A MANET-centric Solution for the Application of NEMO in VANET Using Geographic Routing

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ABSTRACT

In this paper, we propose a novel solution for usage of the Network Mobility Basic Support protocol in vehicular ad hoc networks. The solution adopts geographical routing as a sub-IP ad hoc routing protocol and applies a standard NEMO Mobile Router on top. As a result, Internet access enhanced with IP mobility support is available via a multi-hop path towards an access point. Compared with other approaches, this solution allows for immediate adaptation of data routes to topology changes, as shown by the results of measurements conducted for high rate data traffic. The paper also analyzes the case of vehicular networks isolated from a network infrastructure and suggests basic strategies for the integrated support of connected and disconnected scenarios. Finally, selected items for further research in this area are suggested.

Categories and Subject Descriptors

C.2.2 [**Network Protocols**]: Routing protocols, Protocol architecture

General Terms

Design, Performance

Keywords

MANET, NEMO, VANET, Car2Car, Intelligent Transportation Systems

1. INTRODUCTION

Vehicular communication has recently gained worldwide interest as a promising technology to increase road safety. Although its basic concepts and possible applications had already been identified in the 80s [11], deployment of such systems was not possible due to lack of adequate and affordable communication technology. The development and widespread diffusion of wireless communication technologies, such as devices based on the IEEE 802.11 standard family, have finally made it possible to deploy inter-vehicular communication on a large scale. Various efforts and initiatives such as research projects, industry consortia and standardization bodies are moving from pure research activities towards experimental evaluation and field trials.

Many of these activities consider the possibility of using IEEE 802.11 technology not only for safety, but also for *infotainment*. It is important to the deployment and widespread diffusion of infotainment applications that user devices can be plugged into the communication system of a vehicle, thus getting connected to a potentially huge number of communicating peers and even to the Internet. The applications built on top of such a communication network require the communication system below to cope with the extremely high dynamics of a vehicular network. This, in particular, this is the key factor that has led research and standardization activities to investigate geographic routing for multi-hop communications. Geographic, or position-based routing [19] has in fact been shown to outperform other schemes in highly mobile scenarios [9] due to its reactive nature and capability to perform the forwarder selection on demand based on *soft* states in the form of timestamped entries of a *geo-location table*. Furthermore, it naturally supports *geocasting*, which allows for addressing of all or any vehicle inside a geographic area as required by automotive applications.

Aside from the need for efficient mechanisms to route data packets and distribute information, the integration of nomadic user devices that commonly connect to static access points (e.g. public hotspots) in a moving vehicle poses specific issues for communication protocols. Recent activities on mobility support for IPv6 and, in particular, for entire moving networks, have led to the definition of the NEMO Basic Support protocol [6]. NEMO BS[1] provides session

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[1] In the rest of the paper, we use the abbreviation *NEMO* when referring to the general notion of network mobility

continuity and global reachability to entire moving networks when an attachment point is available. Nevertheless, the application of NEMO to dynamic, multi-hop networks like VANETs has not yet been sufficiently explored and requires that automotive-specific requirements [2] are taken into consideration.

Possible approaches for the application of NEMO to ad hoc networks can be classified as MANET-centric or NEMO-centric. With the first, the multi-hop path between a node and an attachment point relies on a distributed routing protocol which is executed by all nodes participating in the MANET, on top of which NEMO BS is executed. With the latter, multi-hop communication relies on one or more NEMO instances (i.e. Mobile Router) running on other nodes. In [1] we proposed exhaustive definitions and analyzed the two approaches according to technical and economic criteria. We concluded that MANET-centric solutions are better suited for the usage of NEMO in VANETs. We also concluded that existing MANET-centric solutions such as [16] [26] [20] do not specifically address 802.11-based automotive networks and therefore do not consider their requirements in terms of high mobility and integration with vehicles' communication systems.

In this paper, we propose a novel scheme for usage of NEMO BS in VANETs with a MANET-centric approach. Different from other NEMO- and MANET-centric solutions, which adopt topology-based routing protocols, we apply an ad hoc routing scheme to NEMO that utilizes the nodes' geographical positions for packet forwarding (position-based). For the *connected* case, in which a car has connectivity to the infrastructure, our solution adopts NEMO BS. In the case that an infrastructure is not available (*disconnected*), we propose design principles which allow for a smooth switch between the two operating modes. As a first step, we have implemented the solution for the connected case in a software prototype, set up an experimental testbed and conducted laboratory measurements. The results of measurements show that the solution of NEMO over geographic routing can react quickly to topology changes without causing packet losses. Finally, we identify major challenges that may be targeted by research in order to fulfill the specific requirements for IPv6's and NEMO's automotive applications.

The remainder of the paper is organized as follows: Section 2 gives an overview of the approaches of automotive consortia for integration of IPv6 and describes the Car2Car Communication Consortium (C2C-CC [4]) approach, which serves as reference to this paper. Section 3 describes the integration scheme in the NEMO default case of connectivity to the infrastructure. Section 4 analyzes the case without infrastructure connectivity and suggests principles for the design of techniques complementary to NEMO BS. Next, Section 5 describes an implementation of the proposed integrated solution and presents the results of measurements performed with this implementation. Finally, Section 6 suggests future research objectives and Section 7 concludes the paper.

2. REFERENCE SYSTEM

We assume a system based on short-range communication technologies operating in a protected frequency range, such as the IEEE 802.11p draft standard [13]. Research projects and consortia focusing on this technology have designed specific network protocols [23] [4] with different functionalities than the most commonly used protocol for inter-networking, i.e. the Internet Protocol. This is due to the fact that in these applications permanent connectivity to the Internet is not required or is not the primary goal. Thus the design principles are different from the ones that inspired the definition of IP. In particular, some applications only require broadcasting or unicasting of short messages, which can be obtained even without a network layer. Other applications need routing based on geographical positions or take into account the information contained in the packet.

Although primarily designed for safety, vehicular communication is also expected to provide *infotainment* applications, as pointed out by market research [18]. Some of these applications can be custom developed using the newly designed network protocols, but it appears clear that the Internet Protocol is necessary in order to meet the increasing demands of users in terms of applications availability and portability, as well as Internet connectivity. These reasons led to the inclusion of a native IPv6 stack in the main protocol architectures for automotive communications, namely ISO CALM [14], IEEE 1609 [23] and C2C-CC [4]. Among them, IEEE and ISO envisage a single-hop, infrastructure-based approach, where IPv6 applications are possible only when a vehicle is within direct communication range of a point-of-attachment. Thus, this scenario suggests a classical application of NEMO BS which has already been studied in vehicular environments [7]. Instead, C2C-CC also targets vehicle-to-vehicle and multi-hop communication for both safety and non-safety and in both scenarios of infrastructure availability (connected VANET) and non-availability (disconnected VANET). This extended scenario multiplies the number of possible applications of this technology, but also poses challenges for the deployment of IPv6 with respect to addressing, routing, mobility and security/privacy. For these reasons, the C2C-CC scenario is chosen as reference to this paper.

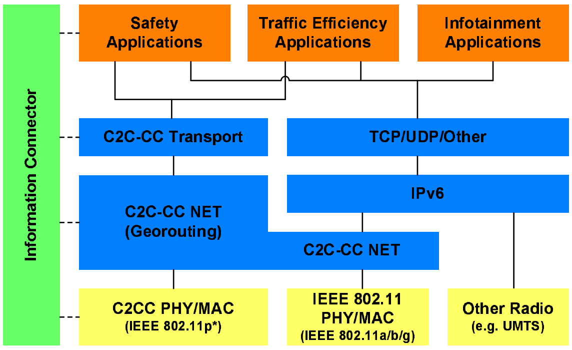

Figure 1: Protocol Stack of a C2C-CC OBU

In the C2C-CC system architecture, vehicles are equipped with devices termed *On-Board Units* (OBU), which implement the communication protocols depicted in Figure 1.

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and *NEMO BS* when referring to the NEMO Basic Support protocol [6].

Units of different cars can communicate with each other or with fixed stations installed along roads termed *Road Side Units* (RSU). OBUs and RSUs implement the same network layer functionalities and form a self-organizing network. RSUs can be connected to a network infrastructure, most presumably an IP-based network. Also, it is reasonable to assume that RSUs will act as IPv6 Access Routers (AR) or as bridges connected to an AR. Passenger or driver devices attached to the vehicle on-board system are called *Application Units* (AU). AUs are assumed to have a standard IPv6 protocol stack.

3. CONNECTED VEHICULAR NETWORKS

The first required functionality for usage of NEMO in ad hoc networks is that a NEMO Mobile Router gains infrastructure connectivity via multi-hop access. The solution proposed here achieves this functionality by (i) extending IPv6 address autoconfiguration so that the Access Router appears to the Mobile Router as if it was directly attached, and (ii), by providing sub-IPv6 geographical ad hoc routing to deliver IPv6 packets over multi-hop. Before illustrating the details of the two methods, we describe the assumed protocol stack.

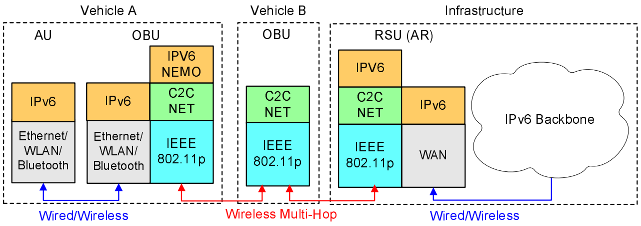

Figure 2: Protocol Stack of Involved Entities in the Proposed Solution

In Figure 2, one RSU and two OBUs with different configurations are shown. The C2C-CC NET layer is common to every node, whereas a standard IPv6 network layer is put on top of the C2C-CC NET in Vehicle A and RSU. The C2C-CC NET layer provides geographic routing as currently considered by C2C-CC and is able to transport and forward IPv6 datagrams, such that OBUs can potentially act as relays even without the IPv6 layer (Vehicle B).

According to C2C-CC preliminary studies [4], the C2C-CC NET protocol should provide routing of unicast and multicast packets based on the geographical position of source, destination and intermediate forwarders. Several variations of geographic routing have been proposed in literature [19]. The standardization of a such protocol is expected to be carried out by the newly created ETSI TC ITS group [8]. In our proposed solution for unicast routing, we adopt the basic *greedy* strategy [15]. In this strategy, after a *location service* signaling for the resolution of the destination node's position has taken place, packets are routed hop-by-hop selecting the closest direct neighbor to the destination location. The *greedy* strategy is enhanced with multicast support based on position, also called *geocast*, where the packet's destination is not a single node but a target area. Geocast is used in the distribution of IPv6 multicast packets.

As depicted in Figure 2, IPv6 is put on top of geographic routing. In order to avoid changes in standard IPv6 behavior, the sub-IP layer presents Ethernet-like characteristics so that standard mechanisms for datagram transport can be used [5]. Moreover, by applying geocast to IP multicast packets, the sub-IP layer provides a geographic partitioning of the VANET, which implies that a subset of the VANET nodes is presented as a single broadcast domain. For address autoconfiguration, RSUs issue IPv6 Router Advertisements (RA) which are distributed in multi-hop fashion and reach nodes that are outside direct communication range. The IPv6 layer of the OBUs receives the RAs from the C2C-CC NET layer, automatically configures an address in the standard way [25] and sets the IPv6 link-local address of the RSU as the default gateway.

Further optimizations for the specific purpose of integration of IPv6 and C2C-CC NET are applied in the proposed solution. In particular, the address resolution procedure usually performed with Neighbor Discovery is disabled. This is achieved by exclusively using autoconfigured IPv6 addresses, where the interface identifier is mapped directly from/into the C2C-CC NET identifier, which is also assumed to have a 64-bit length. Sets of unique MAC addresses are assumed to be pre-assigned by authorities to vehicles. This allows for omitting Duplicate Address Detection, further reducing the signaling overhead. On the other hand, when using autoconfigured IPv6 addresses the MAC address is propagated in the Internet as part of the MR's Care-of Address, introducing potential concerns for location privacy. However, the C2C-CC principles for privacy protection assume that each vehicle periodically picks up a different MAC address from the pre-assigned set. Moreover, the location privacy of a vehicle's users is protected by NEMO BS against off-path[2] malicious users in the infrastructure. The Home Agent shields the MR's Care-of Address when Bidirectional Tunneling mode is used. For more details on privacy protection in VANET refer to [10].

After address configuration, a NEMO MR is ready to register a binding with its Home Agent and then to exchange data traffic via the IPv6 tunnel. All of these data packets use IPv6 unicast addressing involving the MR's Care-of Address and the Home Agent address. IPv6's default behavior for packets to be sent to a different link is to first look for the default route in the routing table. Next, the IPv6 layer passes the AR's link-layer address to the MAC layer where it is used as the destination address in the MAC frame. In the proposed solution, this behavior is not changed: the sub-IP layer takes the AR's link-layer address from IPv6 and builds a C2C-CC NET identifier out of it. This is used in the geonetworking header as the destination and the next hop link-layer address is put into the real MAC header. On the receiving side, the geonetworking layer builds a MAC frame to be delivered to the IPv6 layer, where the source link-layer address is generated from the geonetworking identifier of the source. Consequently, the IPv6 layer believes that the other nodes in the VANET are attached to the same link.

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[2] Malicious nodes located in the path between MR and HA can intercept the signaling messages or the data traffic and presume the vehicle's location based on the Care-of Address.

Once the registration is completed, data packets are exchanged through the tunnel MR-HA. As a result of the sub-IP routing, a 2-level tunneling is used in the ad hoc domain as depicted in Figure 3. This technique increases the header overhead as compared with other solutions that perform ad hoc routing at the IPv6 layer. In this respect we argue that (i) introducing extension headers to perform geographic routing at the IPv6 layer would also cause comparable overhead, and (ii), that our solution's header overhead pays off through prompt adaptation to the frequent topology changes of VANETs.

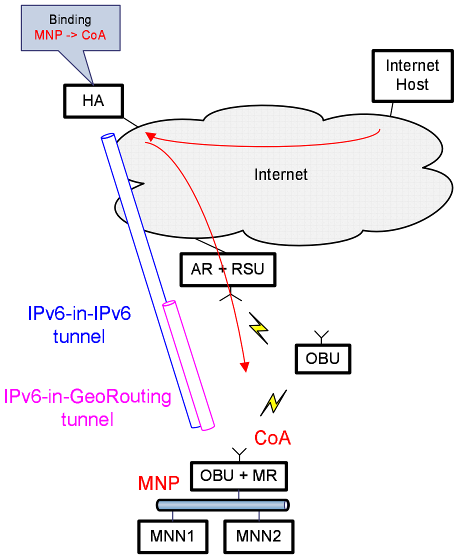

Figure 3: Proposed Usage of NEMO

4. DISCONNECTED VEHICULAR NETWORKS

In vehicular networks based on short-range communication devices, vehicles are often out of range of any access point offering access to an infrastructure network. The scenario of disconnected VANETs, where vehicles potentially without a pre-existing relationship meet and establish communication, is regarded as significant for the widespread diffusion of vehicular communication. On the other hand, the lack of infrastructure implies a lack of hierarchical organization of prefixes and addresses, which makes it impossible to simply adopt existing protocols and applications. Nevertheless, as the demand for applications using this kind of communication has already been identified in the automotive industry and is going to grow in the near future, research and engineering work has to provide efficient solutions.

For the spontaneous establishment of data routes in disconnected VANETs, we can identify two opposite strategies. In the first, vehicles negotiate a topological hierarchy, possibly concluding with newly assigned addresses that are topologically correct within the disconnected VANET. In the second, vehicles explicitly resolve prefixes into hosts (proactively or on demand), which implies the injection of temporary routes and the preservation of addresses. We argue that the second strategy is the only suitable one for VANETs, as it limits signaling overhead, does not imply a renumbering of the in-vehicle network and can be adopted as reactive signaling.

Without defining a particular procedure, which is the subject of ongoing research, we suggest some design principles allowing for efficient integration of the two scenarios, i.e. connected and disconnected VANETs. As a first step, the OBU should detect losses of connectivity to the infrastructure. In this context we regard connectivity as the capability to reach the access point via a multi-hop path. When the connectivity is lost, the OBU should stop acting as a NEMO MR, which means disabling the MR-HA tunnel and erasing the default route. As a second step, we suggest that a reactive behavior should be adopted so that the minimum routing state is created and maintained. This means that if data packets originated by local AUs arrive at the OBU to be forwarded outside, the OBU should try to resolve the identifier of the vehicle (if in direct or multi-hop range) with the Mobile Network Prefix[3] [6] that matches the target of these data packets. If the resolution succeeds, a temporary route should be created. When the OBU regains connectivity to the infrastructure, it should reinstall the standard NEMO behavior, which enforces data packets to traverse the MR-HA tunnel.

5. IMPLEMENTATION AND EVALUATION

The solution for the integration of NEMO BS and geographic routing illustrated in Section 3 has been entirely implemented as a software prototype for the Linux operating system. A Linux kernel module has been implemented for geographic routing as a sub-IP layer, which offers a virtual network interface for the encapsulation of IPv6 packets. Consequently, applications can use the virtual network interface as a standard IPv6 interface and are not aware of the ad hoc routing procedures taking place beneath. In the same way, any IP mobility support implementation (terminal or network mobility) can be placed on top of this virtual interface for both signaling and data exchange.

The NEMO BS protocol has been implemented as a user space daemon utilizing Linux standard libraries for the capture and injection of packets from and to the virtual network interface. For the forwarding between ingress and egress interfaces, we relied on the Linux kernel IPv6 forwarding capabilities, whereas for both OBU's egress interface and AU's address configuration we re-used the standard Router Advertisement daemon (`radvd`). As a result, an IPv6-capable device (PDA and laptop) that is plugged into the in-vehicle network acquires an address and, when the MR is registered with its HA, is able to exchange IPv6 packets with hosts in the infrastructure as depicted in Figure 3. As HA, we utilized the Nautilus6 NEPL implementation [21].

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[3] Since NEMO is not active when the infrastructure is not available, the prefix of the in-vehicle network should not be called MNP anymore. However, for better understanding we keep the NEMO terminology.

In order to validate the integrated solution, we performed laboratory tests with the mentioned implementations of geographic routing and NEMO BS under Linux. The goal of the tests was to evaluate, under heavy data load, the solution's performance in terms of route outage caused by mobility. The scenario is depicted in Figure 4. Car A runs a NEMO BS Mobile Router and has a plain IPv6 Mobile Network Node attached. The Correspondent Node (CN) sends a bulk data stream over UDP to the Mobile Network Node address. Starting from an isolated position, Car A enters the range of Car B, gains 2-hop connectivity, registers with the HA and starts receiving the data stream for the Mobile Network Node. Then, Car A proceeds with constant speed and direction, experiencing direct, 2- and 3-hop connectivity.

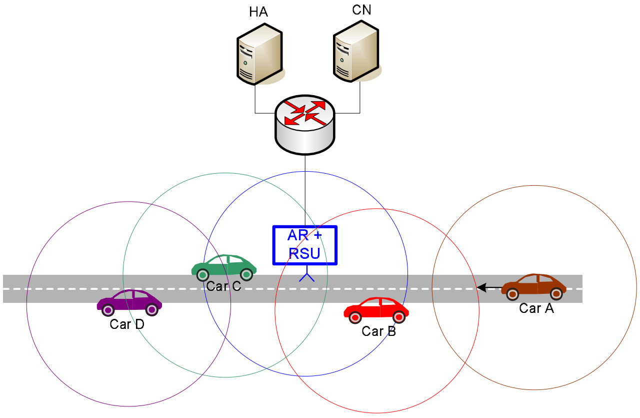

Figure 4: Test Scenario

In order to emulate the scenario, we utilized commercial carPCs and NEC's embedded prototypes as OBU and RSU located in the same laboratory room. Communication range is emulated by filtering out all the incoming packets sent by a node located beyond a predefined distance. Movement of Car A is emulated by periodically feeding the geographical routing module with predefined positions, instead of using a real GPS receiver. As physical and MAC layers we used IEEE 802.11a commercial hardware with the Madwifi driver [17] in pseudo ad hoc mode. More tests details are listed in Table 1.

MAC Layer	Atheros AR5212 802.11a, pseudo ad-hoc mode
PHY Layer	5.8 GHz, 20 MHz channel, 10 dBm tx power, 6 Mb/s
Emulated Communication Range	250 m
Emulated Speed	45 km/h
Flow type	Unidirectional UDP
Flow rates	CBR 1.2 and 1.9 Mb/s

Table 1: Tests Parameters

As test results, we consider the received data rate over time, measured in two tests with different data sending rates. The first data flow consists of UDP packets with a payload of 1.000 Bytes sent at a rate of $1/150s^{-1}$, which results in a data rate of 1.2 Mb/s (considering only the payload). This flow can be transmitted in the ad-hoc domain over 3-hops without exceeding the theoretical channel capacity.[4] The second flow has the same payload size but a generation rate of 200 pkt/s, which results in a sending rate of 1.9 Mb/s and therefore causes saturation of the channel when transmitted over 3 hops.

Figure 5 shows the received data rates over time for the 1.2 Mb/s data flow. The relevant events are the switches between different data routes due to topology changes. In particular, the first route change (i.e. switch from 2-hop connectivity via Car B and direct connectivity) does not cause any packet loss. This implies that the routing algorithm seamlessly adapts and switches to direct communication. The other route changes that take place after Car A exits the communication range of the RSU (i.e. the switch from direct to 2-hop and from 2-hop to 3-hop connectivity) introduce a short outage. This is due to the incapability of a forwarder to realize that the next hop has left its communication range. This is a common issue of every ad-hoc routing protocol and is typically solved in 802.11 networks by using link layer triggers that notify the network layer of a failure in the delivery of a unicast MAC frame. Unfortunately, indoor tests do not allow for usage of link layer triggers, as the communication range is emulated above the MAC layer.[5] However, considering the behavior in the first switch, we argue that by using this trigger, the routing algorithm would be able to react right after the first failed transmission, resulting in a minimum loss caused by the MAC layer and not by the routing algorithm.[6]

Figure 6 shows the received data rates over time for the 1.9 Mb/s data flow. Even under heavy load, results show that no packet is lost due to the routing algorithm. Figure 6 also displays that the wireless channel is saturated when the data flow is relayed over 3 hops. Finally, Figure 7 is presented to illustrate the change of data route that is reflected in the change of delivery latency.

In the tests presented here we investigated the delay introduced by the routing protocol in case of mobility. However, the performance of a VANET communication system under mobility also depends on other aspects such as address autoconfiguration and layer 3 handover. These issues do not directly affect the routing performance analyzed here and are the subject of ongoing research. Further, it is important to observe that the performance obtained in the laboratory represents an upper limit for vehicular networks based on WLAN [22].

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[4] Due to the total header overhead (802.11 MAC frame, Georouting, double IPv6 headers, UDP header), to transmit a payload of 1.000 Bytes, a frame of 1.180 Bytes is transmitted on the air. Given a PHY rate of 6 Mb/s, the theoretical capacity for this packet size is around 5 Mb/s, which, in case of multi-hop transmission, is shared among the hops.

[5] The authors have in previous literature [10] applied this kind of trigger in field measurements or for different purposes, when the testbed allowed for its usage.

[6] At least the packet whose failed transmission fired the trigger would be lost. Packets already queued in the MAC layer when the trigger is fired might be lost, too.

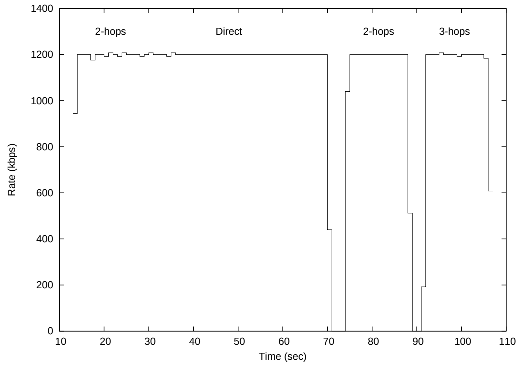

Figure 5: Received Data Rate for Medium Network Load (1.2 Mb/s)

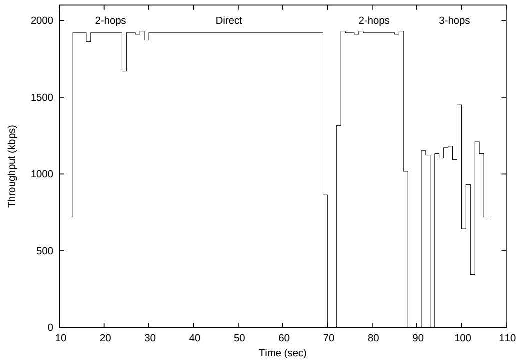

Figure 6: Received Data Rate for Heavy Network Load (1.9 Mb/s)

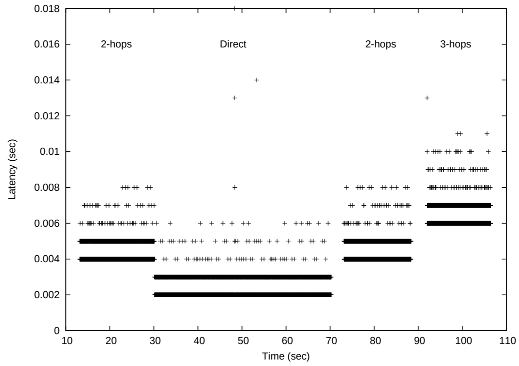

Figure 7: Delivery Latency for Medium Network Load (1.2 Mb/s)

6. FUTURE WORK

As a result of our research activity, we have identified a list of high priority issues that deserve the attention of research in the field of Network Mobility for VANETs.

Security and Privacy. Security aspects are not described in the proposed solution. It is assumed that the C2C-CC NET layer provides functionalities like authentication, confidentiality and non-repudiation, which have been identified as requirements by C2C-CC and European research projects [24]. The IPv6 layer put on top could rely on these functionalities for various purposes, for example, (i) to verify the authenticity of signaling messages issued by RSUs, such as Router Advertisements [12]; (ii) to assure privacy protection in the ad hoc domain between OBUs and RSUs by encrypting the data carried by the C2C-CC NET (i.e. the whole IPv6 datagram); (iii) to verify the Mobile Network Prefix ownership claimed by an OBU for establishment Route Optimization by means of a digital certificate. Consequently, the complete design of security functionalities at the C2C-CC NET layer must take into consideration the usage of IPv6 and NEMO, which in turn can considerably profit from advanced cross-layer interaction for network security purposes.

NEMO Route Optimization. The lack of a standardized Route Optimization (RO) technique[7] to allow a NEMO MR to exchange data directly with a Correspondent Entity (in the ad hoc domain or in the infrastructure) represents an obstacle for the deployment of Network Mobility functionalities. Taking into consideration the complexity due to the multiplicity of Route Optimization scenarios, the authors believe that dedicated, multiple standard solutions should be targeted, in order to satisfy the requirements of the different deployment scenarios. For this reason, the definition of specific automotive requirements for NEMO RO is ongoing [2]. With respect to the solution presented here, a standard NEMO RO technique could run on top of the sub-IP geographic routing in the same way NEMO BS does. As a result, communication performance between OBU and fixed points in the infrastructure (RSU or arbitrary nodes), as well as between OBUs currently connected to the infrastructure would considerably improve particularly in terms of throughput and end-to-end delay.

Disconnected VANET. As described in Section 4, vehicular ad-hoc networks will commonly be isolated from any infrastructure network. Due to the foreseen demand for IP-based applications in this scenario, research should focus on complete solutions that on the one hand take advantage of IPv6 mobility support, and on the other hand allow for spontaneous and direct communication with neighboring vehicles. It is important, though, to distinguish the general Route Optimization issue from mechanisms that spontaneously build connectivity in disconnected VANET. The first should be able to provide a standardized mechanism at the IPv6 layer, whereas the latter is a technology-specific issue and can potentially be solved with cross-layer interaction.

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[7] Several promising solutions have been proposed in literature, such as [3], but none of them has become a standard yet.

7. SUMMARY AND CONCLUSIONS

We have presented a novel solution for application of the NEMO Basic Support protocol with geographic routing in vehicular ad hoc networks, able to cope well with the high dynamics of vehicular networks. This solution allows for running an unmodified NEMO Mobile Router with multi-hop access to the infrastructure. The solution has been implemented in a software prototype used to perform laboratory measurements that show that mobility does not cause packet losses due to route failures. We have also provided guidelines for the design of a solution that enables smooth switching between connected and disconnected operations. Finally we have identified and described the main open issues most fundamental to the actual deployment of Network Mobility concepts in vehicular scenarios.

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