802.11 stack's physical and MAC layers but all the induced modifications can be quite easily obtained by modifying an existing 802.11a ad-hoc stack.

Conditions for a 802.11a hardware to be 802.11-OCB compliant:

- The PHY entity shall be an orthogonal frequency division multiplexing (OFDM) system. It must support the frequency bands on which the regulator recommends the use of ITS communications, for example using IEEE 802.11-OCB layer, in France: 5875MHz to 5925MHz.

- The OFDM system must provide a "half-clocked" operation using 10 MHz channel spacings.

- The chip transmit spectrum mask must be compliant to the "Transmit spectrum mask" from the IEEE 802.11p amendment (but experimental environments tolerate otherwise).

- The chip should be able to transmit up to 44.8 dBm when used by the US government in the United States, and up to 33 dBm in Europe; other regional conditions apply.

Changes needed on the network stack in OCB mode:

- Physical layer:
  - The chip must use the Orthogonal Frequency Multiple Access (OFDM) encoding mode.
  - The chip must be set in half-mode rate mode (the internal clock frequency is divided by two).
  - The chip must use dedicated channels and should allow the use of higher emission powers. This may require modifications to the local computer file that describes regulatory domains rules, if used by the kernel to enforce local specific restrictions. Such modifications to the local computer file must respect the location-specific regulatory rules.

  MAC layer:

  - All management frames (beacons, join, leave, and others) emission and reception must be disabled except for frames of subtype Action and Timing Advertisement (defined below).
  - No encryption key or method must be used.
  - Packet emission and reception must be performed as in ad-hoc mode, using the wildcard BSSID (ff:ff:ff:ff:ff:ff).
  - The functions related to joining a BSS (Association Request/ Response) and for authentication (Authentication Request/Reply, Challenge) are not called.
  - The beacon interval is always set to 0 (zero).
  - Timing Advertisement frames, defined in the amendment, should be supported. The upper layer should be able to trigger such frames emission and to retrieve information contained in received Timing Advertisements.

Appendix D. Protocol Layering

A more theoretical and detailed view of layer stacking, and interfaces between the IP layer and 802.11-OCB layers, is illustrated in Figure 2. The IP layer operates on top of the EtherType Protocol Discrimination (EPD); this Discrimination layer is described in IEEE Std 802.3-2012; the interface between IPv6 and EPD is the LLC_SAP (Link Layer Control Service Access Point).

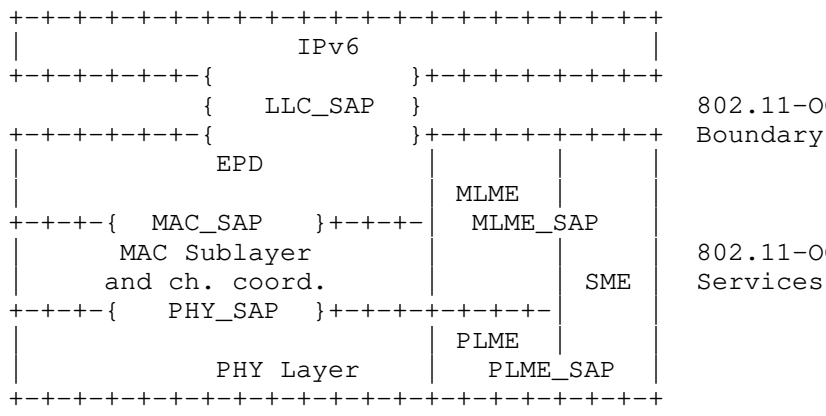


Figure 2: EtherType Protocol Discrimination

Appendix E. Design Considerations

The networks defined by 802.11-OCB are in many ways similar to other networks of the 802.11 family. In theory, the transportation of IPv6 over 802.11-OCB could be very similar to the operation of IPv6 over other networks of the 802.11 family. However, the high mobility, strong link asymmetry and very short connection makes the 802.11-OCB link significantly different from other 802.11 networks. Also, the automotive applications have specific requirements for reliability, security and privacy, which further add to the particularity of the 802.11-OCB link.

Appendix F. IEEE 802.11 Messages Transmitted in OCB mode

For information, at the time of writing, this is the list of IEEE 802.11 messages that may be transmitted in OCB mode, i.e. when dot11OCBActivated is true in a STA:

- The STA may send management frames of subtype Action and, if the STA maintains a TSF Timer, subtype Timing Advertisement;
- The STA may send control frames, except those of subtype PS-Poll, CF-End, and CF-End plus CFAck;
- The STA MUST send data frames of subtype QoS Data.

Appendix G. Examples of Packet Formats

This section describes an example of an IPv6 Packet captured over a IEEE 802.11-OCB link.

By way of example we show that there is no modification in the headers when transmitted over 802.11-OCB networks - they are transmitted like any other 802.11 and Ethernet packets.

We describe an experiment of capturing an IPv6 packet on an 802.11-OCB link. In topology depicted in Figure 3, the packet is an IPv6 Router Advertisement. This packet is emitted by a Router on its 802.11-OCB interface. The packet is captured on the Host, using a network protocol analyzer (e.g. Wireshark); the capture is performed in two different modes: direct mode and 'monitor' mode. The topology used during the capture is depicted below.

The packet is captured on the Host. The Host is an IP-OBU containing an 802.11 interface in format PCI express (an ITRI product). The kernel runs the ath5k software driver with modifications for OCB mode. The capture tool is Wireshark. The file format for save and analyze is 'pcap'. The packet is generated by the Router. The Router is an IP-RSU (ITRI product).

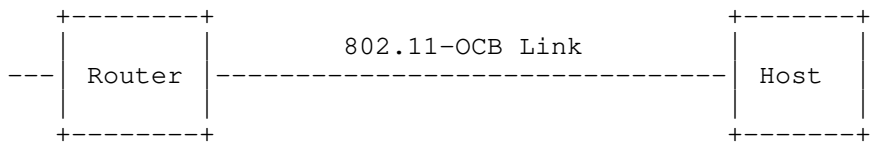


Figure 3: Topology for capturing IP packets on 802.11-OCB

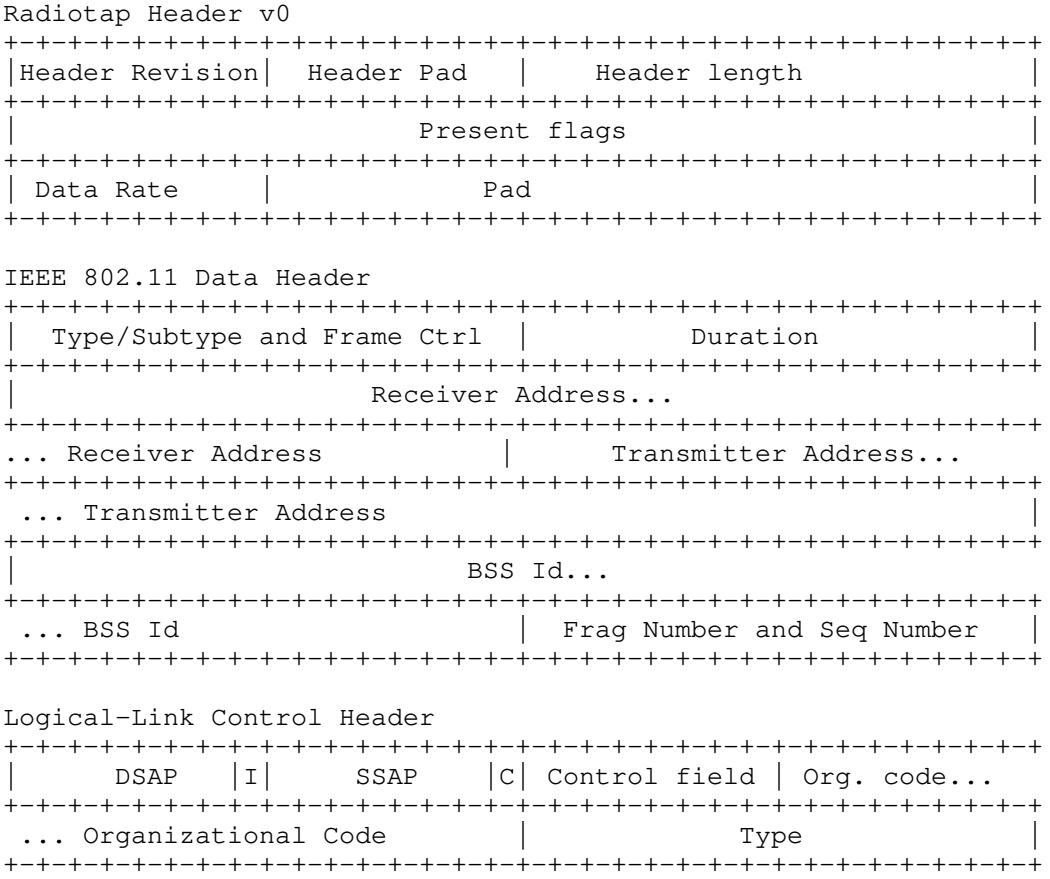
During several capture operations running from a few moments to several hours, no message relevant to the BSSID contexts were captured (no Association Request/Response, Authentication Req/Resp, Beacon). This shows that the operation of 802.11-OCB is outside the context of a BSSID.

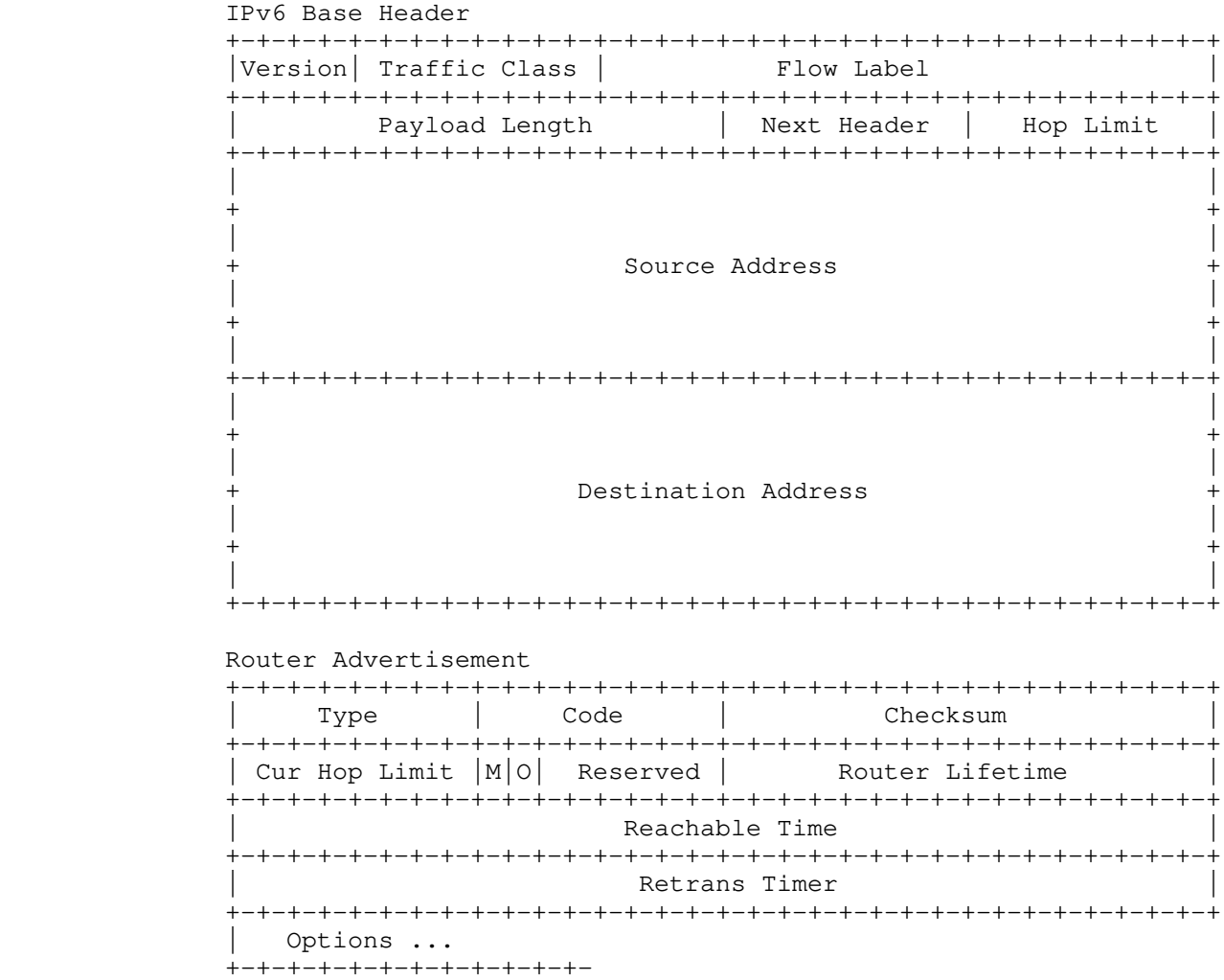
Overall, the captured message is identical with a capture of an IPv6 packet emitted on a 802.11b interface. The contents are precisely similar.

G.1. Capture in Monitor Mode

The IPv6 RA packet captured in monitor mode is illustrated below. The radio tap header provides more flexibility for reporting the characteristics of frames. The Radiotap Header is prepended by this particular stack and operating system on the Host machine to the RA packet received from the network (the Radiotap Header is not present on the air). The implementation-dependent Radiotap Header is useful for piggybacking PHY information from the chip's registers as data in a packet understandable by userland applications using Socket interfaces (the PHY interface can be, for example: power levels, data rate, ratio of signal to noise).

The packet present on the air is formed by IEEE 802.11 Data Header, Logical Link Control Header, IPv6 Base Header and ICMPv6 Header.





The value of the Data Rate field in the Radiotap header is set to 6 Mb/s. This indicates the rate at which this RA was received.

The value of the Transmitter address in the IEEE 802.11 Data Header is set to a 48bit value. The value of the destination address is 33:33:00:00:00:1 (all-nodes multicast address). The value of the BSS Id field is ff:ff:ff:ff:ff:ff, which is recognized by the network protocol analyzer as being "broadcast". The Fragment number and sequence number fields are together set to 0x90C6.

The value of the Organization Code field in the Logical-Link Control Header is set to 0x0, recognized as "Encapsulated Ethernet". The value of the Type field is 0x86DD (hexadecimal 86DD, or otherwise #86DD), recognized as "IPv6".

A Router Advertisement is periodically sent by the router to multicast group address ff02::1. It is an icmp packet type 134. The IPv6 Neighbor Discovery's Router Advertisement message contains an 8-bit field reserved for single-bit flags, as described in [RFC4861].

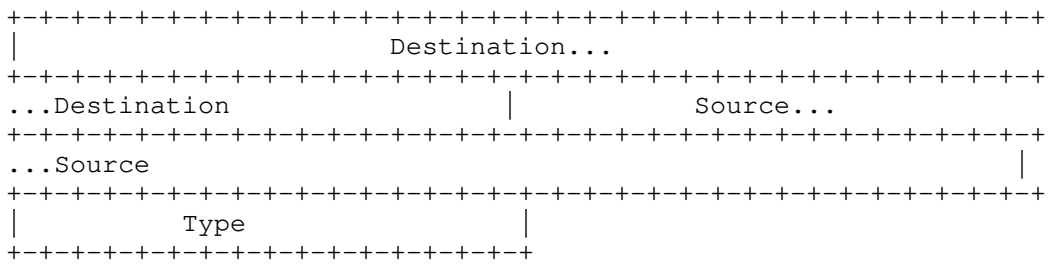
The IPv6 header contains the link local address of the router (source) configured via EUI-64 algorithm, and destination address set to ff02::1.

The Ethernet Type field in the logical-link control header is set to 0x86dd which indicates that the frame transports an IPv6 packet. In the IEEE 802.11 data, the destination address is 33:33:00:00:00:01 which is the corresponding multicast MAC address. The BSS id is a broadcast address of ff:ff:ff:ff:ff:ff. Due to the short link duration between vehicles and the roadside infrastructure, there is no need in IEEE 802.11-OCB to wait for the completion of association and authentication procedures before exchanging data. IEEE 802.11-OCB enabled nodes use the wildcard BSSID (a value of all 1s) and may start communicating as soon as they arrive on the communication channel.

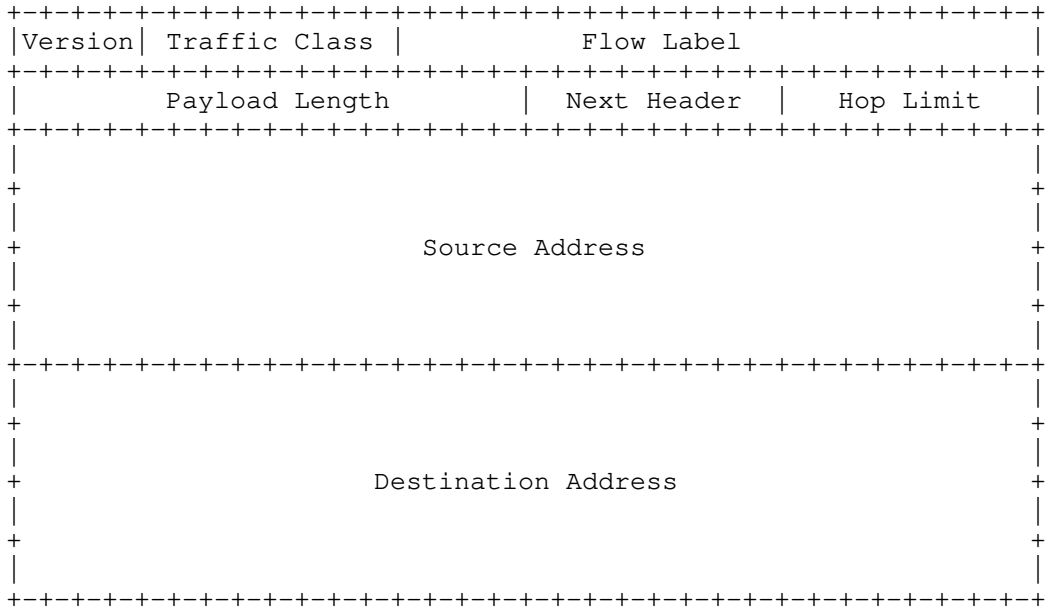
G.2. Capture in Normal Mode

The same IPv6 Router Advertisement packet described above (monitor mode) is captured on the Host, in the Normal mode, and depicted below.

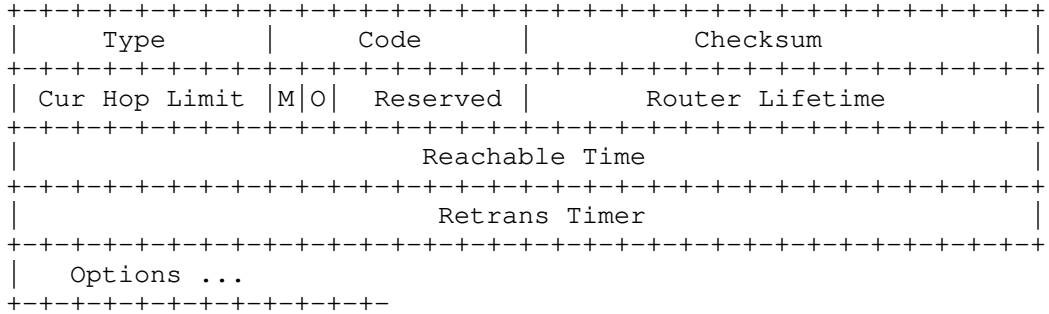
Ethernet II Header



IPv6 Base Header



Router Advertisement



One notices that the Radiotap Header, the IEEE 802.11 Data Header and the Logical-Link Control Headers are not present. On the other hand, a new header named Ethernet II Header is present.

The Destination and Source addresses in the Ethernet II header contain the same values as the fields Receiver Address and Transmitter Address present in the IEEE 802.11 Data Header in the "monitor" mode capture.

The value of the Type field in the Ethernet II header is 0x86DD (recognized as "IPv6"); this value is the same value as the value of the field Type in the Logical-Link Control Header in the "monitor" mode capture.

The knowledgeable experimenter will no doubt notice the similarity of this Ethernet II Header with a capture in normal mode on a pure Ethernet cable interface.

A frame translation is inserted on top of a pure IEEE 802.11 MAC layer, in order to adapt packets, before delivering the payload data to the applications. It adapts 802.11 LLC/MAC headers to Ethernet II headers. In further detail, this adaptation consists in the elimination of the Radiotap, 802.11 and LLC headers, and in the insertion of the Ethernet II header. In this way, IPv6 runs straight over LLC over the 802.11-OCB MAC layer; this is further confirmed by the use of the unique Type 0x86DD.

Appendix H. Extra Terminology

The following terms are defined outside the IETF. They are used to define the main terms in the main terminology Section 2.

DSRC (Dedicated Short Range Communication): a term defined outside the IETF. The US Federal Communications Commission (FCC) Dedicated Short Range Communication (DSRC) is defined in the Code of Federal Regulations (CFR) 47, Parts 90 and 95. This Code is referred in the definitions below. At the time of the writing of this Internet Draft, the last update of this Code was dated October 1st, 2010.

DSRCS (Dedicated Short-Range Communications Services): a term defined outside the IETF. The use of radio techniques to transfer data over short distances between roadside and mobile units, between mobile units, and between portable and mobile units to perform operations related to the improvement of traffic flow, traffic safety, and other intelligent transportation service applications in a variety of environments. DSRCS systems may also transmit status and instructional messages related to the units involve. [Ref. 47 CFR 90.7 - Definitions]

OBU (On-Board Unit): a term defined outside the IETF. An On-Board Unit is a DSRCS transceiver that is normally mounted in or on a vehicle, or which in some instances may be a portable unit. An OBU can be operational while a vehicle or person is either mobile or stationary. The OBUs receive and contend for time to transmit on one or more radio frequency (RF) channels. Except where specifically excluded, OBU operation is permitted wherever vehicle operation or human passage is permitted. The OBUs mounted in vehicles are licensed by rule under part 95 of the respective chapter and communicate with Roadside Units (RSUs) and other OBUs. Portable OBUs are also licensed by rule under part 95 of the respective chapter. OBU operations in the Unlicensed National Information Infrastructure (UNII) Bands follow the rules in those bands. - [CFR 90.7 - Definitions].

RSU (Road-Side Unit): a term defined outside of IETF. A Roadside Unit is a DSRC transceiver that is mounted along a road or pedestrian passageway. An RSU may also be mounted on a vehicle or is hand carried, but it may only operate when the vehicle or hand- carried unit is stationary. Furthermore, an RSU operating under the respectgive part is restricted to the location where it is licensed to operate. However, portable or hand-held RSUs are permitted to operate where they do not interfere with a site-licensed operation. A RSU broadcasts data to OBUs or exchanges data with OBUs in its communications zone. An RSU also provides channel assignments and operating instructions to OBUs in its communications zone, when required. - [CFR 90.7 - Definitions].

Appendix I. Neighbor Discovery (ND) Potential Issues in Wireless Links

IPv6 Neighbor Discovery (IPv6 ND) [RFC4861][RFC4862] was designed for point-to-point and transit links such as Ethernet, with the expectation of a cheap and reliable support for multicast from the lower layer. Section 3.2 of RFC 4861 indicates that the operation on Shared Media and on non-broadcast multi-access (NBMA) networks require additional support, e.g., for Address Resolution (AR) and duplicate address detection (DAD), which depend on multicast. An infrastructureless radio network such as OCB shares properties with both Shared Media and NBMA networks, and then adds its own complexity, e.g., from movement and interference that allow only transient and non-transitive reachability between any set of peers.

The uniqueness of an address within a scoped domain is a key pillar of IPv6 and the base for unicast IP communication. RFC 4861 details the DAD method to avoid that an address is duplicated. For a link local address, the scope is the link, whereas for a Globally Reachable address the scope is much larger. The underlying assumption for DAD to operate correctly is that the node that owns an

IPv6 address can reach any other node within the scope at the time it claims its address, which is done by sending a NS multicast message, and can hear any future claim for that address by another party within the scope for the duration of the address ownership.

In the case of OCB, there is a potentially a need to define a scope that is compatible with DAD, and that cannot be the set of nodes that a transmitter can reach at a particular time, because that set varies all the time and does not meet the DAD requirements for a link local address that could possibly be used anytime, anywhere. The generic expectation of a reliable multicast is not ensured, and the operation of DAD and AR (Address Resolution) as specified by RFC 4861 cannot be guaranteed. Moreover, multicast transmissions that rely on broadcast are not only unreliable but are also often detrimental to unicast traffic (see [draft-ietf-mboned-ieee802-mcast-problems]).

Early experience indicates that it should be possible to exchange IPv6 packets over OCB while relying on IPv6 ND alone for DAD and AR (Address Resolution) in good conditions. In the absence of a correct DAD operation, a node that relies only on IPv6 ND for AR and DAD over OCB should ensure that the addresses that it uses are unique by means others than DAD. It must be noted that deriving an IPv6 address from a globally unique MAC address has this property but may yield privacy issues.

RFC 8505 provides a more recent approach to IPv6 ND and in particular DAD. RFC 8505 is designed to fit wireless and otherwise constrained networks whereby multicast and/or continuous access to the medium may not be guaranteed. RFC 8505 Section 5.6 "Link-Local Addresses and Registration" indicates that the scope of uniqueness for a link local address is restricted to a pair of nodes that use it to communicate, and provides a method to assert the uniqueness and resolve the link-Layer address using a unicast exchange.

RFC 8505 also enables a router (acting as a 6LR) to own a prefix and act as a registrar (acting as a 6LBR) for addresses within the associated subnet. A peer host (acting as a 6LN) registers an address derived from that prefix and can use it for the lifetime of the registration. The prefix is advertised as not onlink, which means that the 6LN uses the 6LR to relay its packets within the subnet, and participation to the subnet is constrained to the time of reachability to the 6LR. Note that RSU that provides internet connectivity MAY announce a default router preference [RFC4191], whereas a car that does not provide that connectivity MUST NOT do so. This operation presents similarities with that of an access point, but at Layer-3. This is why RFC 8505 well-suited for wireless in general.

Support of RFC 8505 may be implemented on OCB. OCB nodes that support RFC 8505 SHOULD support the 6LN operation in order to act as a host, and may support the 6LR and 6LBR operations in order to act as a router and in particular own a prefix that can be used by RFC 8505-compliant hosts for address autoconfiguration and registration.

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IP Wireless Access in Vehicular Environments (IPWAVE): Problem Statement and Use Cases
draft-ietf-ipwave-vehicular-networking-06

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.

- 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.

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

- 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

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

- Cooperative adaptive cruise control in an urban 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 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

- Navigation service;
- Energy-efficient speed recommendation service;
- 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].

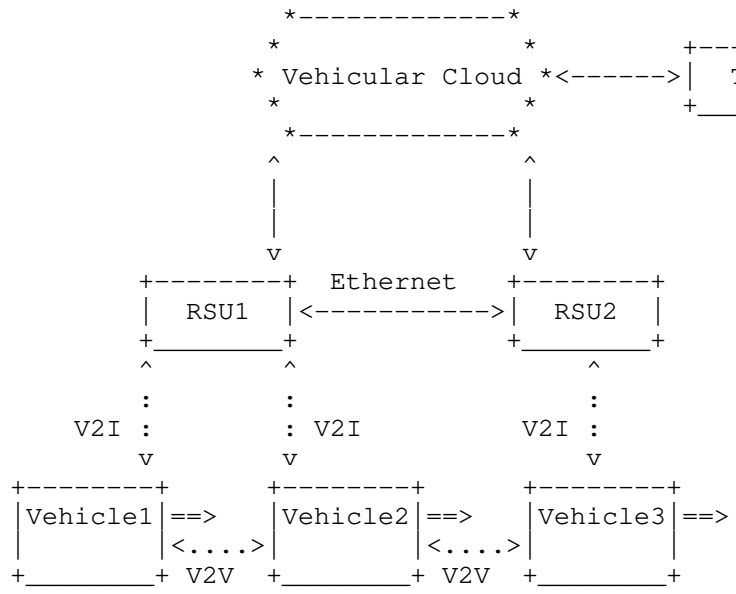


Figure 1: A Vehicular Network Architecture for V2I and V2V Networking

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.

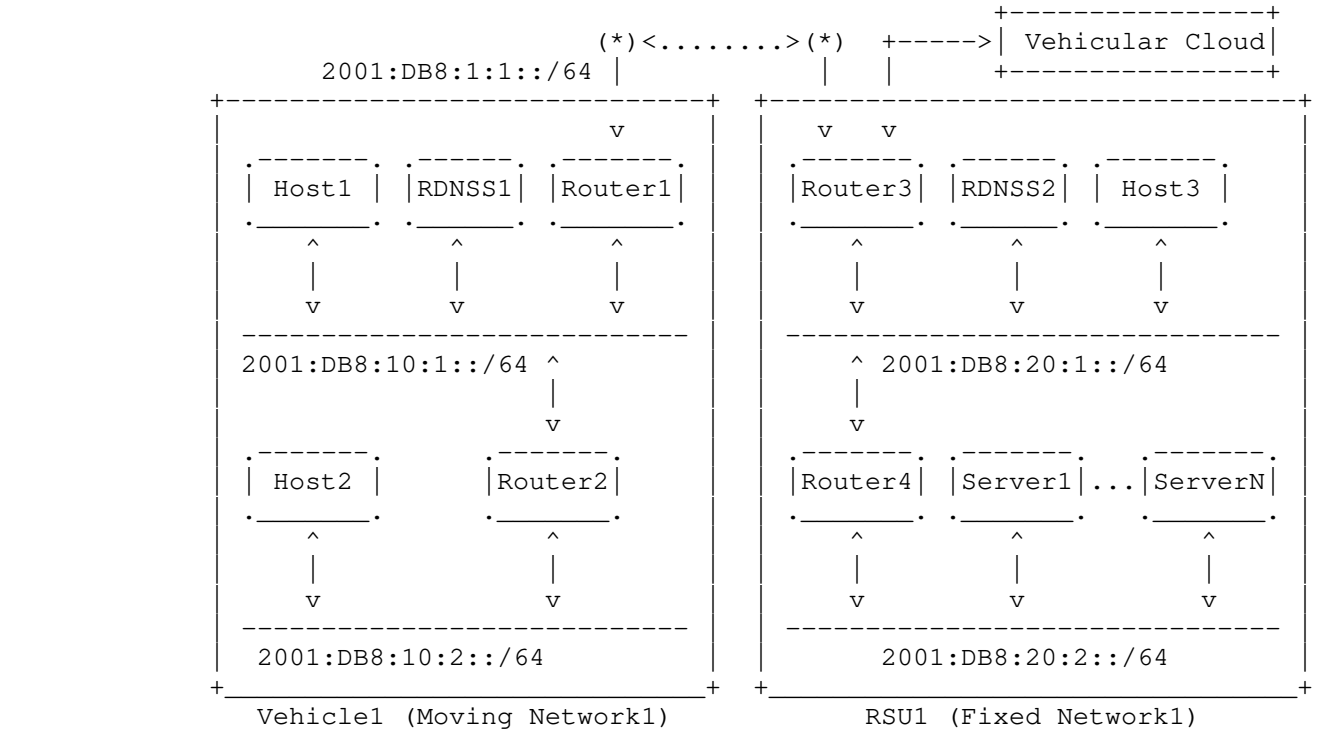


Figure 2: Internetworking between Vehicle Network and RSU Network

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.

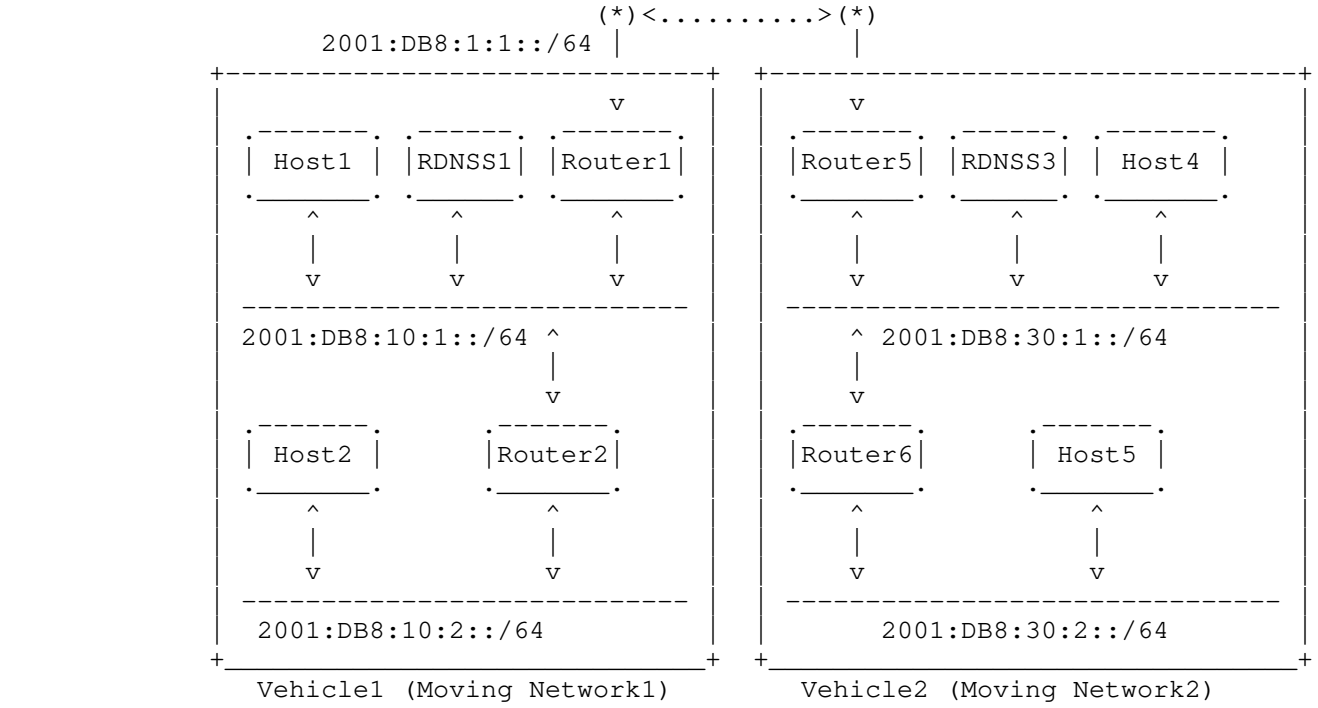
As shown in Figure 2, the vehicle's moving network and the RSU's fixed network are self-contained networks having multiple subnets and having an edge router for the communication with another vehicle or RSU. The method of prefix assignment for each subnet inside the vehicle's mobile network and the RSU's 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 prefixs 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.



<----> 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 (RDNSS3), the two hosts (Host4 and Host5), and the two routers (Router5 and Router6). Vehicle1's Router1 (called mobile router) and Vehicle2's Router5 (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:

- IPWAVE is not power-constrained operation;
- Traffic can be sourced or sinked outside of IPWAVE;
- IPWAVE shall support both distributed and centralized operations;
- 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-05

The following changes are made from draft-ietf-ipwave-vehicular-networking-05:

- In Figure 2 and Figure 3, the vehicle networks and RSU network are updated.

Appendix C. Acknowledgments

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Appendix D. Contributors

This document is a group work of IPWAVE working group, greatly benefiting from inputs and texts by Rex Buddenberg (Naval Postgraduate School), Thierry Ernst (YoGoKo), Bokor Laszlo (Budapest University of Technology and Economics), Jose Santa Lozanoi (Universidad of Murcia), Richard Roy (MIT), Francois Simon (Pilot), Sri Gundavelli (Cisco), Erik Nordmark, and Dirk von Hugo (Deutsche Telekom). The authors sincerely appreciate their contributions.

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IPv6 Wireless Access in Vehicular Environments (IPWAVE): Problem Statement and Use Cases
draft-ietf-ipwave-vehicular-networking-30

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).

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1. Introduction

Vehicular networking studies have mainly focused on improving road safety and efficiency, and also enabling entertainment in vehicular networks. To proliferate the use cases of vehicular networks, several governments and private organizations have committed to allocate dedicated spectrum for vehicular communications. 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). In November 2020, the FCC adjusted the lower 45 MHz (i.e., 5.850 - 5.895 GHz) of the 5.9 GHz band for unlicensed use instead of DSRC-dedicated use [FCC-ITS-Modification]. 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]. Most other countries and regions in the world have adopted the 5.9 GHz band for vehicular networks, though different countries use different ways to divide the band into channels.

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 multichannel 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], Network Mobility (NEMO) [RFC3963], and Locator/ID Separation Protocol (LISP) [I-D.ietf-lisp-rfc6830bis]. 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) so that those protocols can be 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:

* 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 Device (ECD): It is a computing device (or server) at edge for vehicles and vulnerable road users. It co-locates with or connects to an IP-RSU, which has a powerful computing capability for different kinds of computing tasks, such as image processing and classification.

* 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 navigation satellite system (GNSS), such as 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, motorcycle, and a similar one), which has a basic processing ability and can be driven by a low-power CPU (e.g., ARM). 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]. It can play the role of a router connecting multiple computers (or in-vehicle devices) inside a vehicle. See the definition of the term "IP-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 a third IP-enabled wireless interface running in 3GPP C-V2X in addition to the IP-RSU defined in [RFC8691]. 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 "IP-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.

* Urban Air Mobility (UAM): It refers to using lower-altitude aircraft to transport passengers or cargo in urban and suburban areas. The carriers used for UAM can be manned or unmanned vehicles, which can include traditional helicopters, electrical vertical-takeoff-and-landing aircraft (eVTOL), and unmanned aerial vehicles (UAV).

* 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 GNSS radio navigation receiver for efficient navigation. Any device having an IP-OBU and a GNSS receiver (e.g., smartphone and tablet 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).

* V2P: "Vehicle to Pedestrian". It is the wireless communication between a vehicle and a pedestrian's device (e.g., smartphone and IoT device).

* 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.

* 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 term 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 augment 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.

3.1. V2V

The use cases of V2V networking discussed in this section include

* Context-aware navigation for safe driving and collision avoidance;

* Collision avoidance service of end systems of Urban Air Mobility (UAM);

* Cooperative adaptive cruise control in a roadway;

* Platooning in a highway;

* Cooperative environment sensing.

The above use cases are examples for using V2V networking, which can be extended to other terrestrial vehicles, river/sea ships, railed vehicles, or UAM end systems.

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.

A collision avoidance service of UAM end systems in air can be envisioned as a use case in air vehicular environments [I-D.templin-ipwave-uam-its]. This use case is similar to the context-aware navigator for terrestrial vehicles. Through V2V coordination, those UAM end systems (e.g., drones) can avoid a dangerous situation (e.g., collision) in three-dimensional space rather than two-dimensional space for terrestrial vehicles. Also, UAM end systems (e.g., flying car) with only a few meters off the ground can communicate with terrestrial vehicles with wireless communication technologies (e.g., DSRC, LTE, and C-V2X). Thus, V2V means any vehicle to any vehicle, whether the vehicles are ground-level or not.

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 support applications of these V2V use cases, the required functions of IPv6 include IPv6-based packet exchange in both control and data planes, and secure, safe communication between two vehicles. For the support of V2V under multiple radio technologies (e.g., DSRC and 5G V2X), refer to Appendix A.

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;

* UAM navigation service with efficient battery charging.

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, 4G-LTE or 5G 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 equivalent project in Europe is called Public Safety Communications Europe (PSCE) [PSCE], which is developing a network for emergency communications.

An EV charging service with V2I can facilitate 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 or be notified that the charging station is out of service through a battery charging server connected to the IP-RSU. In addition to this EV charging service, other value-added services (e.g., firmware/software update over-the-air and media streaming) can be provided to an EV while it is charging its battery at the EV charging station. For a UAM navigation service, an efficient battery charging plan can improve the battery charging schedule of UAM end systems (e.g., drone) for long-distance flying [CBDN]. For this battery charging schedule, a UAM end system can communicate with a cloud server via an infrastructure node (e.g., IP-RSU). This cloud server can coordinate the battery charging schedules of multiple UAM end systems for their efficient navigation path, considering flight time from their current position to a battery charging station, waiting time in a waiting queue at the station, and battery charging time at the station.

In some scenarios such as vehicles moving in highways or staying in parking lots, a V2V2I network is necessary for vehicles to access the Internet since some vehicles may not be covered by an IP-RSU. For those vehicles, a few relay vehicles can help to build the Internet access. For the nested NEMO described in [RFC4888], hosts inside a vehicle shown in Figure 3 for the case of V2V2I may have the same issue in the nested NEMO scenario.

To better support these use cases, the existing IPv6 protocol must be augmented either through protocol changes or by including a new adaptation layer in the architecture that efficiently maps IPv6 to a diversity of link layer technologies. Augmentation is necessary to support wireless multihop V2I communications in a highway where RSUs are sparsely deployed, so a vehicle can reach the wireless coverage of an IP-RSU through the multihop data forwarding of intermediate vehicles as packet forwarders. Thus, IPv6 needs to be extended for multihop V2I communications.

To support applications of these V2I use cases, the required functions of IPv6 include IPv6 communication enablement with neighborhood discovery and IPv6 address management, reachability with adapted network models and routing methods, transport-layer session continuity, and secure, safe communication between a vehicle and an infrastructure node (e.g., IP-RSU) in the vehicular network.

3.3. V2X

The use case of V2X networking discussed in this section is for a vulnerable road user (VRU) (e.g., pedestrian and cyclist) protection service. Note that the application area of this use case is currently limited to a specific environment, such as construction sites, plants, and factories, since not every VRU (e.g., children) in a public area (e.g., streets) is equipped with a smart device (e.g., smartphone, smart watch, and tablet).

A VRU 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, DSRC, 4G/5G V2X, and BLE) 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. The location information of a VRU from a smart device (e.g., smartphone) is multicasted only to the nearby vehicles. The true identifiers of a VRU's smart device shall be protected, and only the type of the VRU, such as pedestrian, cyclist, and scooter, is disclosed to the nearby vehicles.

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. Note that

it is true that either a pedestrian or a cyclist may have a higher risk of being hit by a vehicle if they are not with a smartphone in the current setting. For this case, other human sensing technologies (e.g., moving object detection in images and wireless signal-based human movement detection [LIFS][DFC]) can be used to provide the motion information of them to vehicles. A vehicle by V2V2I networking can obtain the motion information of a VRU via an IP-RSU that either employs or connects to a human sensing technology.

The existing IPv6 protocol must be augmented through protocol changes in order to 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 IP-RSU through the multihop data forwarding of intermediate vehicles (or pedestrians' smartphones) as packet forwarders. Thus, IPv6 needs to be extended for multihop V2X or V2I2X communications.

To support applications of these V2X use cases, the required functions of IPv6 include 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, and the protection of identifiers of either a vehicle or smart device (such as MAC address and IPv6 address), which is discussed in detail in Section 6.3.

4. Vehicular Networks

This section describes the context for vehicular networks supporting V2V, V2I, and V2X communications. 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.

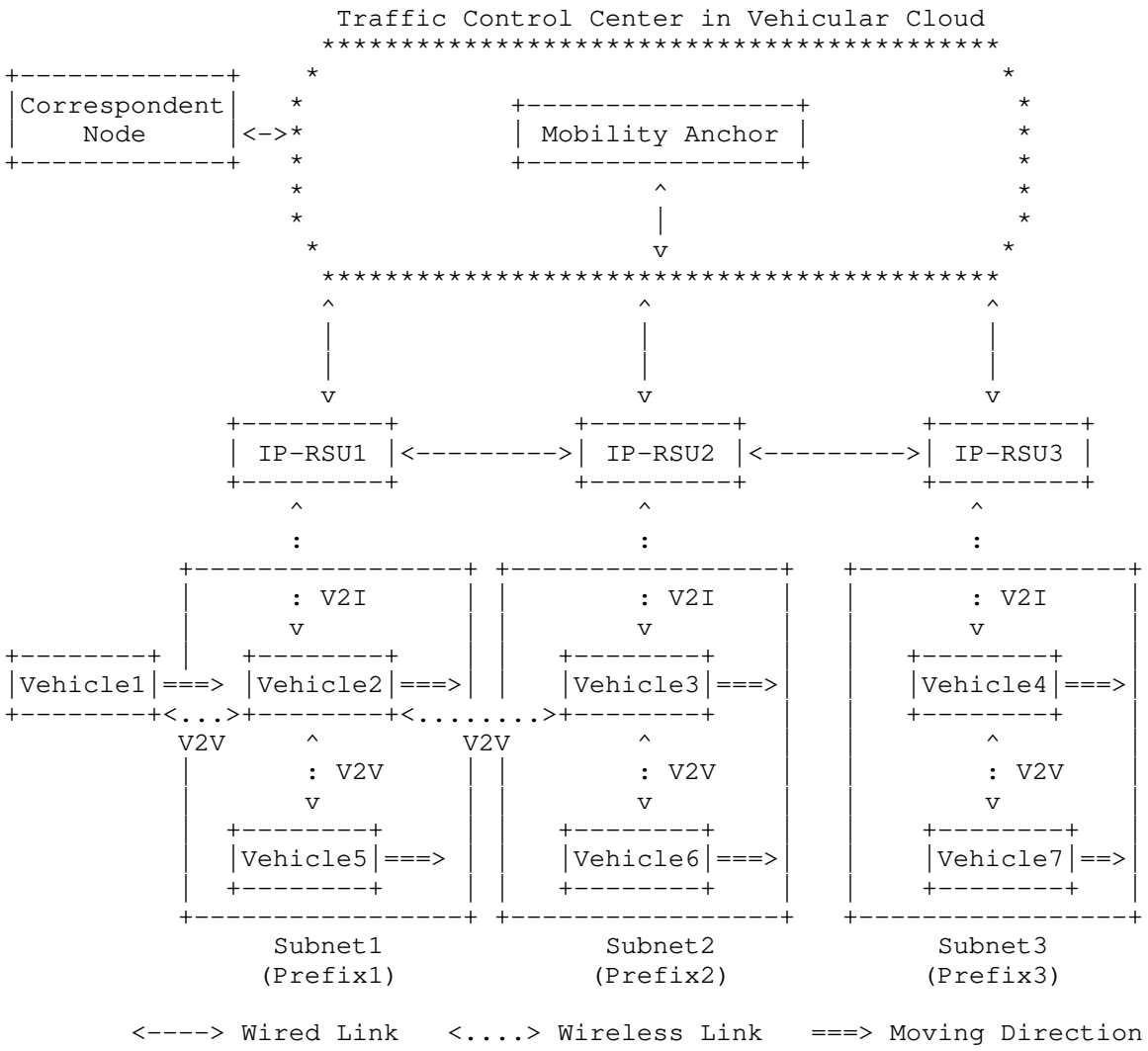

Figure 1: An Example Vehicular Network Architecture for V2I and V2V

4.1. Vehicular Network Architecture

Figure 1 shows an example vehicular network architecture for V2I and V2V in a road network. The vehicular network architecture contains vehicles (including IP-OBU), IP-RSUs, Mobility Anchor, Traffic Control Center, and Vehicular Cloud as 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.

Existing network architectures, such as the network architectures of PMIPv6 [RFC5213], RPL (IPv6 Routing Protocol for Low-Power and Lossy Networks) [RFC6550], and AERO/OMNI [I-D.templin-6man-aero][I-D.templin-6man-omni], can be extended to a vehicular network architecture for multihop V2V, V2I, and V2X, as shown in Figure 1. Refer to Appendix B for the detailed discussion on multihop V2X networking by RPL and OMNI. Also, refer to Appendix A for the description of how OMNI is designed to support the use of multiple radio technologies in V2X. Note that though AERO/OMNI is not actually deployed in the industry, this AERO/OMNI is mentioned as a possible approach for vehicular networks in this document.

As shown in Figure 1, IP-RSUs as routers and vehicles with IP-OBU have wireless media interfaces for VANET. The 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 IP-RSU share a prefix just as 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. Alternatively, mobile nodes can employ a "Bring-Your-Own-Addresses (BYOA)" (or "Bring-Your-Own-Prefix (BYOP)") technique using their own IPv6 Unique Local Addresses (ULAs) [RFC4193] over the wireless network.

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.

As a basic definition 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 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 correspondent 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], NEMO [RFC3963] [RFC4885] [RFC4888], and AERO [I-D.templin-6man-aero]). This document describes issues in mobility management for vehicular networks in Section 5.2. For improving TCP session continuity or successful UDP packet delivery, the multi-path TCP (MPTCP) [RFC8684] or QUIC protocol [RFC9000] can also be used. IP-OBUs, however, may still experience more session time-out and re-establishment procedures due to lossy connections among vehicles caused by the high mobility dynamics of them.

4.2. V2I-based Internetworking

This section discusses the internetworking between a vehicle's internal network (i.e., mobile 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 interactions between the internal network of a vehicle and that of another vehicle or an EN. Note that it is dangerous if the internal network of a vehicle is controlled by a malicious party. These dangers can include unauthorized driving control input and unauthorized driving information disclosure to an unauthorized third party. A malicious party can be a group of hackers, a criminal group, and a competitor for industrial espionage or sabotage. To minimize this kind of risk, an augmented identification and verification protocol, which has an extra means, shall be implemented based on a basic identity verification process. These extra means can be certificate-based, biometric, credit-based, and one-time passcode (OTP) approaches in addition to a used approach [RFC8002]. The parties of the verification protocol can be from a built-in verification protocol in the current vehicle, which is pre-installed by a vehicle vendor. The parties can also be from any verification authorities that have the database of authenticated users. The security properties provided by a verification protocol can be identity-related information, such as the genuineness of an identity, the authenticity of an identity, and the ownership of an identity [RFC7427].

The augmented identification and verification protocol with extra means can support security properties such as the identification and verification of a vehicle, driver, and passenger. First, a credit-based means is to let a vehicle classify the received messages sent by another host to different severity levels for driving safety in order to calculate the credit for the sender. Based on an accumulated credit, a correspondent node can verify the other party to see whether it is genuine or not. Second, a certificate-based means includes a user certificate (e.g., X.509 certificate [RFC5280]) to authenticate a vehicle or its driver. Third, a biometric means includes a fingerprint, face or voice to authenticate a driver or passenger. Lastly, one-time passcode (called OTP) means lets another already-authenticated device (e.g., smartphone and tablet) of a driver or passenger be used to authenticate a driver or passenger.

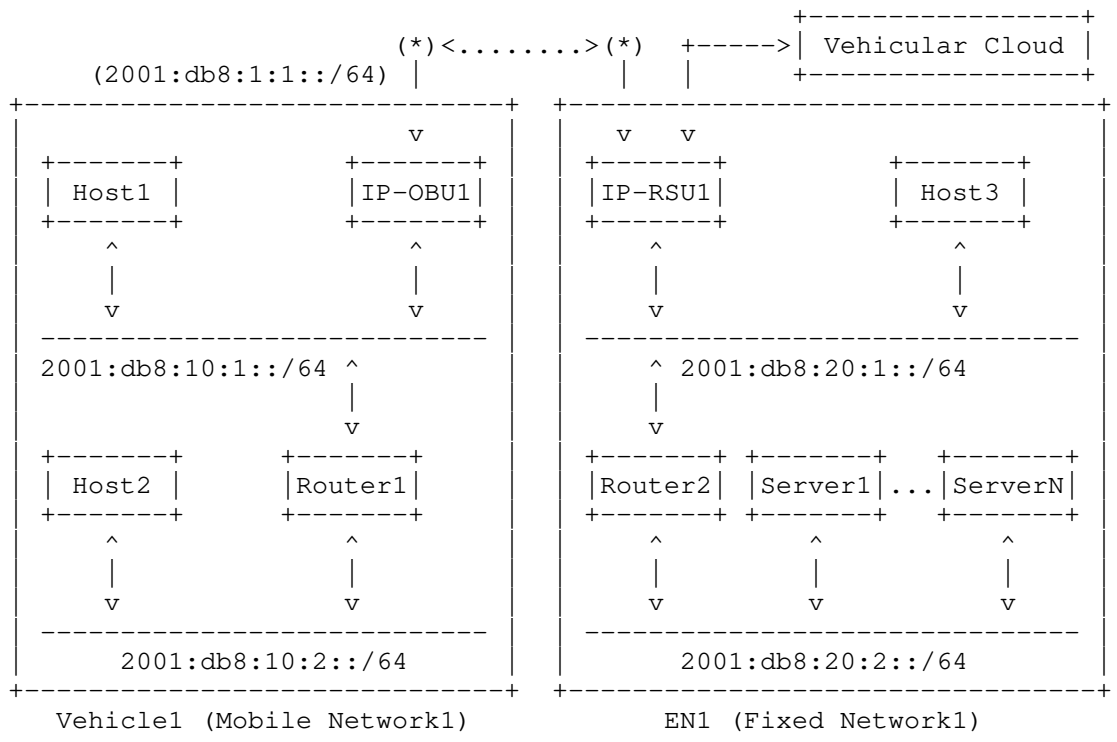

Figure 2: Internetworking between Vehicle and Edge Network

As shown in Figure 2, as internal networks, a vehicle's mobile 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 mobile network) in a vehicle need to be delegated and configured automatically. Note that a mobile network's network prefix can be called a Mobile Network Prefix (MNP) [RFC3963].

Figure 2 also shows the internetworking between the vehicle's mobile network and the EN's fixed network. There exists an internal network (Mobile 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. Note that from a security point of view, a perimeter-based policy enforcement can be applied to protect parts of the internal network of a vehicle.

As shown in Figure 2, the addresses used for IPv6 transmissions over the wireless link interfaces for IP-OBU and IP-RSU can be link-local IPv6 addresses, ULAs, or global IPv6 addresses. When IPv6 addresses are used, wireless interface configuration and control overhead for DAD [RFC4862] and Multicast Listener Discovery (MLD) [RFC2710][RFC3810] should be minimized to support V2I and V2X communications for vehicles moving fast along roadways.

Let us consider the upload/download time of a ground vehicle when it passes through the wireless communication coverage of an IP-RSU. For a given typical setting where 1km is the maximum DSRC communication range [DSRC] and 100km/h is the speed limit in highway for ground vehicles, the dwelling time can be calculated to be 72 seconds by dividing the diameter of the 2km (i.e., two times of DSRC communication range where an IP-RSU is located in the center of the circle of wireless communication) by the speed limit of 100km/h (i.e., about 28m/s). For the 72 seconds, a vehicle passing through the coverage of an IP-RSU can upload and download data packets to/ from the IP-RSU. For special cases such as emergency vehicles moving above the speed limit, the dwelling time is relatively shorter than that of other vehicles. For cases of airborne vehicles, considering a higher flying speed and a higher altitude, the dwelling time can be much shorter.

4.3. V2V-based Internetworking

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

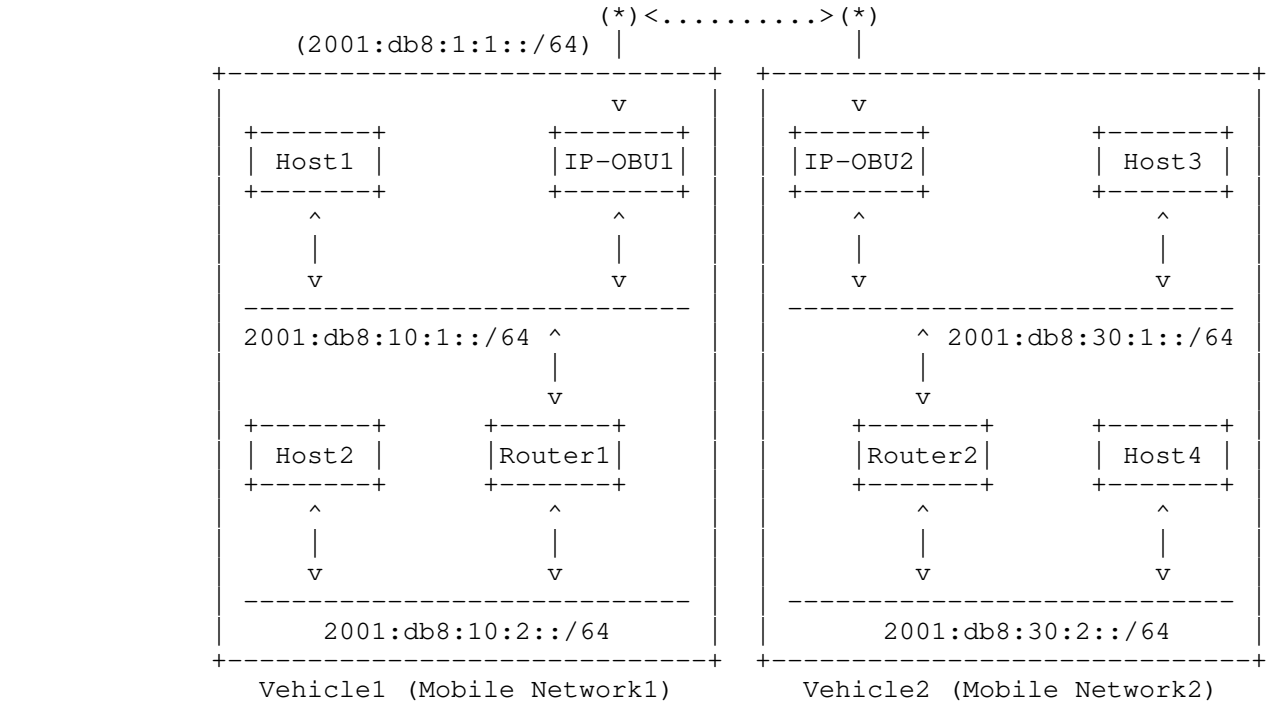

Figure 3: Internetworking between Two Vehicles

Figure 3 shows the internetworking between the mobile networks of two neighboring vehicles. There exists an internal network (Mobile Network1) inside Vehicle1. Vehicle1 has two hosts (Host1 and Host2), and two routers (IP-OBU1 and Router1). There exists another internal network (Mobile 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 mobile network, a wireless link between IP-OBU1 and IP-OBU2, and Vehicle2's mobile network.

As a V2V use case in Section 3.1, Figure 4 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. From a security point of view, before vehicles can be platooned, they shall be mutually authenticated to reduce possible security risks.

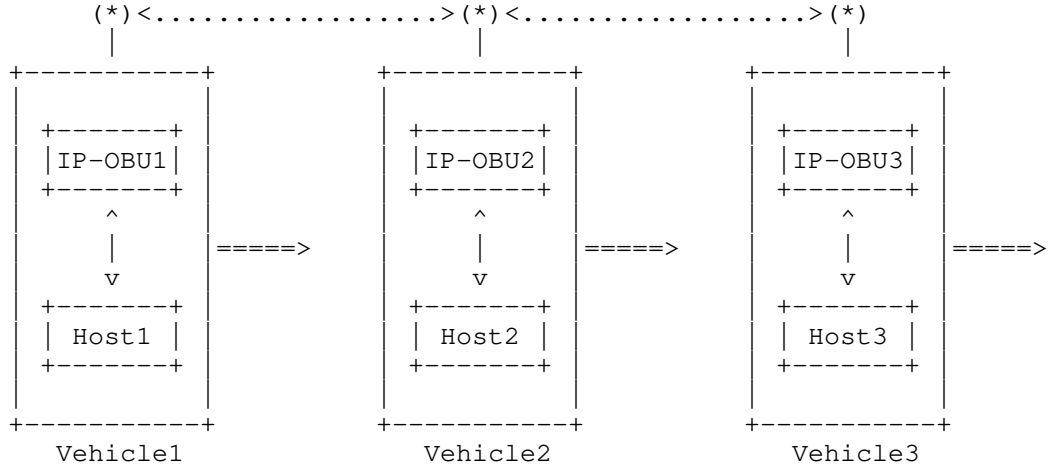

Figure 4: Multihop Internetworking between Two Vehicle Networks

As shown in Figure 4, multihop internetworking is feasible among the mobile 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 VANET, as shown in the figure.

In this section, the link between two vehicles is assumed to be stable for single-hop wireless communication regardless of the sight relationship such as line of sight and non-line of sight, as shown in Figure 3. Even in Figure 4, the three vehicles are connected to each other with a linear topology, however, multihop V2V communication can accommodate any network topology (i.e., an arbitrary graph) over VANET routing protocols.

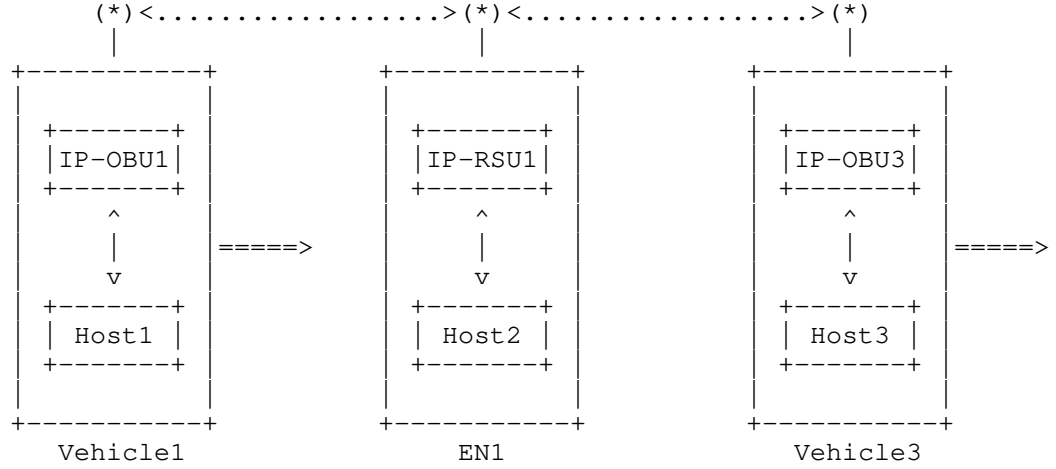

Figure 5: Multihop Internetworking between Two Vehicle Networks via IP-RSU (V2I2V)

As shown in Figure 5, multihop internetworking between two vehicles is feasible via an infrastructure node (i.e., IP-RSU) with wireless connectivity among the mobile networks of two vehicles and the fixed network of an edge network (denoted as EN1) in the same VANET. For example, Host1 in Vehicle1 can communicate with Host3 in Vehicle3 via IP-OBU1 in Vehicle1, IP-RSU1 in EN1, and IP-OBU3 in Vehicle3 in the VANET, as shown in the figure.

For the reliability required in V2V networking, the ND optimization defined in MANET [RFC6130] [RFC7466] improves the classical IPv6 ND in terms of tracking neighbor information with up to two hops and

introducing several extensible Information Bases, which serves the MANET routing protocols such as the different versions of Optimized Link State Routing Protocol (OLSR) [RFC3626] [RFC7181], Open Shortest Path First (OSPF) derivatives (e.g., [RFC5614]), and Dynamic Link Exchange Protocol (DLEP) [RFC8175] with its extensions [RFC8629] [RFC8757]. In short, the MANET ND mainly deals with maintaining extended network neighbors to enhance the link reliability. However, an ND protocol in vehicular networks shall consider more about the geographical mobility information of vehicles as an important resource for serving various purposes to improve the reliability, e.g., vehicle driving safety, intelligent transportation implementations, and advanced mobility services. For a more reliable V2V networking, some redundancy mechanisms should be provided in L3 in cases of the failure of L2. For different use cases, the optimal solution to improve V2V networking reliability may vary. For example, a group of vehicles in platooning may have stabler neighbors than freely moving vehicles, as described in Section 3.1.

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 relatively short time compared to the lifetime of a link between a vehicle and an IP-RSU, or between two vehicles. In these cases, vehicles may not have enough time either to build link-layer connections with each other and may rely more on connections with infrastructure. In other cases, the relative speed between vehicles may be low when vehicles move toward the same direction or are platooned. For those cases, vehicles can have more time to build and maintain connections with each other.

For safe driving, vehicles need to exchange application messages every 0.5 second [NHTSA-ACAS-Report] to let drivers take an action to avoid a dangerous situation (e.g., vehicle collision), so the IPv6 control plane (e.g., ND procedure and DAD) needs to support this order of magnitude for application message exchanges. Also, considering the communication range of DSRC (up to 1km) and 100km/h as the speed limit in highway (some countries can have much higher speed limit or even no limit, e.g., Germany), the lifetime of a link between a vehicle and an IP-RSU is in the order of a minute (e.g., about 72 seconds), and the lifetime of a link between two vehicles is about a half minute. 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 IP-RSU. This relative speed leads the half of the link lifetime between the vehicle and the IP-RSU. In reality, the DSRC communication range is

around 500m, so the link lifetime will be a half of the maximum time. The time constraint of a wireless link between two nodes (e.g., vehicle and IP-RSU) 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, DNS query, and context-aware navigation (in Section 3.1). Regardless of a session's type, to guide all the IPv6 packets to their destination host(s), IP mobility should be supported for the session. In a V2V scenario (e.g., context-aware navigation), the IPv6 packets of a vehicle should be delivered to relevant vehicles efficiently (e.g., multicasting). With this observation, IPv6 protocol exchanges need to be done as short as possible to support the message exchanges of various applications in vehicular networks.

Therefore, 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. Meanwhile, the bandwidth of the wireless link determined by the lower layers (i.e., link and PHY layers) can affect the transmission time of control messages of the upper layers (e.g., IPv6) and the continuity of sessions in the higher layers (e.g., IPv6, TCP, and UDP). Hence, the bandwidth selection according to Modulation and Coding Scheme (MCS) also affects the vehicular network connectivity. Note that usually the higher bandwidth gives the shorter communication range and the higher packet error rate at the receiving side, which may reduce the reliability of control message exchanges of the higher layers (e.g., IPv6). This section presents key topics such as neighbor discovery and mobility management for links and sessions in IPv6-based vehicular networks. Note that the detailed discussion on the transport-layer session mobility and usage of available bandwidth to fulfill the use cases is left as potential future work.

5.1. Neighbor Discovery

IPv6 ND [RFC4861][RFC4862] is a core part of the IPv6 protocol suite. IPv6 ND is designed for link types including point-to-point, multicast-capable (e.g., Ethernet) and Non-Broadcast Multiple Access (NBMA). 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), DAD, MLD 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 IPv6 addresses to 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 DAD packets during a vehicle's travel in a road network, which can guarantee 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 can guarantee 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 be not valid frequently 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]. SLAAC is not compatible with merging and partitioning, and additional work is needed for ND to operate properly under those circumstances. Due to the merging of VANETs, two IPv6 addresses may conflict with each other though they were unique before the merging. An address lookup operation may be conducted by an MA or IP-RSU (as Registrar in RPL) to check the uniqueness of an IPv6 address that will be configured by a vehicle as DAD. Also, the partitioning of a VANET may make vehicles with the same prefix be physically unreachable. An address lookup operation may be conducted by an MA or IP-RSU (as Registrar in RPL) to check the existence of a vehicle under the network coverage of the MA or IP-RSU as NUD. Thus, SLAAC needs to prevent IPv6 address duplication due to the merging of VANETs, and IPv6 ND needs to detect unreachable neighboring vehicles due to the partitioning of a VANET. According to the merging and partitioning, a destination vehicle (as an IPv6 host) needs to be distinguished as either an on-link host or a not-onlink host even though the source vehicle can use the same prefix as the destination vehicle [I-D.ietf-intarea-ippl].

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.

For vehicular networks with high mobility and density, DAD needs to be performed efficiently with minimum overhead so that the vehicles can exchange driving safety messages (e.g., collision avoidance and accident notification) with each other with a short interval suggested by NHTSA (National Highway Traffic Safety Administration) [NHTSA-ACAS-Report]. Since the partitioning and merging of vehicular networks may require re-perform DAD process repeatedly, the link scope of vehicles may be limited to a small area, which may delay the exchange of driving safety messages. Driving safety messages can include a vehicle's mobility information (i.e., position, speed, direction, and acceleration/deceleration) that is critical to other vehicles. The exchange interval of this message is recommended to be less than 0.5 second, which is required for a driver to avoid an emergency situation, such as a rear-end crash.

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. The ND time-related parameters can be an operational setting or an optimization point particularly for vehicular networks. Note that the link-scope multicast messages in ND protocol may cause the performance issue in vehicular networks. [RFC9119] suggests several optimization approaches for the issue.

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. [I-D.jeong-ipwave-vehicular-neighbor-discovery] introduces a Vehicular Neighbor Discovery (VND) process as an extension of IPv6 ND for IP-based vehicular networks.

From the interoperability point of view, in IPv6-based vehicular networking, IPv6 ND should have minimum changes with the legacy IPv6 ND used in the Internet, including DAD and NUD operations, so that IPv6-based vehicular networks can be seamlessly connected to other intelligent transportation elements (e.g., traffic signals, pedestrian wearable devices, electric scooters, and bus stops) that use the standard IPv6 network settings.

5.1.1. Link Model

A subnet 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 subnet 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.
[I-D.thubert-6man-ipv6-over-wireless] introduces other issues in an IPv6 subnet model.

IPv6 protocols work under certain assumptions that do not necessarily hold for vehicular wireless access link types [VIP-WAVE][RFC5889]. For instance, some IPv6 protocols such as NUD [RFC4861] and MIPv6 [RFC6275] assume symmetry in the connectivity among neighboring interfaces. However, radio interference and different levels of transmission power may cause asymmetric links to appear in vehicular wireless links [RFC6250]. 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, unique-local, and global types of IPv6 addresses. In an IPv6 link, it is defined 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 4. 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. Considering that two vehicles in the same VANET configure their IPv6 addresses with the same IPv6 prefix, if they are not in one hop (that is, they have the multihop network connectivity between them), then they may not be able to communicate with each other. 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 4.

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 not-onlink 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 not-onlink. In most cases in vehicular networks, due to the partitioning and merging of VANETs, and the multihop network topology of VANETS, not-onlink prefixes will be used for vehicles as default.

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 interoperability with standard IPv6 links efficiently to support IPv6 DAD, MLD 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].

Note that [I-D.ietf-madinas-mac-address-randomization] discusses more about MAC address randomization, and [I-D.ietf-madinas-use-cases] describes several use cases for MAC address randomization.

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 DAD procedure.

5.1.3. Routing

For multihop V2V communications in either a VANET or VANETs via IP-RSUs, a vehicular Mobile Ad Hoc Networks (MANET) routing protocol 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 [RFC9119].

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.

RPL [RFC6550] defines a routing protocol for low-power and lossy networks, which constructs and maintains Destination-Oriented Directed Acyclic Graphs (DODAGs) optimized by an Objective Function (OF). A defined OF provides route selection and optimization within an RPL topology. The RPL nodes use an anisotropic Distance Vector (DV) approach to form a DODAG by discovering and aggressively maintaining the upward default route toward the root of the DODAG. Downward routes follow the same DODAG, with lazy maintenance and stretched Peer-to-Peer (P2P) routing in the so-called storing mode. It is well-designed to reduce the topological knowledge and routing state that needs to be exchanged. As a result, the routing protocol overhead is minimized, which allows either highly constrained stable networks or less constrained, highly dynamic networks. Refer to Appendix B for the detailed description of RPL for multihop V2X networking.

An address registration extension for 6LoWPAN (IPv6 over Low-Power Wireless Personal Area Network) in [RFC8505] can support light-weight mobility for nodes moving through different parents. [RFC8505], as opposed to [RFC4861], is stateful and proactively installs the ND

cache entries, which saves broadcasts and provides deterministic presence information for IPv6 addresses. Mainly it updates the Address Registration Option (ARO) of ND defined in [RFC6775] to include a status field that can indicate the movement of a node and optionally a Transaction ID (TID) field, i.e., a sequence number that can be used to determine the most recent location of a node. Thus, RPL can use the information provided by the Extended ARO (EARO) defined in [RFC8505] to deal with a certain level of node mobility. When a leaf node moves to the coverage of another parent node, it should de-register its addresses to the previous parent node and register itself with a new parent node along with an incremented TID.

RPL can be used in IPv6-based vehicular networks, but it is primarily designed for low-power networks, which puts energy efficiency first. For using it in IPv6-based vehicular networks, there have not been actual experiences and practical implementations, though it was tested in IoT low-power and lossy networks (LLN) scenarios. Another concern is that RPL may generate excessive topology discovery messages in a highly moving environment such as vehicular networks. This issue can be an operational or optimization point for a practitioner.

Moreover, due to bandwidth and energy constraints, RPL does not suggest using a proactive mechanism (e.g., keepalive) to maintain accurate routing adjacencies such as Bidirectional Forwarding Detection [RFC5881] and MANET Neighborhood Discovery Protocol [RFC6130]. As a result, due to the mobility of vehicles, network fragmentation may not be detected quickly and the routing of packets between vehicles or between a vehicle and an infrastructure node may fail.

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 GNSS receiver as part of a dedicated navigation system or a corresponding smartphone App. Note that the GNSS 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 GNSS receiver for location information.

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

Even though the SLAAC with classic ND costs a DAD during mobility management, the SLAAC with [RFC8505] and/or AERO/OMNI do not cost a DAD. SLAAC for vehicular networks needs to consider the minimization of the cost of DAD with the help of an infrastructure node (e.g., IP-RSU and MA). Using an infrastructure prefix over VANET allows direct routability to the Internet through the multihop V2I toward an IP-RSU. On the other hand, a BYOA does not allow such direct routability to the Internet since the BYOA is not topologically correct, that is, not routable in the Internet. In addition, a vehicle configured with a BYOA needs a tunnel home (e.g., IP-RSU) connected to the Internet, and the vehicle needs to know which neighboring vehicle is reachable inside the VANET toward the tunnel home. There is non-negligible control overhead to set up and maintain routes to such a tunnel home [RFC4888] over the VANET.

For the case of a multihomed network, a vehicle can follow the first-hop router selection rule described in [RFC8028]. For example, an IP-OBU inside a vehicle may connect to an IP-RSU that has multiple routers behind. In this scenario, because the IP-OBU can have multiple prefixes from those routers, the default router selection, source address selection, and packet redirect process should follow the guidelines in [RFC8028]. That is, the vehicle should select its default router for each prefix by preferring the router that advertised the prefix.

Vehicles can use the TCC as their Home Network having a home agent for mobility management as in MIPv6 [RFC6275], PMIPv6 [RFC5213], and NEMO [RFC3963], so the TCC (or an MA inside the TCC) maintains the mobility information of vehicles for location management. Also, in vehicular networks, asymmetric links sometimes exist and must be considered for wireless communications such as V2V and V2I. [I-D.jeong-ipwave-vehicular-mobility-management] discusses a Vehicular Mobility Management (VMM) scheme to proactively do handover for vehicles.

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 paramount in V2I, V2V, and V2X networking along with neighbor discovery and mobility management.

Vehicles and infrastructure must be authenticated to each other by a password, a key, and/or a fingerprint in order to participate in vehicular networking. For the authentication in vehicular networks, vehicular cloud needs to support a Public Key Infrastructure (PKI) efficiently, as either a dedicated or a co-located component inside a TCC. To provide safe interaction between vehicles or between a vehicle and infrastructure, only authenticated nodes (i.e., vehicle and infrastructure node) can participate in vehicular networks. 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 securely. Even though a vehicle is perfectly authenticated by another entity and legitimate to use the data

generated by another vehicle, 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. Note that when driver/passenger's mobile devices are connected to a vehicle's internal network, the vehicle may be more vulnerable to possible attacks from external networks due to the exposure of its in-flight traffic packets. [I-D.jeong-ipwave-security-privacy] discusses several types of threats for Vehicular Security and Privacy (VSP).

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 2 [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 3.

For secure V2I/V2V 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). Note that any key management approach can be used for the secure communication, and particularly for IPv6-based vehicular networks, a new or enhanced key management approach resilient to wireless networks is required.

IEEE 1609.2 [WAVE-1609.2] specifies security services for applications and management messages, but this WAVE specification is optional. Thus, if the link layer 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.

6.1. Security Threats in Neighbor Discovery

For the classical IPv6 ND (i.e., the legacy ND), 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. [RFC6959] introduces threats enabled by IP source address spoofing. This possibility indicates that vehicles and IP-RSUs need to filter out suspicious ND traffic in advance. [RFC8928] introduces a mechanism that protects the ownership of an address for 6loWPAN ND from address theft and impersonation attacks. Based on the SEND [RFC3971] mechanism, the authentication for routers (i.e., IP-RSUs) can be conducted by only selecting an IP-RSU that has a certification path toward trusted parties. For authenticating other vehicles, cryptographically generated addresses (CGA) can be used to verify the

true owner of a received ND message, which requires using the CGA ND option in the ND protocol. This CGA can protect vehicles against DAD flooding by DAD filtering based on the verification for the true owner of the received DAD message. For a general protection of the ND mechanism, the RSA Signature ND option can also be used to protect the integrity of the messages by public key signatures. For a more advanced authentication mechanism, a distributed blockchain-based approach [Vehicular-BlockChain] can be used. However, for a scenario where a trustable router or an authentication path cannot be obtained, it is desirable to find a solution in which vehicles and infrastructures can authenticate each other without any support from a third party.

When applying the classical IPv6 ND process to VANET, one of the security issues is that an IP-RSU (or an IP-OBU) as a router may receive deliberate or accidental DoS attacks from network scans that probe devices on a VANET. In this scenario, the IP-RSU can be overwhelmed for processing the network scan requests so that the capacity and resources of IP-RSU are exhausted, causing the failure of receiving normal ND messages from other hosts for network address resolution. [RFC6583] describes more about the operational problems in the classical IPv6 ND mechanism that can be vulnerable to deliberate or accidental DoS attacks and suggests several implementation guidelines and operational mitigation techniques for those problems. Nevertheless, for running IPv6 ND in VANET, those issues can be more acute since the movements of vehicles can be so diverse that it leaves a large room for rogue behaviors, and the failure of networking among vehicles may cause grave consequences.

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. Since cybersecurity issues in vehicular networks may cause physical vehicle safety issues, it may be necessary to consider those physical security concerns when designing protocols in IPWAVE.

To identify malicious vehicles among vehicles, an authentication method may be required. A Vehicle Identification Number (VIN) (or a vehicle manufacturer certificate) 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 2, 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.

6.2. Security Threats in Mobility Management

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).

6.3. Other Threats

For the setup of a secure channel over IPsec or TLS, the multihop V2I communications over DSRC or 5G V2X (or LTE V2X) is required in a highway. In this case, multiple intermediate vehicles as relay nodes can help to forward association and authentication messages toward an IP-RSU (gNodeB or eNodeB) connected to an authentication server in the vehicular cloud. In this kind of process, the authentication messages forwarded by each vehicle can be delayed or lost, which may increase the construction time of a connection or some vehicles may not be able to be authenticated.

Even though vehicles can be authenticated with valid certificates by an authentication server in the vehicular cloud, the authenticated vehicles may harm other vehicles. To deal with this kind of security issue, for monitoring suspicious behaviors, vehicles' communication activities can be recorded in either a centralized approach through a logging server (e.g., TCC) in the vehicular cloud or a decentralized approach (e.g., an edge computing device and blockchain [Bitcoin]) by the help of other vehicles and infrastructure.

There are trade-offs between centralized and decentralized approaches in logging for vehicles' behaviors (e.g., location, speed, direction, acceleration, deceleration, and lane change) and communication activities (e.g., transmission time, reception time, and packet types such as TCP, UDP, SCTP, QUIC, HTTP, and HTTPS). A centralized approach is more efficient than a decentralized approach in terms of logging data collection and processing in a central server in the vehicular cloud. However, the centralized approach may cause a higher delay than a decentralized approach in terms of the analysis of the logging data and counteraction in a local edge computing device or a distributed database like a blockchain. The centralized approach stores logging data collected from VANET into a remote logging server in a vehicular cloud as a central cloud, so it takes time to deliver the logging data to a remote logging server. On the other hand, the decentralized approach stores the logging data into a nearby edge computing device as a local logging server or a nearby blockchain node, which participates in a blockchain network. On the stored logging data, an analyzer needs to perform a machine learning technique (e.g., Deep Learning) and seek suspicious behaviors of the vehicles. If such an analyzer is located either within or near the edge computing device, it can access the logging data with a short delay, analyze it quickly, and generate feedback to allow for a quick counteraction against such malicious behaviors. On the other hand, if the vehicular cloud with the logging data is far away from a problematic VANET with malicious behaviors, the centralized approach takes a long time with the analysis with the logging data and the decision-making on malicious behaviors than the decentralized approach. If the logging data is encrypted by a secret key, it can be protected from the observation of a hacker. The secret key sharing among legal vehicles, edge computing devices, and vehicular clouds should be supported efficiently.

Logging information can release privacy breakage of a vehicle. The logging information can contain the MAC address and IPv6 address for a vehicle's wireless network interface. If the unique MAC address of the wireless network interface is used, a hacker can track the vehicle with that MAC address, so can track the privacy information of the vehicle's driver (e.g., location information). To prevent this privacy breakage, a MAC address pseudonym can be used for the MAC address of the wireless network interface, and the corresponding IPv6 address should be based on such a MAC address pseudonym. By solving a privacy issue of a vehicle's identity in logging, vehicles may observe activities of each other to identify any misbehavior without privacy breakage. Once identifying a misbehavior, a vehicle shall have a way to either isolate itself from others or isolate a suspicious vehicle by informing other vehicles.

For completely secure vehicular networks, we shall embrace the concept of "zero-trust" for vehicles in which no vehicle is trustable and verifying every message (such as IPv6 control messages including ND, DAD, NUD, and application layer messages) is necessary. In this way, vehicular networks can defense many possible cyberattacks. Thus, we need to have an efficient zero-trust framework or mechanism for the vehicular networks.

For the non-repudiation of the harmful activities from malicious vehicles, which it is difficult for other normal vehicles to identify them, an additional and advanced approach is needed. One possible approach is to use a blockchain-based approach [Bitcoin] as an IPv6 security checking framework. Each IPv6 packet 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 [Bitcoin] [Vehicular-BlockChain]. For a blockchain's efficient consensus in vehicular networks having fast moving vehicles, a new consensus algorithm needs to be developed, or an existing consensus algorithm needs to be enhanced. In addition, a consensus-based mechanism for the security of vehicular networks in the IPv6 layer can also be considered. A group of servers as blockchain infrastructure can be part of the security checking process in the IP layer.

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][RFC8981]. 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.

The privacy exposure to the TCC and via V2I is mostly about the location information of vehicles, and may also include other in-vehicle activities such as transactions of credit cards. The assumed, trusted actors are the owner of a vehicle, an authorized vehicle service provider (e.g., navigation service provider), and an authorized vehicle manufacturer for providing after-sales services. In addition, privacy concerns for excessively collecting vehicle activities from roadway operators such as public transportation administrators and private contractors may also pose threats on

violating privacy rights of vehicles. It might be interesting to find a solution from a technology point of view along with public policy development for the issue.

The "multicasting" of the location information of a VRU's smartphone means IPv6 multicasting. There is a possible security attack related to this multicasting. Attackers can use "fake identifiers" as source IPv6 addresses of their devices to generate IPv6 packets and multicast them to nearby vehicles in order to make a confusion that those vehicles are surrounded by other vehicles or pedestrians. As a result, navigation services (e.g., Google Maps [Google-Maps] and Waze [Waze]) can be confused with fake road traffic by those vehicles or smartphones with "fake identifiers" [Fake-Identifier-Attack]. This attack with "fake identifiers" should be detected and handled by vehicular networks. To cope with this attack, both legal vehicles and legal VRUs' smartphones can be registered with a traffic control center (called TCC) and their locations can be tracked by the TCC. With this tracking, the TCC can tell the road traffic conditions caused by those vehicles and smartphones. In addition, to prevent hackers from tracking the locations of those vehicles and smartphones, either a MAC address pseudonym [I-D.ietf-madinas-mac-address-randomization] or secure IPv6 address generation [RFC7721] can be used to protect the privacy of those vehicles and smartphones.

7. IANA Considerations

This document does not require any IANA actions.

8. References

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Appendix A. Support of Multiple Radio Technologies for V2V

Vehicular networks may consist of multiple radio technologies such as DSRC and 5G V2X. Although a Layer-2 solution can provide support for multihop communications in vehicular networks, the scalability issue related to multihop forwarding still remains when vehicles need to disseminate or forward packets toward multihop-away destinations. In addition, the IPv6-based approach for V2V as a network layer protocol can accommodate multiple radio technologies as MAC protocols, such as DSRC and 5G V2X. Therefore, the existing IPv6 protocol can be augmented through the addition of a virtual interface (e.g., OMNI [I-D.templin-6man-omni] and DLEP [RFC8175]) and/or protocol changes in order to support both wireless single-hop/multihop V2V communications and multiple radio technologies in vehicular networks. In such a way, vehicles can communicate with each other by V2V communications to share either an emergency situation or road hazard information in a highway having multiple kinds of radio technologies.

Appendix B. Support of Multihop V2X Networking

The multihop V2X networking can be supported by RPL (IPv6 Routing Protocol for Low-Power and Lossy Networks) [RFC6550] and Overlay Multilink Network Interface (OMNI) [I-D.templin-6man-omni] with AERO [I-D.templin-6man-aero] .

RPL defines an IPv6 routing protocol for low-power and lossy networks (LLN), mostly designed for home automation routing, building automation routing, industrial routing, and urban LLN routing. It uses a Destination-Oriented Directed Acyclic Graph (DODAG) to construct routing paths for hosts (e.g., IoT devices) in a network. The DODAG uses an objective function (OF) for route selection and optimization within the network. A user can use different routing metrics to define an OF for a specific scenario. RPL supports multipoint-to-point, point-to-multipoint, and point-to-point traffic, and the major traffic flow is the multipoint-to-point traffic. For example, in a highway scenario, a vehicle may not access an IP-RSU directly because of the distance of the DSRC coverage (up to 1 km). In this case, the RPL can be extended to support a multihop V2I since a vehicle can take advantage of other vehicles as relay nodes to reach the IP-RSU. Also, RPL can be extended to support both multihop V2V and V2X in the similar way.

RPL is primarily designed to minimize the control plane activity, which is the relative amount of routing protocol exchanges versus data traffic; this approach is beneficial for situations where the power and bandwidth are scarce (e.g., an IoT LLN where RPL is typically used today), but also in situations of high relative mobility between the nodes in the network (also known as swarming, e.g., within a variable set of vehicles with a similar global motion, or a variable set of drones flying toward the same direction).

To reduce the routing exchanges, RPL leverages a Distance Vector (DV) approach, which does not need a global knowledge of the topology, and only optimizes the routes to and from the root, allowing Peer-to-Peer (P2P) paths to be stretched. Although RPL installs its routes proactively, it only maintains them lazily, that is, in reaction to actual traffic, or as a slow background activity. Additionally, RPL leverages the concept of an objective function (called OF), which allows adapting the activity of the routing protocol to use cases, e.g., type, speed, and quality of the radios. RPL does not need converge, and provides connectivity to most nodes most of the time. The default route toward the root is maintained aggressively and may change while a packet progresses without causing loops, so the packet will still reach the root. There are two modes for routing in RPL such as non-storing mode and storing mode. In non-storing mode, a node inside the mesh/swarm that changes its point(s) of attachment to the graph informs the root with a single unicast packet flowing along the default route, and the connectivity is restored immediately; this mode is preferable for use cases where Internet connectivity is dominant. On the other hand, in storing mode, the routing stretch is reduced, for a better P2P connectivity, while the Internet connectivity is restored more slowly, during the time for the DV operation to operate hop-by-hop. While an RPL topology can quickly scale up and down and fits the needs of mobility of vehicles, the total performance of the system will also depend on how quickly a node can form an address, join the mesh (including Authentication, Authorization, and Accounting (AAA)), and manage its global mobility to become reachable from another node outside the mesh.

OMNI defines a protocol for the transmission of IPv6 packets over Overlay Multilink Network Interfaces that are virtual interfaces governing multiple physical network interfaces. OMNI supports multihop V2V communication between vehicles in multiple forwarding hops via intermediate vehicles with OMNI links. It also supports multihop V2I communication between a vehicle and an infrastructure access point by multihop V2V communication. The OMNI interface supports an NBMA link model where multihop V2V and V2I communications use each mobile node's ULAs without need for any DAD or MLD Messaging.

In OMNI protocol, an OMNI virtual interface can have a ULA [RFC4193] indeed, but wireless physical interfaces associated with the OMNI virtual interface are using any prefix. The ULA supports both V2V and V2I multihop forwarding within the vehicular network (e.g., via a VANET routing protocol) while each vehicle can communicate with Internet correspondents using global IPv6 addresses via OMNI interface encapsulation over the wireless interface.

For the control traffic overhead for running both vehicular ND and a VANET routing protocol, the AERO/OMNI approach may avoid this issue by using MANET routing protocols only (i.e., no multicast of IPv6 ND messaging) in the wireless underlay network while applying efficient unicast IPv6 ND messaging in the OMNI overlay on an as-needed basis for router discovery and NUD. This greatly reduces the overhead for VANET-wide multicasting while providing agile accommodation for dynamic topology changes.

Appendix C. Support of Mobility Management for V2I

The seamless application communication between two vehicles or between a vehicle and an infrastructure node requires mobility management in vehicular networks. The mobility management schemes include a host-based mobility scheme, network-based mobility scheme, and software-defined networking scheme.

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][I-D.ietf-dmm-fpc-cpdp]. Note that Forwarding Policy Configuration (FPC) in [I-D.ietf-dmm-fpc-cpdp], 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.

Appendix D. Support of MTU Diversity for IP-based Vehicular Networks

The wireless and/or wired-line links in paths between both mobile nodes and fixed network correspondents may configure a variety of Maximum Transmission Units (MTUs), where all IPv6 links are required to support a minimum MTU of 1280 octets and may support larger MTUs. Unfortunately, determining the path MTU (i.e., the minimum link MTU in the path) has proven to be inefficient and unreliable due to the uncertain nature of the loss-oriented ICMPv6 messaging service used for path MTU discovery. Recent developments have produced a more reliable path MTU determination service for TCP [RFC4821] and UDP [RFC8899] however the MTUs discovered are always limited by the most restrictive link MTU in the path (often 1500 octets or smaller).

The AERO/OMNI service addresses the MTU issue by introducing a new layer in the Internet architecture known as the "OMNI Adaptation Layer (OAL)". The OAL allows end systems that configure an OMNI interface to utilize a full 65535 octet MTU by leveraging the IPv6 fragmentation and reassembly service during encapsulation to produce fragment sizes that are assured of traversing the path without loss due to a size restriction. (This allows end systems to send packets that are often much larger than the actual path MTU.)

Performance studies over the course of many decades have proven that applications will see greater performance by sending smaller numbers of large packets (as opposed to larger numbers of small packets) even if fragmentation is needed. The OAL further supports even larger

packet sizes through the IP Parcels construct [I-D.templin-intarea-parcels] which provides "packets-in-packet" encapsulation for a total size up to 4MB. Together, the OAL and IP Parcels will provide a revolutionary new capability for greater efficiency in both mobile and fixed networks. On the other hand, due to the high dynamics of vehicular networks, a high packet loss may not be able to be avoided. The high packet loss on IP parcels can simultaneously cause multiple TCP sessions to experience packet re-transmissions, session time-out, or re-establishment of the sessions. Other protocols such as MPTCP and QUIC may also experience the similar issue. A mechanism for mitigating this issue in OAL and IP Parcels should be considered.

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TLS Authentication using ETSI TS 103 097 and IEEE 1609.2 certificates
draft-tls-certieee1609-02.txt

Abstract

This document specifies the use of a new certificate type to authenticate TLS entities. The first type enables the use of a certificate specified by the Institute of Electrical and Electronics Engineers (IEEE) and the European Telecommunications Standards Institute (ETSI).

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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Table of Contents

1. Introduction

The TLS protocol [RFC8446] [RFC5246] uses X509 and Raw Public Key in order to authenticate servers and clients. This document describes the use of certificates specified either by the Institute of Electrical and Electronics Engineers (IEEE) [IEEE1609.2] or the European Telecommunications Standards Institute (ETSI) [TS103097]. It is worth mentioning that the ETSI TS 103097 certificate is a profile of IEEE 1609.2 certificate and uses the same data structure. These standards are defined in order to secure communications in vehicular environments. Existing authentication methods, such as X509 and Raw Public Key, are designed for Internet use, particularly for flexibility and extensibility, and are not optimized for bandwidth and processing time to support delay-sensitive applications. That is why size-optimized certificates were standardized by ETSI and IEEE to secure data exchange in highly dynamic vehicular environment in Intelligent Transportation System (ITS).

2. Requirements Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3. Extension Overview

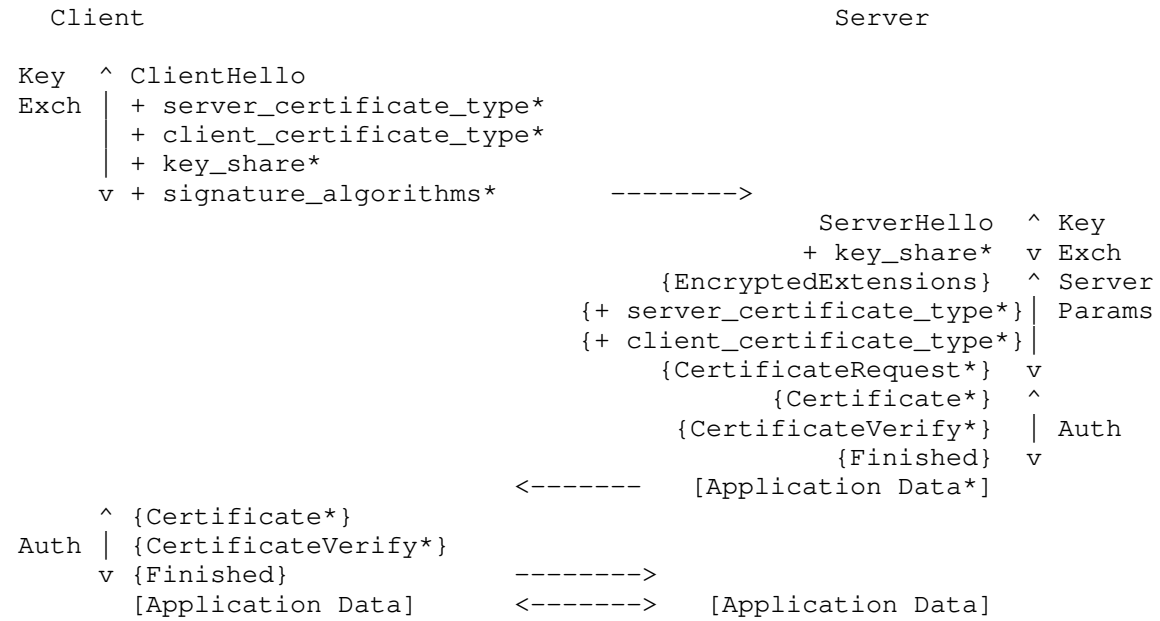
This specification extends the Client Hello and Server Hello messages, by using the "extension_data" field of the ClientCertType Extension and the ServerCertType Extension structures defined in RFC7250. In order to negotiate the support of IEEE 1609.2 or ETSI TS 103097 certificate-based authentication, the clients and the servers MAY include the extension of type "client_certificate_type" and "server_certificate_type" in the extended Client Hello and "EncryptedExtensions". The "extension_data" field of this extension SHALL contain a list of supported certificate types proposed by the client as provided in the figure below:

```
  /* Managed by IANA */
   enum {
       X509(0),
       RawPublicKey(2),
       1609Dot2(?), /* Number 3 will be requested for 1609.2 */
       (255)
   } CertificateType;

   struct {
       select (certificate_type) {

           /* certificate type defined in this document.*/
            case 1609Dot2:
            opaque cert_data<1..2^24-1>;

            /* RawPublicKey defined in RFC 7250*/
           case RawPublicKey:
           opaque ASN.1_subjectPublicKeyInfo<1..2^24-1>;

           /* X.509 certificate defined in RFC 5246*/
           case X.509:
           opaque cert_data<1..2^24-1>;

            };

         Extension extensions<0..2^16-1>;
      } CertificateEntry;
```

In case where the TLS server accepts the described extension, it selects one of the certificate types in the extension described above. Note that a server MAY authenticate the client using other authentication methods. The end-entity certificate's public key has to be compatible with one of the certificate types listed in the extension described above.

4. TLS Client and Server Handshake

The "client_certificate_type" and "server_certificate_type" extensions MUST be sent in handshake phase as illustrated in Figure 1 below. The same extension shall be sent in Server Hello for TLS 1.2.



+ Indicates noteworthy extensions sent in the previously noted message.

* Indicates optional or situation-dependent messages/extensions that are not always sent.

{} Indicates messages protected using keys derived from a [sender]_handshake_traffic_secret.

[] Indicates messages protected using keys derived from [sender]_application_traffic_secret_N.

Figure 1: Message Flow with certificate type extension for Full TLS 1.3 Handshake

4.1. Client Hello

In order to indicate the support of IEEE 1609.2 or ETSI TS 103097 certificates, client MUST include an extension of type "client_certificate_type" and "server_certificate_type" in the extended Client Hello message. The Hello extension is described in Section 4.1.2 of TLS 1.3 [RFC8446].

The extension 'client_certificate_type' sent in the client hello MAY carry a list of supported certificate types, sorted by client preference. It is a list in the case where the client supports multiple certificate types.

Client MAY respond along with supported certificates by sending a "Certificate" message immediately followed by the "CetificateVerify" message. These specifications are valid for TLS 1.2 and TLS 1.3.

All implementations SHOULD be prepared to handle extraneous certificates and arbitrary orderings from any TLS version, with the exception of the end-entity certificate which MUST be first.

4.2. Server Hello

When the server receives the Client Hello containing the client_certificate_type extension and/or the server_certificate_type extension, the following options are possible:

- The server supports the extension described in this document. It selects a certificate type from the client_certificate_type field in the extended Client Hello and must take into account the client authentication list priority.

- The server does not support the proposed certificate type and terminates the session with a fatal alert of type "unsupported_certificate".

- The server does not support the extension defined in this document. In this case, the server returns the server hello without the extensions defined in this document in case of TLS 1.2.

- The server supports the extension defined in this document, but it does not have any certificate type in common with the client. Then, the server terminates the session with a fatal alert of type "unsupported_certificate".

- The server supports the extensions defined in this document and has at least one certificate type in common with the client. In this case, the server MUST include the client_certificate_type extension in the Server Hello for TLS 1.2 or in Encrypted Extension for TLS 1.3. Then, the server requests a certificate from the client (via the certificate_request message)

It is worth to mention that the TLS client or server public keys are obtained from a certificate chain from a web page.

5. Certificate Verification

Verification of an IEEE 1609.2/ ETSI TS 103097 certificates or certificate chain is described in section 5.5.2 of [IEEE1609.2].

6. Examples

Some of exchanged messages examples are illustrated in Figures 2 and 3.

6.1. TLS Server and TLS Client use the 1609Dot2 Certificate

This section shows an example where the TLS client as well as the TLS server use the IEEE 1609.2 certificate. In consequence, both the server and the client populate the client_certificate_type and server_certificate_type with extension IEEE 1609.2 certificates as mentioned in figure 2.

Figure 2: TLS Client and TLS Server use the IEEE 1609.2 certificate

6.2. TLS Client uses the IEEE 1609.2 certificate and TLS Server uses the X 509 certificate

This example shows the TLS authentication, where the TLS Client populates the server_certificate_type extension with the X509 certificate and Raw Public Key type as presented in figure 3. the client indicates its ability to receive and to validate an X509 certificate from the server. The server chooses the X509 certificateto make its authentication with the Client.

Figure 3: TLS Client uses the IEEE 1609.2 certificate and TLS Server uses the X 509 certificate

7. Security Considerations

This section provides an overview of the basic security considerations which need to be taken into account before implementing the necessary security mechanisms. The security considerations described throughout [RFC8446] and [RFC5246] apply here as well.

For security considerations in a vehicular environment, the minimal use of any TLS extensions is recommended such as :

The "client_certificate_type" [IANA value 19] extension who's purpose was previously described in [RFC7250].

The "server_certificate_type" [IANA value 20] extension who's purpose was previously described in [RFC7250].

The "SessionTicket" [IANA value 35] extension for session resumption.

In addition, servers SHOULD not support renegotiation [RFC5746] which presented Man-In-The-Middle (MITM) type attacks over the past years for TLS 1.2.

8. Privacy Considerations

For privacy considerations in a vehicular environment the use of EEE 1609.2/ETSI TS 103097 certificate is recommended for many reasons:

In order to address the risk of a personal data leakage, messages exchanged for V2V communications are signed using IEEE 1609.2/ETSI TS 103097 pseudonym certificates

The purpose of these certificates is to provide privacy relying on geographical and/or temporal validity criteria, and minimizing the exchange of private data

9. IANA Considerations

Existing IANA references have not been updated yet to point to this document.

IANA is asked to register a new value in the "TLS Certificate Types" registry of Transport Layer Security (TLS) Extensions [TLS-Certificate-Types-Registry], as follows:

- Value: TBD Description: 1609Dot2 Reference: [THIS RFC]

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IPv6 Neighbor Discovery for IP-Based Vehicular Networks
draft-xiang-ipwave-vehicular-neighbor-discovery-00

Abstract

This document specifies a Vehicular Neighbor Discovery (VND) as an extension of IPv6 Neighbor Discovery (ND) for IP-based vehicular networks. An optimized Address Registration and a multihop Duplicate Address Detection (DAD) mechanism are established for both operation efficiency and the saving of wireless bandwidth and vehicle energy. Also, the two new ND options for a rapid prefix and service discovery are used to announce the network prefixes and services inside a vehicle (i.e., a vehicle's internal network). Finally, a mobility management scheme is proposed for moving vehicles in vehicular environments to support seamless communication for the continuity of transport-layer sessions (e.g., TCP connections).

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Table of Contents

1. Introduction

Vehicular Ad Hoc Networks (VANET) have been researched for Intelligent Transportation System (ITS) such as driving safety, efficient driving and entertainment. Considering the high-speed mobility of vehicular network based on Dedicated Short-Range Communications (DSRC), IEEE 802.11p [IEEE-802.11p] has been specialized and was renamed IEEE 802.11 Outside the Context of a Basic Service Set (OCB) [IEEE-802.11-OCB] in 2012. IEEE has standardized Wireless Access in Vehicular Environments (WAVE) [DSRC-WAVE] standard which is considered as a key component in ITS. The IEEE 1609 standards such as IEEE 1609.0 [WAVE-1609.0], 1609.2

[WAVE-1609.2], 1609.3 [WAVE-1609.3], 1609.4 [WAVE-1609.4] provide a low-latency and alternative network for vehicular communications. What is more, IP-based vehicular networks specialized as IP Wireless Access in Vehicular Environments (IPWAVE) [IPWAVE-PS] can enable many use cases over vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) communications.

VANET features high mobility dynamics, asymmetric and lossy connections, and moderate power constraint (e.g., electric cars and unmanned aerial vehicles). Links among hosts and routers in VANET can be considered as undetermined connectivities with constantly changing neighbors described in [RFC5889]. IPv6 [RFC8200] is selected as the network-layer protocol for Internet applications by IEEE 1609.0 and 1609.3. However, the relatively long-time Neighbor Discovery (ND) process in IPv6 [RFC4861] is not suitable in VANET scenarios.

To support the interaction between vehicles or between vehicles and Rode-Side Unit (RSU), this document specifies a Vehicular Neighbor Discovery (VND) as an extension of IPv6 ND for IP-based vehicular networks. VND provides vehicles with an optimized Address Registration, a multihop Duplicate Address Detection (DAD), and an efficient mobility management scheme to support efficient V2V, V2I, and V2X communications.

2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

3. Terminology

This document uses the terminology described in [RFC4861], [RFC4862], and [RFC6775]. In addition, the following new terms are defined as below:

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

- 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.

- Mobility Anchor (MA): A node that maintains IP addresses and mobility information of vehicles in a road network to support the address autoconfiguration and mobility management of them. It has end-to-end connections with RSUs under its control. It maintains a DAD table having the IP addresses of the vehicles moving within the communication coverage of its RSUs.

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

- 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 and has MAs under its management.

4. Overview

This document proposes an optimized ND, which has a more adaptive structure for vehicular networks considering fast vehicle mobility and wireless control traffic overhead related to the ND. Further more, prefix and service discovery can be implemented as part of the ND's process along with an efficient Address Registration procedure and DAD mechanism for moving vehicles. This document specifies a set of behaviors between vehicles and RSUs to accomplish these goals.

4.1. Link Model

There is a relationship between a link and a network prefix along with reachability scopes, such as link-local and global scopes. The legacy IPv6 ND protocol [RFC4861] has the following link model. All IPv6 nodes in the same on-link subnet, which use the same subnet prefix with on-link bit set, are reachable with each other by one-hop link. The symmetry of the connectivity among the nodes is preserved, that is, bidirectional connectivity among two on-link nodes. On the other hand, a link model in vehicular networks (called vehicular link model) should consider the asymmetry of the connectivity that unidirectional links can exist due to interference in wireless

channels and the different levels of transmission power in wireless network interfaces.

The on-link subnet can be constructed by one link (as a basic service set) or multiple links (as an extended service set) called a multi-link subnet [RFC6775]. In the legacy multi-link subnet, an all-node-multicasted packet is copied and related to other links by an ND proxy. On the other hand, in vehicular networks having fast moving vehicles, multiple links can share the same subnet prefix for operation efficiency. For example, if two wireless links under two adjacent RSUs are in the same subnet, a vehicle as an IPv6 host does not need to reconfigure its IPv6 address during handover between those RSUs. However, the packet relay by an RSU as an ND proxy is not required because such a relay can cause a broadcast storm in the extended subnet. Thus, in the multi-link subnet, all-node-multicasting needs to be well-calibrated to either being confined to multicasting in the current link or being disseminated to other links in the same subnet.

In a connected multihop VANET, for the efficient communication, vehicles in the same link of an RSU can communicate directly with each other, not through the relay of the RSU. This direct wireless communication is similar to the direct wired communication in an on-link subnet using Ethernet as a wired network. The vehicular link model needs to accommodate both the ad-hoc communication between vehicles and infrastructure communication between a vehicle and an RSU in an efficient and flexible way.

Therefore, the IPv6 ND should be extended to accommodate the concept of a new IPv6 link model in vehicular networks.

4.2. ND Optimization

This document takes advantage of the optimized ND for Low-Power Wireless Personal Area Network (6LoWPAN) [RFC6775] because vehicular environments have common parts with 6LoWPAN, such as the reduction of unnecessary wireless traffic by multicasting and the energy saving in battery. Note that vehicles tend to be electric vehicles whose energy source is from their battery.

In the optimized IPv6 ND for 6LoWPAN, the connections among nodes are assumed to be asymmetric and unidirectional because of changing radio environment and loss signal. The authors proposed an improved IPv6 ND which greatly eliminates link-scope multicast to save energy by constructing new options and a new scheme for address configurations. Similarly, this document proposes an improved IPv6 ND by eliminating many link-scope-multicast-based ND operations, such as DAD for IPv6 Stateless Address Autoconfiguration (SLAAC) [RFC4862].

Thus, this document suggests an extension of IPv6 ND as vehicular ND tailored for vehicular networks along with new ND options (e.g., prefix discovery, service discovery, and mobility information options).

4.3. Design Goals

The vehicular ND in this document has the following design goals:

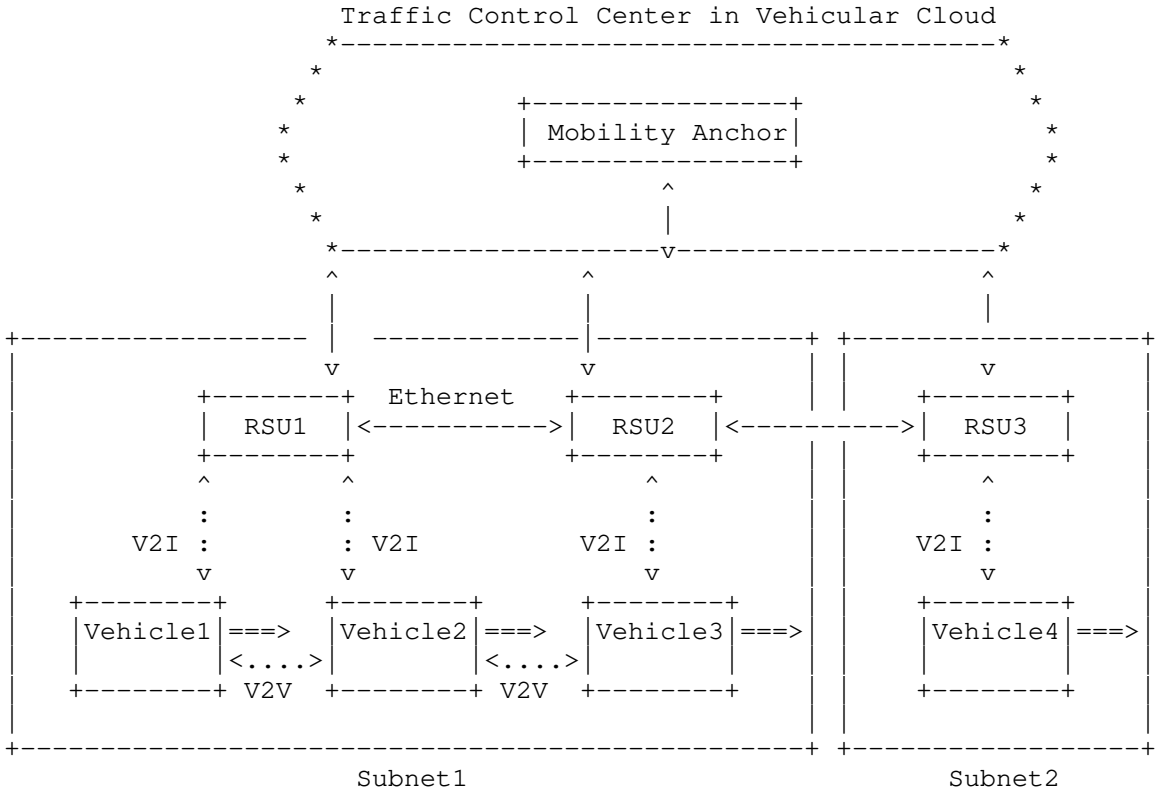
- To perform prefix and service discovery through ND procedure;
- To implement host-initiated refresh of Router Advertisement (RA) and remove the need for routers to use periodic or unsolicited multicast RA to find hosts;
- To create Neighbor Cache Entries (NCE) for all registered vehicles in RSUs by adding Address Registration Option (ARO) in Neighbor Solicitation (NS), Neighbor Advertisement (NA) messages;
- To support a multihop DAD with two new ICMPv6 messages called Duplicate Address Request(DAR) and Duplicate Address Confirmation(DAC) to eliminate multicast storm and save energy; and
- To provide a mobility management mechanism for seamless communication during a vehicle’s travel in subnets via RSUs.

5. Network Architecture

This section describes a vehicular network architecture for V2V and V2I communication as well as an example message interaction for ND scheme designed in this document.

5.1. Vehicular Network Architecture

A vehicular network architecture for V2V and V2I is illustrated in Figure 1. Three RSUs are deployed along roadside and are connected to an MA through wired links. There are two subnets such as Subnet1 and Subnet2. The wireless links of RSU1 and RSU2 belong to the same subnet named Subnet1, but the wireless link of RSU3 belongs to another subnet named Subnet2. Vehicle1 and Vehicle2 are wirelessly connected to RSU1 while Vehicle3 and Vehicle4 are connected to RSU2 and RSU3, respectively. Vehicles can directly communicate with each other through V2V connection (e.g., Vehicle1 and Vehicle2) to share driving information. Vehicles are assumed to start the connection to an RSU when they entered the coverage of the RSU.



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

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

The document recommends a multi-link subnet involving multiple RSUs, as shown in Figure 1. This recommendation aims at the reduction of the frequency with which vehicles have to change their IP address during handover between two adjacent RSUs. When they pass through RSUs in the same subnet, vehicles do not need to perform the Address Registration and DAD again because they can use their current IP address in the wireless coverage of the next RSU, belonging to the same subnet. On the other hand, if they enter the wireless coverage of an RSU belonging to another subnet with a different prefix, vehicles repeat the Address Registration and DAD procedure to update their IP address with the new prefix.

In Figure 1, RSU1 and RSU2 are deployed in the a multi-link subnet with the same prefix in their address. When vehicle1 leaves the coverage of RSU1 and enters RSU2, it maintains its address and ignores Address Registration and DAD steps. If vehicle1 moves into

the coverage of RSU3, since RSU3 belongs to another subnet and holds a different prefix from RSU1 and RSU2, so vehicles must do Address Registration and DAD just as connecting to a new RSU. Note that vehicles and RSUs have their internal networks having in-vehicle devices and servers, respectively. The structures of the internal networks are described in [IPWAVE-PS].

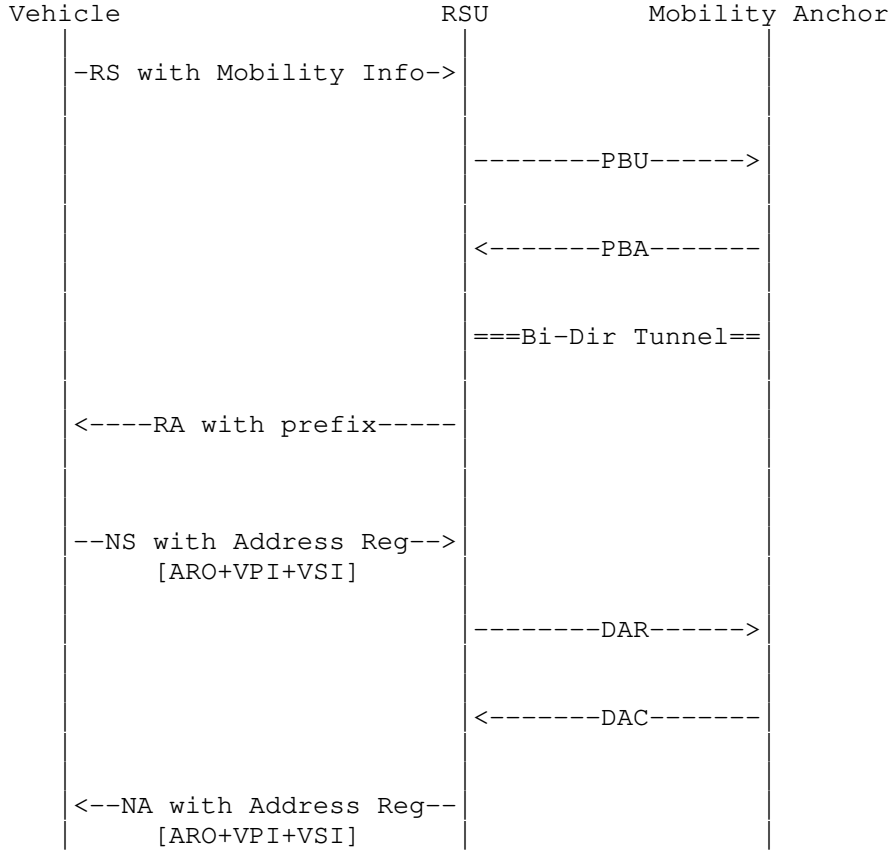


Figure 2: Message Interaction for Vehicular Neighbor Discovery

5.2. Message Exchange Procedure

Figure 2 shows an example of message exchange procedure in vehicular networks. The detailed steps of the procedure are explained in Section 6, Section 7, and Section 8.

Note that RSUs as routers do not transmit periodical and unsolicited multicast RA messages including a prefix for energy saving in vehicular networks. Vehicles as hosts periodically initiate an RS

message according to a time interval (considering its position and an RSU's coverage). Note that since they have a digital road map with the information of RSUs (e.g., position and communication coverage), vehicles can know when they will go out of the communication range of an RSU along with the signal strength (e.g., Received Channel Power Indicator (RCPI) [VIP-WAVE]) from the RSU. RSUs replies with a solicited RA in unicast only when they receive an RS message.

6. ND Extension for Prefix and Service Discovery

In this document, prefix and service discovery can be achieved via ND messages (e.g., NS and NA) by vehicular ND, which eliminates an additional prefix and service discovery scheme, such as DNS-based Service Discovery [RFC6763] (e.g., Multicast DNS (mDNS) [RFC6762] and DNSNA [ID-DNSNA]), other than ND.

6.1. New Options in Vehicular Neighbor Discovery

Two new ND options for prefix and service discovery are defined in [Vehicular-ND-Discovery]: (i) the Vehicular Prefix Information (VPI) Option and (ii) the Vehicular Service Information (VSI) Option are employed in this process. The formats of VPI and VSI are defined in Section 5.2 and Section 5.3 of [Vehicular-ND-Discovery].

6.2. Prefix and Service Discovery

Prefix discovery enables hosts (e.g., vehicles and in-vehicle devices) to distinguish destinations on the same link from those only reachable via RSUs. A vehicle (or its in-vehicle devices) can directly communicate with on-link vehicles (or their in-vehicle devices) without the relay of an RSU, but through V2V communications along with VPI ND option. This VPI option contains IPv6 prefixes in a vehicle's internal network.

Vehicles announce services in their internal networks to other vehicles through an VSI ND option. The VSI option contains a list of vehicular services in a vehicle's or an RSU's internal network.

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

Note that a vehicle could also perform the prefix and service discovery simultaneously along with Address Registration procedure, as shown in Figure 4.

7. Address Registration and Duplicate Address Detection

This section explains address configuration, consisting of IP Address Autoconfiguration, Address Registration, and multihop DAD.

This document recommends a new Address Registration and DAD scheme in order to avoid multicast flooding and decrease link-scope multicast for energy and wireless channel conservation on a large-scale vehicular network. Host-initiated refresh of RA removes the need for routers to use periodic and unsolicited multicast RAs to accommodate hosts. This also enables the same IPv6 address prefix(es) to be used across a subnet.

There are two scenarios about Address Registration part. If they have already configured their IP addresses with the prefix obtained from the previous RSU, and the current RSU located in the same subnet as the previous RSU, which means that they have the same prefix, then vehicles have no need to repeat the Address Registration and multihop DAD. However, if the current RSU belongs to another subnet, vehicles need to perform the Address Registration and multihop DAD in the following subsections.

7.1. Address Autoconfiguration

A vehicle as an IPv6 host creates its link-local IPv6 address and global IPv6 address as follows [RFC4862]. When they receive RS messages from vehicles, RSUs send back RA messages containing prefix information. The vehicle makes its global IPv6 addresses by combining the prefix for its current link and its link-layer address.

The address autoconfiguration does not perform the legacy DAD as defined in [RFC4862]. Instead, a new multihop DAD is performed in Section 7.3.

7.2. Address Registration

After its IP tentative address autoconfiguration with the known prefix from an RSU and its link-layer address, a vehicle starts to register its IP address to the serving RSU along with multihop DAD. Address Register Option (ARO) is used in this step and its format is defined in [RFC6775].

ARO is always host-initiated by vehicles. The information contained in ARO becomes included in multihop Duplicate Address Request (DAR) and Duplicate Address Confirmation (DAC) messages used between RSU and MA, but ARO is not directly used in these two messages.

An example message exchange procedure of Address Registration is presented in Figure 3. Since Address Registration is performed simultaneously with the multihop DAD, the specific procedure is together described with the DAD mechanism in Section 7.3.

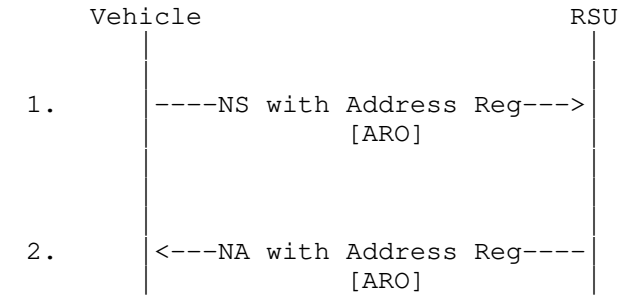


Figure 3: Neighbor Discovery Address Registration

7.3. Multihop Duplicate Address Detection

Before it can exchange data, a node should determine whether its IP address is already used by another node or not. In the legacy IPv6 ND, hosts multicast NS messages to all nodes in the same on-link subnet for DAD. Instead of this, an optimized multihop DAD is designed to eliminate multicast messages for energy-saving purpose. For this multihop DAD, Neighbor Cache and DAD Table are maintained by each RSU and an MA, respectively, for the duplicate address inspection during the multihop DAD process. That is, each RSU makes Neighbor Cache Entries (NCE) of all the on-link hosts in its Neighbor Cache. Similarly, the MA stores all the NCEs reported by the RSUs in its DAD Table.

With the multihop DAD, a vehicle can skip the multicast-based DAD in its current wireless link whenever it enters the coverage of another RSU in the same subset, leading to the reduction of traffic overhead in vehicular wireless links.

For the multihop DAD, two new ICMPv6 message types are defined in [RFC6775], such as Duplicate Address Request (DAR) and the Duplicate Address Confirmation (DAC). Information carried by ARO options are copied into these two messages for the multihop DAD in the MA.

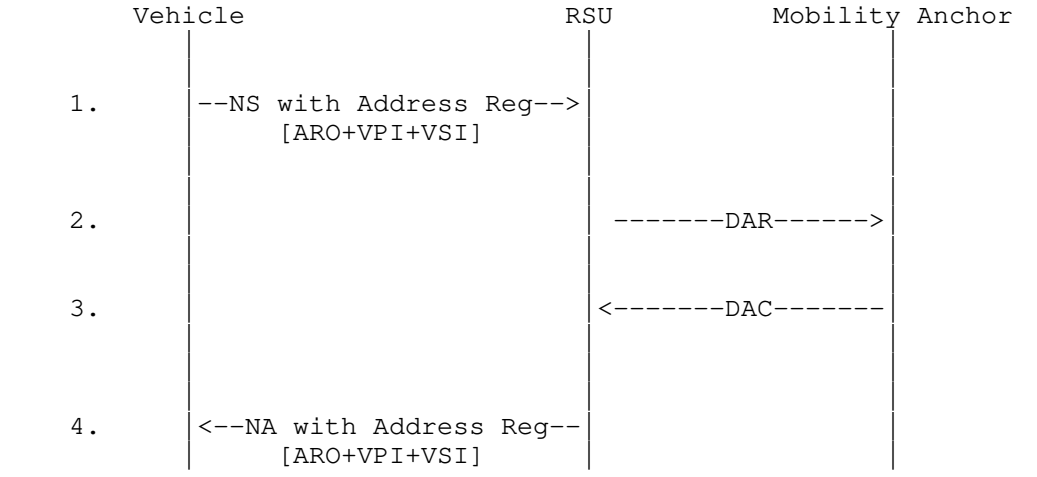


Figure 4: Neighbor Discovery Address Registration with Multihop DAD

Figure 4 presents the procedure of Address Registration and multihop DAD. The detailed steps are explained as follows.

1. A vehicle sends an NS message to the current RSU in unicast, containing the ARO to RSU to register its address.

2. The RSU receives the NS message, and then inspects its Neighbor Cache to check whether it is duplicate or not. If there is no duplicate NCE, a tentative NCE is created for this address, and then the RSU sends a DAR to the MA for the multicast DAD.

3. When the MA receives a DAR from an RSU, it checks whether the register-requested address exists in its DAD Table or not. If an entry with the same address exists in the DAD Table, which means that the address is considered "Duplicate Address", then MA returns a DAC message to notify the RSU of the address duplication. If no entry with the same address exists in the DAD Table, which means that an entry for the address is created, then MA replies a DAC message to the RSU to confirm the uniqueness of the register-requested address to the RSU.

4. If the address duplication is notified by the MA, the RSU deletes the tentative NCE, and sends back an NS to the address-registration vehicle to notify the registration failure. Otherwise, the RSU changes the tentative NCE into a registered NCE in its Neighbor Cache, and then send back an NS to the vehicle to notify the registration success.

Thus, the multihop DAD is processed simultaneously with the Address Registration. Note that the tentative address is not considered assigned to the vehicle until the MA confirms the uniqueness of the register-requested address in the multihop DAD.

7.4. Pseudonym Handling

Considering the privacy protection of a vehicle, a pseudonym mechanism for its link-layer address is requested. This mechanism periodically modifies the link-layer address, leading to the update of the corresponding IP address. A random MAC Address Generation mechanism is proposed in Appendix F.4 of [IEEE-802.11-OCB] by generating the 46 remaining bits of MAC address using a random number generator. When it changes its MAC address, a vehicle should ask the serving RSU to update its own NCE, and to register its IP address into the MA again.

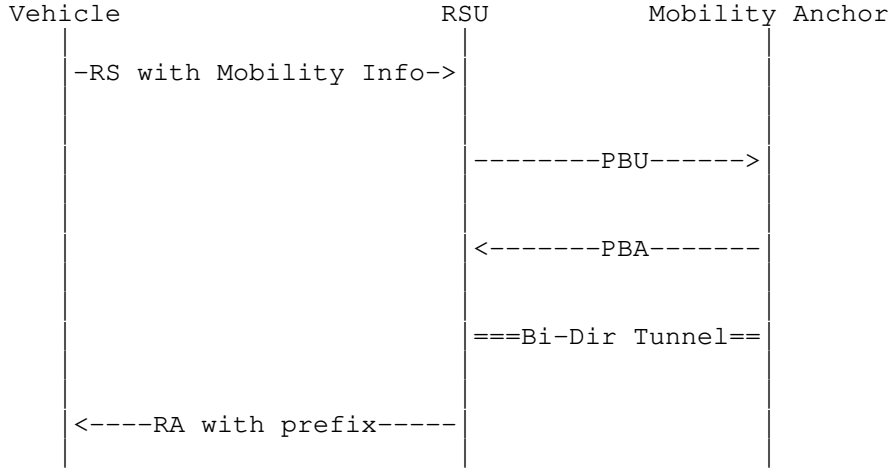


Figure 5: Message Interaction for Vehicle Attachment

8. Mobility Management

A mobility management is required for the seamless communication of vehicles moving between the RSUs. When a vehicle moves into the coverage of another RSU, a different IP address is assigned to the vehicle, resulting in the reconfiguration of transport-layer session information (i.e., end-point IP address) to avoid service disruption. Considering this issue, this document proposes a handover mechanism for seamless communication.

In [VIP-WAVE], the authors constructed a network-based mobility management scheme using Proxy Mobile IPv6 (PMIPv6) [RFC5213], which is highly suitable to vehicular networks. This document uses a mobility management procedure similar to PMIPv6 along with prefix discovery.

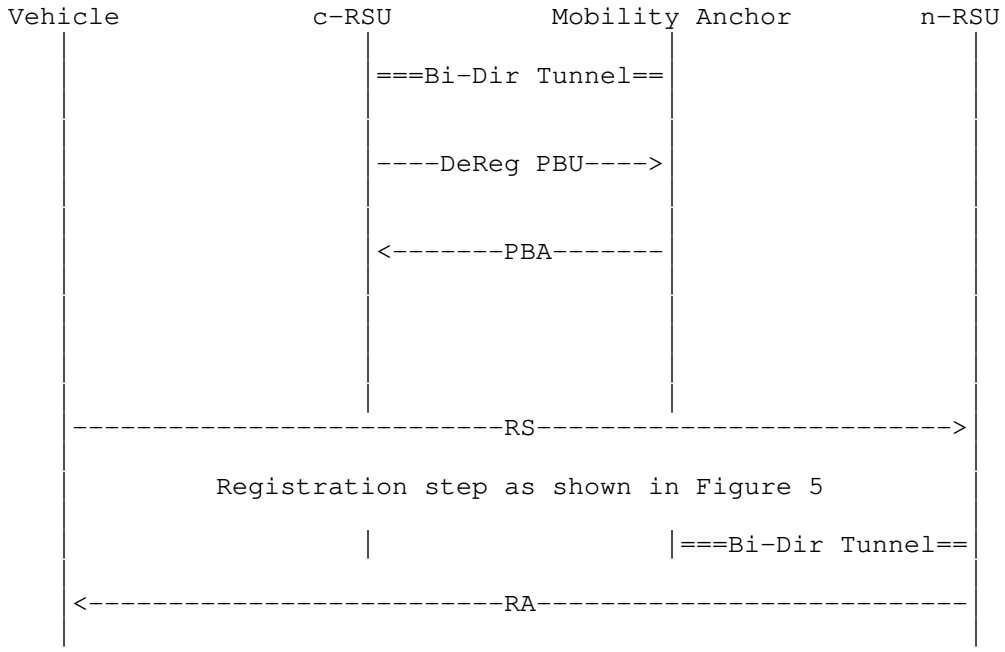


Figure 6: Message Interaction for Vehicle Handoff

Figure 5 shows the binding update flow when a vehicle entered the subnet of an RSU. RSUs act as Mobility Anchor Gateway (MAG) defined in [VIP-WAVE]. When it receives RS messages from a vehicle containing its mobility information (e.g., position, speed, and direction), an RSU sends its MA a Proxy Binding Update (PBU) message [RFC5213][RFC3775], which contains a Mobility Option for the vehicle's mobility information. The MA receives the PBU and sets up a Binding Cache Entry (BCE) as well as a bi-directional tunnel (denoted as Bi-Dir Tunnel in Figure 5) between the serving RSU and itself. Through this tunnel, all traffic packets to the vehicle are encapsulated toward the RSU. Simultaneously, the MA sends back a Proxy Binding Acknowledgment (PBA) message to the serving RSU. This serving RSU receives the PBA and sets up a bi-directional tunnel with the MA. After this binding update, the RSU sends back an RA message to the vehicle including its own prefix for the address autoconfiguration.

When the vehicle changes its location, the MA has to change the end-point of the tunnel for the vehicle into the new RSU's IP address. As shown in Figure 6, when the MA receives a new PBU from the new RSU, it changes the tunnel's end-point from the current RSU (c-RSU) to the new RSU (n-RSU). If there is ongoing IP packets toward the vehicle, the MA encapsulates the packets and then forwards them towards the new RSU. Through this network-based mobility management, the vehicle is not aware of any changes at its network layer and can maintain its transport-layer sessions without any disruption.

9. Security Considerations

This document shares all the security issues of the neighbor discovery protocol and 6LoWPAN protocol. This document can get benefits from secure neighbor discovery (SEND) [RFC3971] in order to protect ND from possible security attacks.

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