VANET addressing scheme incorporating geographical information in standard IPv6 header.

W. Vandenberghe, D. Carels, I. Moerman, P. Demeester
INTEC Broadband Communication Networks
Ghent University, Belgium
Wim.vandenberghe@intec.ugent.be

E. Van de Velde, J. Bergs, C. Blondia
Performance Analysis of Telecommunication Systems
University of Antwerp
Antwerp, Belgium
Erwin.vandevelde@ua.ac.be

***Abstract*—Several networking approaches exist in the domain of Vehicular Ad Hoc Networks (VANET). IPv6 networking, non-IP geographical networking, or a combination of both of them is commonly used as the foundation of the developed solutions. In this paper, an addressing scheme is proposed that incorporates all required geographical data in a standard IPv6 header. Step by step it is discussed how starting from this technique, a solution for VANET networking can be constructed that is entirely based on IPv6, and fulfills all imposed requirements in a simple yet effective manner.**

Keywords-VANET, adressing, IPv6

I. Introduction

Intelligent Transport Systems (ITS) are ICT systems that enable a more efficient and safer traffic through the use of a wide range of diverse technologies. In the ITS domain, Cooperative Systems are innovative applications that rely on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication to increase the "time horizon", the quality and reliability of information available to the drivers about the road conditions and other vehicles and road users in their immediate environment. To enable such forms of interaction, vehicles equipped with local wireless communication interfaces are interconnected in Vehicular Ad hoc Networks (VANET).

Numerous research efforts have already given attention to the VANET domain. Diverse routing and broadcasting protocols have been developed in several initiatives, using Internet Protocol version 6 (IPv6) as well as non-IP based geonetworking solutions, each providing different functionalities for data exchange and dissemination. To cover all communication requirements imposed by the cooperative applications, several efforts have focused on combining IPv6 and geonetworking into a common ITS communication system architecture. In this paper, an IPv6 addressing scheme is presented that incorporates geographical information in a standard IPv6 header, enabling the combination of the functionalities provided by both the IPv6 and the geonetworking approaches in a single IPv6 based networking solution.

The paper is organized as follows: Section II gives a more detailed description of the different available approaches to VANET networking. Section III performs an analysis of the required data dissemination functionalities from an application viewpoint, and recites other design requirements imposed by the typical ITS architecture. Section IV describes the technical details of the proposed solution, and section V focuses on the feasibility of this solution. Finally, section VI concludes the paper and describes the future work.

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II. Classification of Networking Techniques

The numerous VANET networking techniques that have been developed in past research efforts can be clearly divided in two classes: IPv6 based networking techniques, and non-IP solutions. Both approaches are explained in more detail in this section.

A. *IPv6 networking*

Applying IPv6 for VANET networking has some significant advantages. References [1] and [2] enumerated several of them. First of all, IP can support all types of ITS applications, while allowing developers to rely on established networking APIs. IP can also bring legacy Internet applications (web browsing, video streaming, peer-to-peer file sharing, online gaming, etc.) to the vehicles. Since it is the de-facto standard for data exchange, IP ensures interoperability of ITS communication systems with other communication systems (e.g. education, health-care, army, etc.). Using IP, applications can run transparently over diverse underlying communication media.

The most important reason to adopt IPv6 in the VANET domain instead of the common IPv4 protocol is the fact that IPv4 does not provide a sufficient amount of available IP addresses. In 1997, there were 600 millions of cars worldwide. At present trend, this amount will double by 2030 [2]. However, because IPv4 addresses are 32 bits long, the size of the entire address space is 2^{32} or approx. 4.3 billion, of which the major part has already been assigned. According to recent estimates, the unallocated address pool will exhaust in the period 2011-2012 [3]. IPv6 addresses have a length of 128 bits, resulting in an address space size of 2^{128}, completely resolving the address exhausting problem. Other advantages of IPv6 are the provided auto-configuration capabilities and network mobility support.

A disadvantage of IPv6 is that it has no built in notion of geographical information. This means that it does not support concepts such as geocasting where data is disseminated to all vehicles within a given distance of the data source. Therefore, routing protocols have to rely on topology information instead of geographic information. Typically, IPv6 VANET routing protocols adapt existing ad hoc protocols such as Ad Hoc On-Demand Distance Vector Routing (AODV) or Optimized Link State Routing Protocol (OLSR). For example, [4] extended AODV with a notion of neighborhood density to avoid the broadcast storm problem when flooding route request messages. Reference [5] adjusted OLSR to prefer most stable paths instead of shortest paths, and [6] proposes DHT-OLSR, combining OLSR with dynamic clustering and distributed hash table routing.

B. *Non-IP networking*

Several VANET networking protocols have been developed that do not rely on IP. There are two common reasons that induce researchers to build new protocols from scratch: they want to optimize efficiency for repetitive local broadcasting of vehicle status info (e.g. position, heading, speed, etc), or they want to introduce geographic data dissemination concepts such as georouting or geocasting.

1) *Topology broadcasts*

Topology broadcast protocols disseminate packets from a source node to all nodes located at a specific distance, in terms of hops. WAVE Short Message Protocol (WSMP) and CALM FAST are the two most important topology broadcast protocols that aim to achieve higher repetitive broadcasting efficiency by substituting the IP protocol. WSMP is standardized by IEEE as part of the IEEE 1609.3 standard which defines network services for WAVE (Wireless Access in Vehicular Environment) systems [7]-[8]. It defines a short message header, containing information such as WSM length, version number, security info, application class, application context data and transmission power, rate and channel. The length of the packet is 9 bytes plus the variable byte size of the application context data. WSMP only supports single-hop broadcasting, not multi-hop [9].

CALM FAST is a networking protocol currently being standardized by ISO [10]. It combines networking and protocol layer functionalities. It is a slim protocol based on a two octet network header containing the source and destination address of the packet. The protocol is primarily designed for single-hop communications, although it supports n-hop broadcasts in the Extended CALM FAST protocol variant. For geographic networking it will rely on the protocols being developed by the Car 2 Car Communication Consortium (C2C-CC), which will be standardized by ETSI.

2) *Geographic networking*

The basic idea behind geographic networking is that nodes can be addressed using geographic concepts such as locations and areas, and routing decisions can be based on inter-node distance, relative movement, etc. Depending on the destination type, several geo-routing schemes may be used [11]. *Geo-unicast* routes data from a source node to a single destination node for which the exact geographical location is known. Since this location will change over time, a position service is required that maintains a mapping in real-time between vehicle identity and exact location. *Geo-anycasting* refers to the situation where data is routed from a source node to one random node that is located within a defined geographical broadcasting area. In general this random node is the first node that is reached in the specified geographical area. *Geo-broadcasting* is used when data is routed from a source node to all nodes located within a defined geographical area. In geo-broadcast, the source node may be located inside or outside of the targeted geographical area. In the latter the broadcast packet is first forwarded towards the targeted area until reaching a node belonging to it. This node will then take care of broadcasting the packet to all nodes located within this destination geographical area.

The most important geographic networking standard which is currently under development is the protocol defined by the C2C-CC (that will be standardized by ETSI). Technical details regarding the chosen routing techniques are not yet publically available. It is however likely that they will be based on techniques common in geonetworking literature. One technique that is applied by many (not always following the same terminology) is *opportunistic broadcasting*, where the probability that a node will rebroadcast a received message is dependant of the distance between the node and the sender node: the greater the distance, the higher the probability that the receiving node will re-broadcast [12]-[14]. Another common technique is *irresponsible forwarding*, where the probability that a node will rebroadcast a received message is dependant of the neighborhood density [4], [15]-[16]. *Greedy forwarding* is a technique where the sender node itself selects the next node that will rebroadcast the message, aiming to achieve a maximum travelling distance per rebroadcast [17]-[18]. In urban environments, *intersection routing strategies* are often utilized [19]-[20].

C. *Combined solutions*

It is very likely VANETs will have to support the different functionalities provided by both the IPv6 as the non-IP solutions for the deployment of cooperative applications. This vision is shared by the different standardization bodies active in this domain. In the GeoNet project[1] it was researched how IPv6 connectivity can be provided on top of the non-IP based networking protocols CALM FAST and the C2C-CC geographic networking protocol. Similar, the IEEE 1609.x family of standards will provide both WSMP and IPv6 support.

III. COMMUNICATION REQUIREMENTS

A. *Application requirements*

An enumeration of common cooperative ITS applications is given by different standardization organizations such as the C2C-CC and ETSI [21]-[22]. An analysis of their different requirements regarding supported networking techniques can result in a common list of requirements imposed on any generic VANET networking solution.

[1] http://www.geonet-project.eu/

TABLE I. General capabilities for C2C-CC applications

Application name	V2V Cooperative awareness	V2V Unicast Exchange	V2V Decentralized Environmental Notification	Infrastructure 2 Vehicle (One-Way)	Local RSU Connection	Internet Protocol Roadside Unit Connection
Communication Type	Broadcast, Geocast	Unicast	Broadcast, Geocast	Broadcast, Geocast	Unicast	Unicast
Communication Range	300 meters to 1 kilometer	0 meters to 5 kilometers	300 meters to 20 kilometers	300 meters to 5 kilometers	0 meters to 1 kilometer	0 meters to full radio range. Possible multi-hop extension.
Roadside units	N/A	N/A	Not required but can aid applications	Required	Required	Required
Security	V2V Trust	V2V Trust	Originator Trust	Vehicle must trust RSU	RSU/OBU must trust each other	Internet Security (IPsec, application layer security)

The C2C-CC investigated a large number of use cases such as Cooperative Forward Collision Warning, Hazardous Location V2V notification, Green Light Optimal Speed Advisory, Remote Diagnostics, etc. Based on that analysis, the consortium was able to define six generic applications that together can support all use cases. *Vehicle 2 Vehicle Cooperative Awareness* supports the requirement for applications to share information with each other without any persistent communication link between the vehicles. *Vehicle 2 Vehicle Unicast Exchange* enables a communication link between vehicles for the exchange of information. *Vehicle 2 Vehicle Decentralized Environmental Notification* provides information about events and roadway characteristics that are probably interesting to vehicles or drivers for a certain time in a certain area. *Infrastructure 2 Vehicle (One-Way)* supports the communication from roadside units (RSU) to vehicles without a persistent communication link between vehicles and RSUs. *Local RSU* connection supports use cases where data between a vehicle and a RSU needs to be sent from the vehicle to the RSU or bi-directionally. The last application, *Internet Protocol Roadside Unit Connection*, supports services that are offered to the driver by servers located in the Internet. A technical analysis of all six applications, containing among others the required communication techniques, is described in the C2C-CC Manifesto. An overview of the general requirements is given in TABLE I. The results are in line with the results obtained in the ETSI application analysis which deduced seven basic applications from a larger set of use cases, and which are similar to the C2C-CC applications. From TABLE I it can be concluded that from an application point of view, a VANET should support some form of unicasting (IP- or geographical based), topology broadcasting and geocasting.

B. Design requirements

The European ITS Communication Architecture described in the COMeSafety project [23] defined the ITS station as the core component in the following instantiations: ITS Vehicle Station, ITS Personal Station, ITS Roadside Station and ITS Central Station. ITS Vehicle Stations and ITS Roadside Stations consist of a Communication & Control Unit (CCU) and one or more Application Units (AU). The CCU shall be equipped with at least a single ITS external communication interface to provide connectivity to external networks. This will typically be a short-range wireless network interface for VANET communication, often accompanied by a mobile data network interface for continuous Internet connectivity. Both the CCU and the AUs are also equipped with an ITS internal communication interface for data exchange between the different ITS Station components, typically an Ethernet interface, but other technologies such as 802.11 wireless LAN, Bluetooth or ZigBee are also valid candidates.

A list of important communication requirements introduced by such an architecture is given in [24]. It states that the proposed solution must satisfy the following requirements:

- It must remain as close to the IP standard as possible, no strong modifications to the IP stack of the involved components should be required.
- Because of throughput limitation on the radio interface, the introduced overhead should be kept as low as possible.
- No modifications should be required in the AUs, since these can be IP standard legacy devices.

IV. SOLUTION DESCRIPTION

In the previous sections an overview of possible VANET networking approaches was given. Based on an analysis of cooperative applications it was determined which of the networking techniques have to be supported by all VANET solutions. These requirements were supplemented with requirements imposed by the European ITS Communication Architecture. Based on this set of requirements, the VANET networking solution presented in this paper can be designed.

In section III-A it was determined that unicasting, topology broadcasting and geocasting should be supported. However, no requirements are imposed on the unicast technique: as long as it is possible to address and route data from a source to one well defined destination, it does not matter if this destination is defined on an IP basis, or on a geographical basis. Important recent developments as described in section II-C support both since they combine geographical networking protocols and IPv6 protocols in a single solution. However, this combination requires tunneling of the IP packets in geographical packets for communication across the VANET [1],[25]. This introduces a complexity in the routing process that could be avoided. If a networking solution would choose to only support IPv6 unicasting, and not geographical unicasting, it would still fulfill the communication requirements imposed by the applications, but it would not need to support the more complex tunneling. Another advantage of this approach is that the position service required for geographical unicasting would also not be necessary. This service overcomes the issue that the geographical network address of a node will change over time, due to the mobility inherent to VANET nodes. It performs a real-time mapping between vehicle ID and current geographical networking address. This additional complexity is not required in IP unicasting.

Based on these observations, the VANET networking solution presented in this paper is designed as a pure IPv6 solution. This means that all data packets communicated across any of the ITS Station's network interfaces will always be an IPv6 packet with a standard IPv6 header. This way, unicasting implementation is straightforward, and topology broadcasting can easily be supported by combining multicasting with correct usage of the Hop Limit header field. Geocasting however requires further refinement of the proposed solution. A mechanism is required to incorporate all required geographical data in the standard IPv6 header. In the following subsections our VANET networking solution is described in more detail. Most important components of this pure IPv6 based approach are the chosen methodology for address assignment, the mechanism to incorporate geographical information in the standard IPv6 header, and the routing methodology.

A. Automatic address assignment

The main idea behind the chosen approach for automatic address assignment is that the CCU receives a valid IPv6 address block from his operator or ISP (if the CCU has no mobile Internet uplink, this is performed once in a special configuration session at home, in the garage, etc.), divides this in smaller subnets, dedicates a subnet to every attached network (VANET, Internet uplink, internal station network, etc.) and correctly configures its own interfaces. Once these steps are performed, it starts broadcasting IPv6 router advertisements on its local network interfaces, just like any other IPv6 router would, enabling IPv6 Stateless Address Autoconfiguration for all connected AUs.

The IETF recommends that "mobile networks such as vehicles or mobile phones with an additional network interface (such as Bluetooth or 802.11b) should receive a static /64 prefix to allow the connection of multiple devices through one subnet" [26]. However, this range is too small for modern vehicular networks where more than one additional network interface is foreseen (VANET and one or more internal communication network). Since the IPv6 Addressing Architecture defines that all global unicast addresses other than those that start with binary 000 have a 64 bit interface ID field [27], the CCU cannot divide the received prefix in smaller subnets. Therefore, we propose that the CCU should follow the general case described in [26], and receive a /48 prefix. This way, the CCU can construct the required global unicast address as follows: the first 48 bits contain the received static prefix, the next 16 bits define the subnets for the different connected networks, and the last 64 bits are the interface ID which are constructed using standard stateless configuration mechanisms.

This approach is simple and needs no adjustments to the AUs. The addresses used for the VANET networking interface are dependent of the static prefix assigned to the CCU, and are therefore guaranteed to be unique. This means that there is no need for Neighbor Discovery and Stateless Address Autoconfiguration within the VANET, which require more complex techniques to be supported in the VANET domain since they rely on multicast capable links which are lacking in VANETs [1].

B. IPv6 geographical addressing scheme

This paper defines a VANET networking solution based entirely on IPv6. Since geocasting is a crucial requirement for many cooperative applications, a mechanism that incorporates the necessary geographical data is indispensable. To define this mechanism, a more profound insight in the required geographical data is required. Reference [11] defines a position vector containing the following data fields: MAC id, C2C NET ID, timestamp, position in latitude, longitude and altitude, and speed and heading. Since this paper chooses to work with IPv6 only, the MAC id and C2C NET ID can be dispensed. Position in latitude and longitude is absolutely required for geocasting. A timestamp can be extremely useful both to support delay tolerant networking techniques in sparse networking conditions, and as an input for the applications to determine message validity. Heading information can be used to limit rebroadcasting to certain areas (e.g. only towards oncoming traffic on a highway), which could be a valuable mechanism to tackle the broadcast storm problem in dense networking conditions. Speed and altitude are interesting parameters that can further refine the geographical addressing of network nodes, but they seem less decisive than the other parameters.

There are different techniques to include this geographical information in VANETs [24]-[25]. The first approach is to include it in the application layer, e.g. using an extended DNS that is capable to store geographic information. This could be easily implemented, but the drawback is that it is not really adapted to a mobile environment, and the scalability of this approach is unclear. Another approach is to store it in a geographical protocol, and transport the IP packets using this geographical protocol. This is not an option in our case, since it was previously decided that the presented solution should be IPv6 only. The third approach is to include all information in the IPv6 protocol. This can be done in three different ways: all information can be put in the IPv6 destination address using a special addressing scheme, it can be put in the existing IPv6 header fields by redefining their interpretation, or it can be encoded in a newly defined IPv6 Extension Header.

Applying a new IPv6 Extension Header allows a comprehensible integration of the required geographical data into the IPv6 packets. However, the downside is that is causes additional overhead on top of the 40 bytes IPv6 standard header. Since one of the requirements is that overhead should be kept as low as possible, it is preferred to define an addressing scheme that can incorporate all required geographical data in the standard IPv6 header. A suitable

8 bits	4 bits	4 bits	32 bits	32 bits	16 bits	4 bits	4 bits	16 bits	1 bit	7 bits
Multicast	flags	Scope	Latitude	Longitude	Radius	Heading 1	Heading 2	Timestamp	AM/PM	Duration
0xFF	0x1	0x5	Single float	Single float	uint16	uint4	uint4	uint16	0/1	uint7

Figure 1. Geographical IPv6 addressing scheme

addressing scheme is depicted in Figure 1. It has some similarities with the format of the IPv6 multicast address for a circular area presented in [28]. However, the approach presented in Figure 1 uses another technique to encode area coordinates, it uses 2 headings to define the broadcasting zone within the circular area, and it contains a timestamp.

As in any IPv6 address, the first 8 bits define the address type. For geocasting we will use multicast packets, hence the value of these bits should be 0xFF. The next 4 bits, the flags, indicate if the multicast address is permanently assigned by the Internet Assigned Number Authority (IANA), or if it is a transient address. Since the addresses used in this geographical addressing scheme are constructed in real time by the nodes, they are transient, and this field should have the value 0x1. The next 4 bits define the scope of the multicast group. Since this addressing scheme will be used to address other nodes within the VANET, site-local is the most appropriate scope, leading to the value 0x5 for this field. The next 32 bits contain the latitude of the center of the geocast area as a floating point number, similar to [28], while the following 32 bits contain the longitude. The next 16 bits define the radius of the circular communication area in meters. This allows ranges up to 65 km, well within range of the application requirements. The following 4 bits contain Heading 1. It is an unsigned integer of 4 bits, leading to 16 possible values. Therefore the actual heading value retrieved from the GPS receiver should be mapped to the closest fixed heading as depicted in Figure 2. Together with Heading 2 (the next 4 bits), the broadcast area is defined as the section between the circular area and the zone between the two headings. This is depicted in Figure 2. Circular geocasting can be achieved by putting the 0x0 value in both heading fields.

The next 16 bits are used as a message generation timestamp, they indicate the second of the day. Since an unsigned 16 bit integer has a maximum value of 65536, this is not large enough to define a unique second in an entire day. Therefore the 16 bit timestamps defines a second between 0h and 12h, and the next bit is used to determine if this second was in the morning or the afternoon. The last 7 bits of the address are interpreted as an unsigned integer, and define the validity duration in seconds after the generation time. The maximum

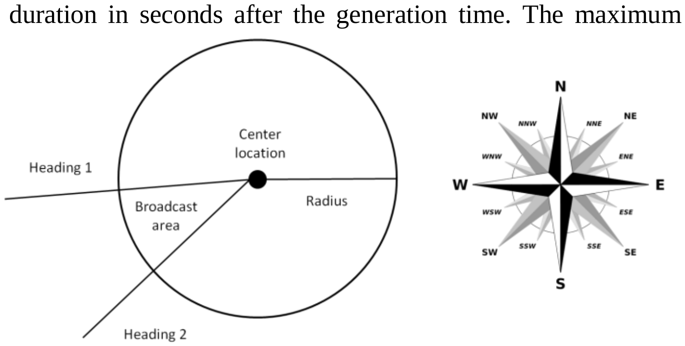

Figure 2: Headings concept

value is 128, which should be more than sufficient for delay tolerant networking.

C. *Interpretation of IPv6 header parameters*

The addressing scheme proposed in the previous subsections allows us to define receiver nodes in both place and time. This covers all geographical parameters that were identified as significant. In practical implementations, some additional information can be very useful. These can be added to the standard IPv6 header by reinterpreting some existing IPv6 header fields.

A notion of packet ID, not available in the standard IPv6 header, assists flooding mechanisms to avoid double retransmission of the same packet. This can be stored in the Flow Label field of the IPv6 header. For every new packet created on the VANET interface, the used Flow Label value should be increased with 1. To support topology broadcasts, similar to CALM FAST or WSMP, correct values should be used in the Hop Limit field in combination with a large circular geocast area. The traffic class value can be used to signal the IEEE 802.11p (or CALM-M5) MAC layer which priority to be used. The source of any (uni-, broad- or geo-) cast packet should always be the global unicast IPv6 address of the VANET interface, since multicast addresses may not be used as source addresses [27]. This also allows unicast communication with nodes that were discovered through broad- or geocast announcement.

D. *Routing methodology*

The presented VANET solution requires no changes on the AUs IP stack. Applications can translate their communication needs to specific destination addresses and header values, and create the correct packets to forward to the CCU. The only requirement is that they have access to raw socket APIs. To receive certain data, they cannot rely on standard multicast group membership management functions, since the used addresses do not correspond to predefined geographical zones. Hence the applications cannot determine multicast group IDs to join. Therefore they need to apply some protocol to inform the CCU about the sockets that they are listening on to receive specific data. This interaction with such a CCU service however can be entirely implemented on the application level.

The CCU routing functionality requires some adjustments on the IP stack. It has to interpret the used geocast addresses, and has to know how to forward them on the VANET. The other way around, it has to be able to decide if it’s within the broadcast range of a geocast message received on the VANET interface, and to duplicate it on the appropriate local interfaces to inform the listening applications on all AUs. To decide when and how to rebroadcast or route messages, it can apply any desired multicasting or routing protocol. This flexibility is an important advantage of the proposed solution.

V. Feasibility analysis

In section III it was concluded that a VANET should support some form of unicasting (IP- or geographical based), topology broadcasting and geocasting. Since our solution supports IPv6 unicast, IPv6 topology broadcasting and incorporates all geographical information in the standard IPv6 header, this indeed is the case. Another requirement was that the proposed solution should remain as close as possible to the IP stack, should limit the overhead and should not require modifications to the AUs. These requirements are also fulfilled. The 40 bytes IPv6 header is a bit longer then the headers used by CALM FAST or WSMP, but this seems negligible on a 6 Mbps VANET link such as IEEE 802.11p. The fact that an IPv6 header extension could be avoided is a plus.

The feasibility of the proposed solution has also been explored on a small scale vehicular testbed. An implementation in line with the principles proposed in this paper has been implemented on the Click Modular Router software platform. A proof-of-concept demonstration of this platform was extensively tested in preparation of the closing event of the IBBT NextGenITS project, with positive results in the field of reliability and timeliness. Footage of this demonstrator was also made publically available[2].

VI. Conclusions and future work

In this paper an IPv6 addressing scheme was presented that incorporates geographical data in a standard IPv6 header. Starting from an overview of possible networking techniques and an enumeration of the imposed requirements, it was demonstrated that based on the proposed scheme, a VANET networking solution can be constructed that is entirely based on IPv6. The advantage of the proposed solution is that it removes some of the complexities of combined solutions (such as tunneling and position services), it supports all required communication forms, requires no modifications to the AUs, and introduces only a limited overhead. The proposed solution was also validated in a proof-of-concept demonstrator. Future work will include the performance validation on a larger scale, and the research of suitable routing and broadcasting protocols.

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