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► **To cite this version:**

Choi Jinhyeock, Yacine Khaled, Manabu Tsukada, Thierry Ernst. IPv6 support for VANET with geographical routing. Intelligent Transport System Telecommunicaitons, Oct 2008, Phuket, Thailand. 2008. <inria-00336450>

HAL Id: inria-00336450

<https://hal.inria.fr/inria-00336450>

Submitted on 26 Jan 2009

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IPv6 support for VANET with geographical routing

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Abstract— IPv6 support is needed in vehicular ad hoc network (VANET) with geographical routing. Basic IPv6 protocols such as address auto-configuration assume multicast capable link. However, in VANET, link becomes fuzzy and it is difficult to support link-scope multicast. Artificial emulation of multicast capable link like Ethernet is possible but may cause low efficiency and high cost. A new way to efficiently run IPv6 over VANET is needed and this paper proposes such a scheme. Our proposal takes C2C-CC scenario as a reference system and exploits C2C-CC inherent features to perform IPv6 operations without link-scope multicast.

I. INTRODUCTION

Next generation vehicles are expected to exchange information with other vehicles and road side infrastructure for safety and non-safety applications. Through vehicle ad hoc network (VANET), vehicles will communicate each other in order to anticipate trajectories, coordinate merging maneuvers and avoid a traffic accident. In this context, a vehicle's actual position and trajectory information is important and, sometimes, even only meaningful factor for the communication. It's generally accepted that position-based routing is useful for VANET environments [12]. Position-based routing or geographic routing makes a forwarding decision based on the geographic location of communication peers such as source, destination and neighbors.

VANET should support IPv6. The advantage of IP is that it enables diverse communication technologies to interoperate and easily accommodates existing and future applications. ITS usage will require uninterrupted and transparent access to Internet. There are several activities to combine IPv6 and geonetworking. Inside EU, GeoNet project is launched to integrate geonetworking into IPv6 [10]. [3] proposes a scheme to run IPv6 over geonetworking layer by emulating Ethernet link. [18] defines a new option to carry geographic information in IPv6 packet. However it's not clear how to combine IPv6 and geonetworking in VANET environments. The problem is that basic IPv6 protocols such as RFC 4861 [15], [17] are written for multicast capable link, i.e. a link that supports a native mechanism at the link layer for sending packets to all or some neighbors. VANET lacks such a native link-scope multicast and, even, clear link boundary.

This paper present a new way to run IPv6 in VANET environment. Instead of emulation, we relies on geonetworking specific features for IPv6 operation. Our solution exploits inherent location managements functions to efficiently perform basic IPv6 protocols, i.e. Neighbor Discovery [15] and Stateless Address Autoconfiguration [17].

The organization of the paper is as follows: Section II describes Car2Car communication consortium (C2C-CC) [6] approach which is our reference system. Section III provides the requirements and objective for our proposal with brief solution sketch. Section IV and Section V gives the detailed procedures for IP configuration and IP packet delivery respectively. Section VI concludes the paper.

II. C2C-CC ARCHITECTURE

We consider Car-to-Car Communication Consortium (C2C-CC) [6] scenario as reference to this paper. The main objective of C2C-CC is to ensure car-to-car and multi-hop communication for both safety and non-safety and with taking into consideration both availability and non-availability of infrastructure.

C2C-CC is designing a separate network protocol [6] different from Internet Protocol (IP). C2C protocol is tailored for vehicular environments and would rely on position-based routing. This protocol would define a separate C2C header with a separate C2C identifier, tentatively 64-bit length, identifying C2C node. C2C header is planned to carry source C2C identifier, destination C2C identifier, source geographic location and destination geographic location.

C2C-CC also requires IPv6 support for its system to run such applications as infotainment. This demands results in including IPv6 stack in the main protocol architecture as depicted in Figure 1.

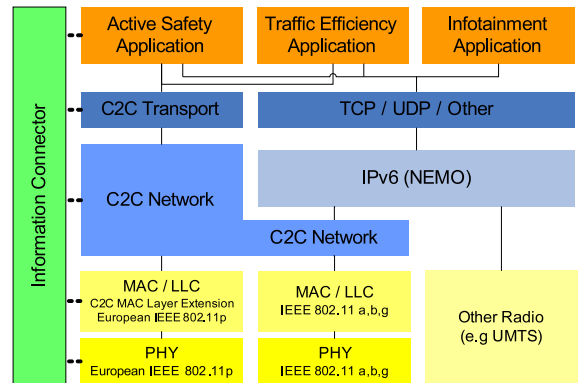


Fig. 1. C2C-CC Architecture

Some applications are directly over C2C layer and some are indirectly through IPv6. We focus on the second case. Here C2C layer is the lower-layer for IPv6 and, inside C2C network boundary, packets are delivered with C2C specific forwarding

mechanism, i.e. position based routing. As described in [3], packet forwarding is done in C2C layer and won't go up to IP layer. There can be multiple wireless technologies below C2C layer but, for convenience, we assume only 802.11p as wireless link in this paper.

It's not clear how C2C layer can play the sub-layer role for IPv6. C2C layer is much different from traditional sub-layer, i.e. Ethernet. There is neither clear-cut link nor generic link-scope multicast. [3] proposed to make C2C layer to emulate Ethernet with geographically defined link. However, our proposal, instead of emulating Ethernet, exploits genuine C2C features to support IPv6.

III. OBJECTIVES AND REQUIREMENTS

For IPv6 to run over C2C layer, two operations are needed, IP configuration and IP packet delivery. IP configuration is for a node to acquire necessary IP parameters for communication such as IPv6 address and prefix information. IP packet delivery is for a node to efficiently deliver a packet to its destination using C2C layer.

A. IP configuration

For IP configuration, a node should discover a reachable access router with a suitable prefix information as of RFC 4861 [15]. It also should acquire a valid IP address and be able to perform Duplicate Address Detection (DAD) as of RFC 4862 [17]. These operations are not difficult in Ethernet link with link-scope multicast support. However, C2C layer playing the role of IPv6 sub-layer lacks generic link-scope multicast support. Even the concept of link becomes extremely ambiguous there. It's possible to artificially define a link and emulate Ethernet in C2C layer but that would bring forth low efficiency and high complexity. Instead, we propose a node to maintain two kinds of links i) C2C link and ii) virtual point-to-point link. Each node forms a virtual point-to-point link with an access router through C2C tunnel. Since this is a point-to-point link, the node can easily perform Neighbor Discovery and Stateless Address Autoconfiguration with DAD as of [4], [14]. For ordinary data transmission, the node uses the other C2C link. We'll describe detailed IP configuration procedures in section IV.

B. IP packet delivery

We briefly sketch IP packet delivery framework in IPv6 over C2C environment. Four main entities are involved in IP packet delivery, i) source, ii) L2 neighbor, iii) IP next hop and iv) destination.

i) **Source** originates a packet and adds IPv6, C2C and 802.11p header with suitable address and identifier.

ii) **L2 neighbors** are the nodes which can communicate directly each other over wireless connection, i.e. 802.11p link. Take notice that L2 neighbor is different from the neighbor in IP link. Usually neighbors in IP link are the nodes on the same IP link. So there is transitive relationship among neighbors. If node A and node B are neighbors and node B and node C are neighbors, node A and node C are neighbors. However such transitivity doesn't hold for L2 neighbors in our definition.

Upon generating an IP packet, a source chooses an L2 neighbor and forwards the packet to the L2 neighbor in 802.11p frame. The chosen L2 neighbor is designated by the destination MAC address in 802.11p frame.

iii) **IP next hop** is the next hop in IP viewpoint. Take notice that L2 neighbor is the next hop in 802.11p viewpoint. IP next hop is the end node to which the packet is delivered by C2C forwarding mechanism. IP next hop is a destination in C2C viewpoint. Before IP next hop, all intermediary nodes only check the packet's C2C header and ignore its IP header. Only IP next hop consults IP header to make a forwarding decision.

If a destination is reachable through C2C mechanism, the destination is IP next hop. If not, an access router is IP next hop. An IPv6 packet is encapsulated in C2C header and IP next hop is designated by the destination C2C identifier in C2C header.

iv) **Destination** is the node to which IP packets are delivered and designated by the destination IPv6 address in IPv6 header.

A packet is generated from source, forwarded to L2 neighbor, then IP next hop and finally destination in that order. For example, in figure.2, a packet is originated at node 1 and delivered to a corresponding node across an access router. Here node 1 is the source, node 2 the next L2 neighbor, access router the IP next hop and the corresponding node the destination.

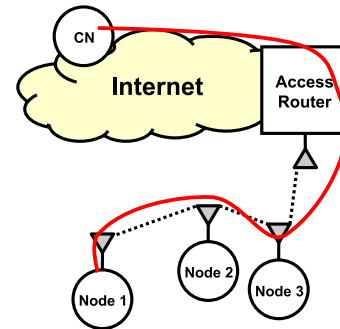


Fig. 2. IP packet delivery

Source generates an IPv6 packet with destination IPv6 address, encapsulates it with C2C header with IP next hop's C2C identifier and encapsulates it once more with 802.11p header with neighbor's 802.11p MAC address as in figure 3. Take notice that 802.11p header designates the neighbor, C2C header the IP next hop and IPv6 header the designation.

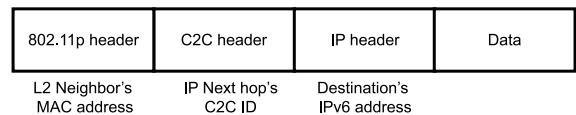


Fig. 3. Packet encapsulation

For IP packet delivery, a source node performs 2 tasks, i) IP next hop determination, ii) L2 neighbor determination and address resolution.

i) **IP next hop determination** is to find the IP next hop's C2C identifier from a given destination IPv6 address.

ii) **L2 neighbor determination and address resolution** is to find the next L2 neighbor's C2C identifier and 802.11p MAC address from a given IP next hop's C2C identifier.

Traditionally these tasks require link-scope multicast support, but, in VANET environment, that is difficult and costly. So instead we rely on location management features in C2C layer to perform those functions. C2C layer maintains the information about communication peers. For example, a node manages the list of its L2 neighbors. Our proposal exploits this information maintenance features to resolve IP next hop and next neighbor information in C2C layer without link-scope multicast. We'll describe detailed IP packet delivery procedures in section V.

IV. IP CONFIGURATION PROCEDURES

For IP configuration, a node should discover a router which can provide an access to the Internet. The node should receive a Router Advertisement (RA) message to acquire a necessary IP parameter for global communication such as a valid prefix. In case of address autoconfiguration, the node should perform Duplicate Address Detection (DAD) to assure the address uniqueness.

A. Link types

In our proposal, a node manages two kinds of links i) **C2C link** and ii) **virtual point-to-point link** to an access router. C2C link is used for data transmission, i.e. IP packet delivery and virtual point-to-point link for signaling procedure, i.e. IP configuration. From IP viewpoint, it has two interfaces, one to C2C link of non-broadcast multi-access (NBMA) type and one to point-to-point link with an access router. Neighbor discovery messages [15] to the access router use the point-to-point interface. All other packets use C2C interface. This section describes a way to manage the point-to-point link. C2C link usage for packet delivery is provided in the next section.

B. Access router search

A node first should find an access router to the Internet. It should acquire IPv6 address, C2C identifier and geographic location of an access router. There are 3 ways to achieve this.

i) **Map based**

Nowadays a vehicle is equipped with a navigation system containing a road map. We can include in this map the information of access routers along the roads. The map can contain roadside access routers' IP address, C2C identifier and geographic location. With this map with access router information, a vehicle can choose a suitable access router by comparing its geographic location and access routers'.

ii) **Beaconing based**

An access router can send a beaconing message with a router flag to indicate that it's an access router. Upon receiving this, a node can acquire necessary access router information.

iii) **RS/ RA based**

A node can send a Router Solicitation (RS) message to ask for a Router Advertisement (RA) message. An RS

message can be delivered within a certain geographic area to reach an access router.

A node can acquire necessary access router information with the above and moreover several enhancements are also possible for performance improvement.

C. Virtual point-to-point link establishment

Upon finding an access router's C2C identifier, a node forms a virtual point-to-point link with the access router via C2C tunnel. The C2C tunnel end points are defined by its C2C identifier and the access router's. Through this tunnel, the node sends the access router an RS encapsulated in C2C header. Upon receiving the RS from an unknown C2C node, the access router also forms a virtual point-to-point link with the same C2C tunnel and sends an RA through the tunnel. With this virtual point-to-point link, the node can perform Neighbor Discovery and Stateless Address Autoconfiguration easily. Take notice that, if a node is attached to multiple access routers, the node manages different point-to-point link with different access router.

D. Stateless address autoconfiguration

If the access router allows the node stateless address autoconfiguration, it includes a prefix with A-bit set in the RA as in [15]. For each node, the access router manages a separate virtual point-to-point link and assigns a different prefix. From the prefix, the node can configure an address and perform DAD as defined in [17]. Since it belongs to a point-to-point link, the operation is trivial as in IPv6 over 802.16 WiMAX case in RFC 5121 [16].

Such a configured global IPv6 address can be used in both point-to-point link and C2C link. Because a different prefix is assigned to a different node, there is no address conflict. However, we recommend nodes to restrict link-local address usage only for point-to-point link with an access router because its uniqueness is not guaranteed in C2C link. Also access routers may perform ingress filtering to drop packets with invalid source address, i.e. an address with a prefix which is not assigned by the router.

V. IP PACKET DELIVERY PROCEDURES

In this section, we present IP packet delivery mechanism in detail.

A. IP aware location management

C2C layer maintains the location information of communication peers. It performs i) beaconing, ii) location table management and iii) location service.

Beaconing is about to exchange geographic location information among L2 neighbors. Location table management is to record a communication peer's geographic location and, possibly, a route to the peer. Location service is to resolve a communication peer's geographic location from the peer's identifier. We propose to make these location management functions be aware of IP information as below.

TABLE I
INFORMATION ENTRIES FOR LOCATION MANAGEMENT

Location management	IPv6 address	C2C identifier	Geographic location	802.11p MAC address
Beaconing	Source	Source	Source	Source
Location table	L2 neighbor list	Source	Source	Source
	Destination cache	Destination	Destination, IP next hop, L2 neighbor	IP next hop L2 neighbor
	Router list	×	Router	Router ×
Location service	Destination	Destination	Destination	×

1) *Beaconing*: Each node sends a beaconing message with its interface. (*IPv6 address, C2C identifier, 802.11p MAC address, geographic location*).

The beaconing message may also include time stamp, velocity vector, location information accuracy and other information to improve performance.

2) *Location table*: conceptually location table is divided into three sub-tables i) L2 neighbor list, ii) destination cache and iii) router list. However all three tables can be merged into one location table in implementation.

i) **L2 neighbor list**

L2 neighbor list maintains L2 neighbor information. L2 neighbor list records L2 neighbor's (*IPv6 address, C2C identifier, 802.11 MAC address, geographic location*).

L2 neighbor list may also include time stamp, velocity vector, location information accuracy and other information to improve performance. L2 neighbor list is generated with beaconing messages from L2 neighbors.

ii) **Destination cache**

Destination cache records a route to a destination. Destination cache maintains the destination's information, its IP next hop's information and next L2 neighbor's information. Destination cache records (*Destination IPv6 address, Destination C2C identifier, IP next hop C2C identifier, IP next hop geographic location, L2 neighbor C2C identifier, L2 neighbor 802.11p MAC address*).

Destination cache is for performance enhancement. IP packet can be delivered even without destination cache but its presence greatly facilitates the data delivery. Take notice that, with an entry in the destination cache, IP next hop determination, L2 neighbor determination and address resolution is trivial. Given a destination IPv6 address, necessary IP next hop and L2 neighbor information can be found easily. In general, after sending a packet, a node records the destination, IP next hop, L2 neighbor information in destination cache for future use.

iii) **Router list**

Router list maintains the information of access routers which can provide an access to the Internet. Router list records (*router C2C identifier, router geographic location*).

Router list may also include router IPv6 address and other information to improve performance.

3) *Location service*: Location service provides a destination's geographic location from its identifier. When a source has only destination's identifier but doesn't know its geographic location, it relies on location service. It send a query with a destination's identifier and location service replies with the destination's geographic location. Detailed method to provide location service can be found in [13]. To map identifier to geographic location, location service manages 2-tuple of node's (identifier, geographic location).

In our scheme, location service manages 3-tuples of node's (IPv6 address, C2C identifier, geographic location). When a source has only destination IPv6 address, it sends a query to location service with the IPv6 address and location service replies with the destination's C2C identifier and its geographic location. [13] enlists various schemes for location service and all those can be easily modified to deal with 3-tuples of (IPv6 address, C2C identifier, geographic location).

Table 1 describes the IP aware location management functions and the information entities maintained by them. Take notice that there are 4 involving entities, i) source, ii) L2 neighbor, iii) IP next hop and iv) destination and 4 different information about them, i) IPv6 address, ii) C2C identifier, iii) geographic location and iv) 802.11p MAC address.

B. Data transmission procedures

In this section, with IP aware location management, we present a way for IPv6 packet delivery, i.e. a way to deliver an IPv6 packet to first L2 neighbor, then IP next hop and finally its destination.

To send an IPv6 packet, next hop determination and address resolution are necessary. In Neighbor Discovery protocol [11], these functions are performed with link-local multicast message. However, our proposal uses IP aware location management to accomplish those functions without relying on link-local multicast message. In a source C2C layer with the functional blocks depicted in Figure.4, an IPv6 packet is encapsulated in C2C header with IP next hop's C2C identifier and send to 802.11p layer with next neighbor's 802.11p MAC address.

We divide IP packet delivery into three cases i) Case 1: an entry in destination cache, ii) Case 2: no entry in destination cache but a reply from location service, iii) Case 3: no entry in destination cache and no reply from location service.

1) *Case 1: an entry in destination cache* : After a source generate an IPv6 packet, the packet is delivered to IP next

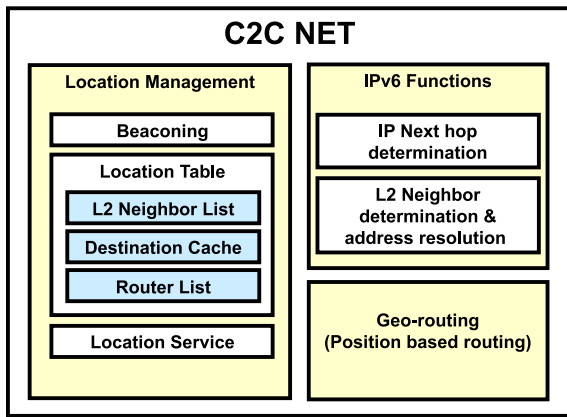


Fig. 4. Functional block

hop determination module in C2C layer as in Figure.4. There the source consults its destination cache to see whether it has an entry for the destination IPv6 address. If there is has an entry, the destination cache provides with the IP next hop's C2C identifier, its geographic location and next L2 neighbor's 802.11p MAC address. Take notice that, with IP next hop's C2C identifier and its geographic location, underlying C2C forwarding mechanism can deliver the IPv6 packet to the IP next hop. C2C header for IP next hop is generated with its C2C identifier and its geographic location. The IPv6 packet is encapsulated in the C2C header and delivered to 802.11p layer with the next L2 neighbor's 802.11p MAC address from the destination cache. 802.11p layer generates 802.11p frame with the next L2 neighbor's MAC address, which encapsulates the C2C NET packet. This way, the IPv6 packet is forwarded to the next L2 neighbor, then IP next hop. In IP next hop and only there, the packet is delivered upto IP layer. If it's the destination, the packet is sent to upper layer. If not, the IP next hop is an access router and the packet is forwarded to the destination in Internet with standard IP routing mechanism.

2) *Case 2: no entry in destination cache but a reply from location service:* Assume there is no entry for a given destination IPv6 address in the destination cache. C2C layer asks location service with the destination IPv6 address. Then location service replies with the destination's C2C identifier and geographic location. Take notice that this implies that the destination is its IP next hop. With the destination/IP next hop's C2C identifier and geographic location, the packet can be delivered to the destination with underlying C2C forwarding mechanism as below. The source consults its geographic routing module and its L2 neighbor list to determine the next L2 neighbor to which it forwards the packet. The neighbor list also provides the 802.11p MAC address for the L2 neighbor. With these information, the packet is sent to the destination as described in Case 1.

3) *Case 3: no entry in destination and no reply from location service:* Assume there is no entry for a given IPv6 address in destination cache and location service provide no information for the destination either. Then the source assumes

that the destination is unreachable with C2C forwarding mechanism and in Internet beyond an access router. As IP next hop for the destination, the source picks one access router from its router list with the access router's C2C identifier and geographic location. With those information, the packet is delivered to the access router with underlying C2C forwarding mechanism as described in Case 2.

VI. CONCLUSION

This paper presents a new way to run IPv6 in VANET with geographic routing mechanism, i.e. C2C-CC environment. The solution exploits inherent location management features to perform basic IPv6 protocols such as Neighbor Discovery and Stateless Address Autoconfiguration [15], [17]. Our scheme enables efficient IP configuration and IP packet delivery procedures without link-scope multicast. Vehicles can configure global IPv6 address and, with the address, communicate with peers on and off-VANET.

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