IP Mobility Management for Vehicular Communication Networks: Challenges and Solutions

Sandra Céspedes and Xuemin (Sherman) Shen, University of Waterloo
Christian Lazo, Universidad Austral de Chile

ABSTRACT

Vehicular communication networks have emerged as a promising platform for the deployment of safety and infotainment applications. The stack of protocols for vehicular networks will potentially include Network Mobility Basic Support (NEMO BS) to enable IP mobility for infotainment and Internet-based applications. However, the protocol has performance limitations in highly dynamic scenarios, and several route optimization mechanisms have been proposed to overcome these limitations. This article addresses the problem of IP mobility and its specific requirements in vehicular scenarios. A qualitative comparison among the existent IP mobility solutions that optimize NEMO BS in vehicular networks is provided. Their improvements with respect to the current standard, their weaknesses, and their fulfillment of the specific requirements are also identified. In addition, the article describes some of the open research challenges related to IP mobility in vehicular scenarios.

INTRODUCTION

The emergence of new applications designed for vehicular environments has triggered interest in conducting research on vehicular communication networks (VCNs). These applications were initially designed for safety-oriented communications, but the role of infotainment applications has rapidly taken an important place. Examples of applications on the safety-oriented side are notifications of emergency situations (e.g., car accidents or bad weather conditions). On the other side, examples of infotainment applications go from using vehicle-to-infrastructure (V2I) communications for driver assistance services or for traditional Internet-based applications (e.g., the downloading of music and video files) to using vehicle-to-vehicle (V2V) communications such as in distributed games played among passengers in neighboring vehicles.

Although the primary objective of a VCN is to increase safety for drivers and passengers in vehicular scenarios, the infotainment applications are likely to motivate faster adoption of the required equipment and supporting infrastructure. Therefore, it is critical to guarantee seamless, reliable, and ubiquitous communications in order to provide a satisfactory user experience to early adopters. Moreover, it becomes necessary to have protocols that facilitate not only the intelligent and secure flooding of information, but also the mobility management of mobile networks such as buses, trains, or cars that provide connection to their passengers.

VCNs consist of in-car (onboard units [OBUs]) and on-road (roadside units [RSUs]) with communications, positioning, and computing capabilities (Fig. 1). Both the OBU and RSU incorporate the stack of protocols defined for vehicular communications. The stacks proposed by various standard development organizations include a special set of protocols to handle safety and emergency communications, and a parallel stack to handle IP-based applications.[1] In this way, general IPv6 traffic and Internet-based applications are also supported in the VCN. In addition to the inclusion of IPv6, it has been suggested that IP mobility could be managed by the Internet Engineering Task Force (IETF) standards Mobile IPv6 (MIPv6) and Network Mobility Basic Support (NEMO BS) [1].

NEMO BS is meant to provide continuous network connectivity to a group of nodes that are moving together (i.e., a mobile network). As depicted in Fig.1, the mobile network is managed by a mobile router (MR) that provides connection to the group of nodes (the mobile network nodes [MNNs]). Similar to MIPv6, NEMO BS uses the concept of a fixed IPv6 prefix (the mobile network prefix [MNP]) to provide global reachability to the mobile network. When the MR connects to an access router (AR) in a visited network, it acquires a topologically valid IP address (care-of address [CoA]), followed by a registration of this CoA with the home agent (HA). Then the HA creates an entry that directs the traffic destined to the mobile network to be routed to the newly assigned CoA. In this way, NEMO BS establishes a bidirection-

[1] Some examples are the stack proposed by IEEE (http://standards.ieee.org/) in 1609-IEEE Trial-Use Standard for Wireless Access in Vehicular Environments (WAVE), and the stack proposed by ETSI (http://www.etsi.org/website/homepage.aspx) for an integrated standard based on the recommendations of the Car-to-Car Consortium and ISO TC 204 WG16 (CALM).

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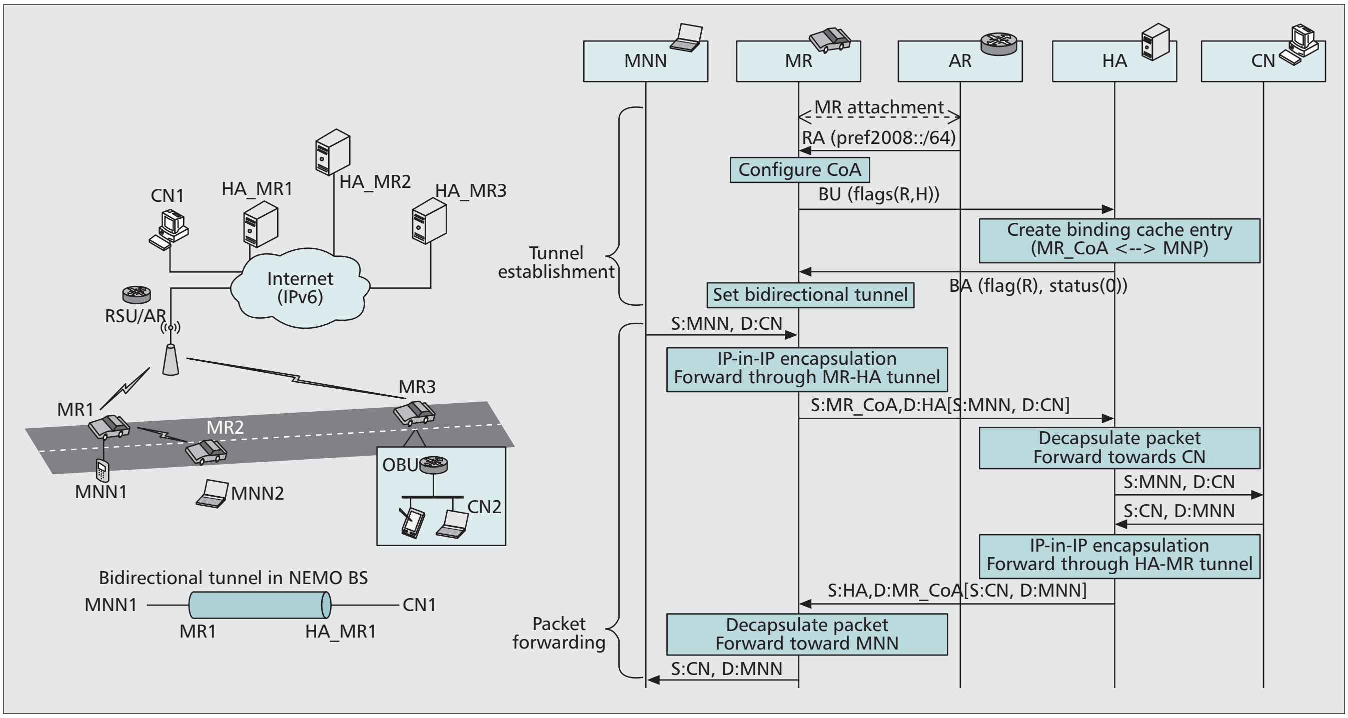

Figure 1. *Operation of NEMO BS in a VCN.*

al tunnel between the MR and the HA, which is used every time an MNN communicates with any correspondent node (CN).

Although NEMO BS seems to fit well in the context of terrestrial transport systems, it has not been designed to support the dynamics and special characteristics of VCNs. The current version of NEMO BS, as defined by the standard, does not incorporate a route optimization (RO) mechanism, as its counterpart MIPv6 does, and that affects its performance in vehicular scenarios. In addition, vehicles roaming along heterogeneous access networks (i.e., IEEE 802.11p, WiMaX, WiFi, third-generation/Long Term Evolution [3G/LTE]), as well as multihomed vehicles connecting simultaneously to more than one access network pose additional challenges for IP mobility management. Therefore, in this article we examine the specific requirements of VCNs in terms of IP mobility, survey and evaluate the existing approaches to improve the performance of NEMO BS by means of RO mechanisms in vehicular scenarios, and outline the emerging challenges. Other surveys in RO for NEMO BS exist,[2] but to the best of our knowledge, none of them focuses on vehicular scenarios.

Overview of the IP Mobility in VCN

In vehicular scenarios, similar to any IP-based scenario that involves mobile networks, a mechanism is required to handle the change of point of attachment to the IP network. With this mechanism, session continuity is provided and the changes are transparent to end users. However, the special characteristics of VCNs create unique requirements for IP mobility mechanisms. Some characteristics are high velocities, non-restricted power and processing resources (as opposed to generic mobile ad hoc networks), and extended area of coverage (citywide, countrywide, and worldwide).

There is also a combination of independent stacks of protocols and IP mobility mechanisms at the mobile end devices/routers, which coupled with the ability for these devices to communicate in ad hoc or infrastructure-based fashion, convert IP mobility in VCNs into a challenging task.

NEMO BS is an IP mobility protocol for mobile networks; thus, it is a potential candidate for providing IP mobility in VCNs. However, in its design, NEMO BS uses the tunnel MR-HA every time an MNN communicates with any CN. This may affect the performance of certain applications — especially delay-sensitive ones such as voice over IP — due to the added delay when the two peers use a non-direct path. The suboptimality of the protocol appears when the distance between CN-MRs is smaller than the distance between MR-HAs. An example in a NEMO-enabled VCN (Fig. 1) is illustrated in Fig. 2. For instance, when MNN1 communicates with CN2, the data packets are transmitted first to HA_MR1 and HA_MR3 instead of going directly through the path MR1-AR-MR3- CN2.

The problems of NEMO BS are documented in RFC 4888 [2]. However, an optimized version is not yet standardized. The optimization of NEMO BS is currently addressed by the IETF working group Mobilty Extensions for IPv6 (MEXT WG), which evaluates RO mechanisms for different contexts of application.[3]

In general, an IP mobility mechanism should meet the following requirements [3]:

1. *Reduced transmission power at end devices*: The end devices' proximity to the MR allows them to use less power-consuming interfaces.

[2] *See RFC 4889 [2] for a taxonomy of RO models in NEMO.*

[3] *Three possible contexts were identified in the MEXT WG's charter in 2007: automotive scenarios, aeronautics and space exploration, and personal area networks. A set of requirements for RO in aeronautics was published in RFC 5522, and a new charter document was adopted in September 2010.*

2. *Reduced handover events*: The MR should hide the changes of attachment point from the group of MNNs.
3. *Reduced complexity*: The MNNs should not be required to run their own IP mobility protocol. In this way, the complexity at end devices can be reduced.
4. *Reduced bandwidth consumption*: The MR should cluster the signaling required to keep the nodes globally reachable, therefore consuming less bandwidth resources. Even MIPv6-enabled nodes should benefit from the stable CoA configured from the mobile network prefix.

On the other hand, regardless of the adopted technique to provide RO for the IP mobility mechanism, the technique should efficiently utilize the network resources and improve the network performance (i.e., end-to-end delay, susceptibility to link failures, and data efficiency [overhead to payload ratio]).

In the particular case of vehicular scenarios, an additional set of requirements to be addressed by NEMO BS and the RO technique are summarized as follows (draft-ietf-mextnemo-ro-automotive-req-02 [2]):

5. *Minimum signaling*: The RO technique must carry the fewest possible signaling messages.
6. *Separability*: The MR must determine if the RO strategy is enabled on a per-flow basis and according to predefined policies. Any information about the CN's location could be relevant to define such policies.
7. *Security*: There must be mechanisms to validate the MNP and CoA ownership claimed by the MR that sends the binding update (BU).
8. *Binding privacy protection*: The content of the BU (CoAs, MNP) must only be revealed to the entities involved in tunnel establishment.
9. *Multihoming*: The MR must be able to simultaneously connect available egress interfaces to multiple access networks.
10. *Switching HA*: The MR must be able to switch its registration to the closest HA (when available). This is very important given the aforementioned areas of coverage that are possible in vehicular networks.

Furthermore, a vehicle's OBU is likely to have more than one network interface, which means it is able to connect to more than one access network at the same time, as well as to switch between different radio access technologies (e.g., 3G/LTE, WiMAX, 802.11p, or WiFi) in order to achieve seamless communications. This heterogeneous nature at the infrastructure side of the VCN poses additional challenges to the IP mobility management mechanism.

On one hand, there is still a lack of full integration between IP-based networks and cellular networks, in terms of the entities and signaling employed to provide IP mobility. For example, in traditional 3G networks, a proprietary protocol named GTP is used as part of IP mobility. In the case of LTE network architecture, there have been efforts to adopt Internet standards in order to comply with the concept of all-IP networks; however, the gap between the protocol elements defined by LTE and the entities defined by MIPv6/NEMO BS has not yet been closed. On the other hand, for a vehicle roaming at high speeds along dissimilar radio access technologies, the vehicular scenario imposes stricter requirements on the handover latency, especially for fleeting network connectivity such as that offered by WiFi access.

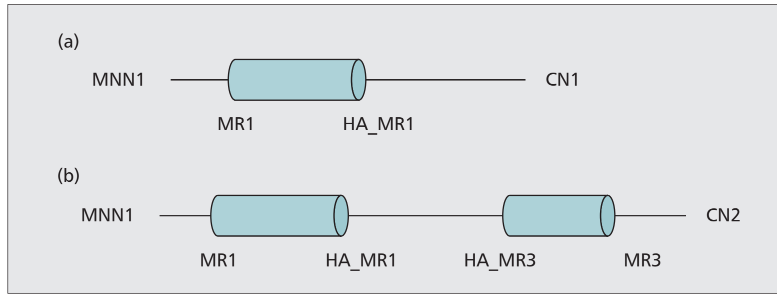

Figure 2. *Examples of tunneling in NEMO BS: a) MNN1 communicates with CN1; b) MNN1 communicates with CN2.*

In the following section, we classify the suboptimality problems of NEMO BS and the RO techniques proposed to solve them. They are evaluated and compared in the context of vehicular scenarios. We also present a survey of RO solutions for NEMO BS that are dedicated to vehicular scenarios and introduce the ongoing research along the lines of IP mobility in heterogeneous vehicular access networks.

Optimization of NEMO BS in Vehicular Scenarios

To analyze the suboptimality of NEMO BS, we look at the connection between VCNs and the fixed network from two different perspectives:

- Using single-hop connections to reach the fixed network (i.e., the vehicle has direct connection to an access point in the infrastructure; MR1, Fig. 1)
- Using multihop connections to reach the fixed network (i.e., vehicles connect to neighboring vehicles in order to reach the infrastructure; MR2, Fig. 1)

When NEMO BS is employed as the IP mobility management mechanism in the first category, packets follow suboptimal paths to reach the CN due to the pass through the HA before reaching the destination. The use of suboptimal paths between two peers is a recurrent problem of IP mobility solutions that use intermediary agents. The vehicular scenario is not exempt to that problem either, especially if delay-sensitive/throughput-sensitive applications are to be deployed. Studies show that, for a NEMO-enabled configuration, the effective throughput of TCP applications is reduced at least in half compared to the throughput perceived by applications that do not traverse the HA [4].

In addition, when V2V communications take place between NEMO-enabled vehicles in the same VCN, they end up using paths that traverse the fixed network instead of using the direct link between them. Experiments show that this effect could increase the regular round-trip time (RTT) between two vehicles using 802.11b from 8 ms to approximately 40 ms [5]. In gener-

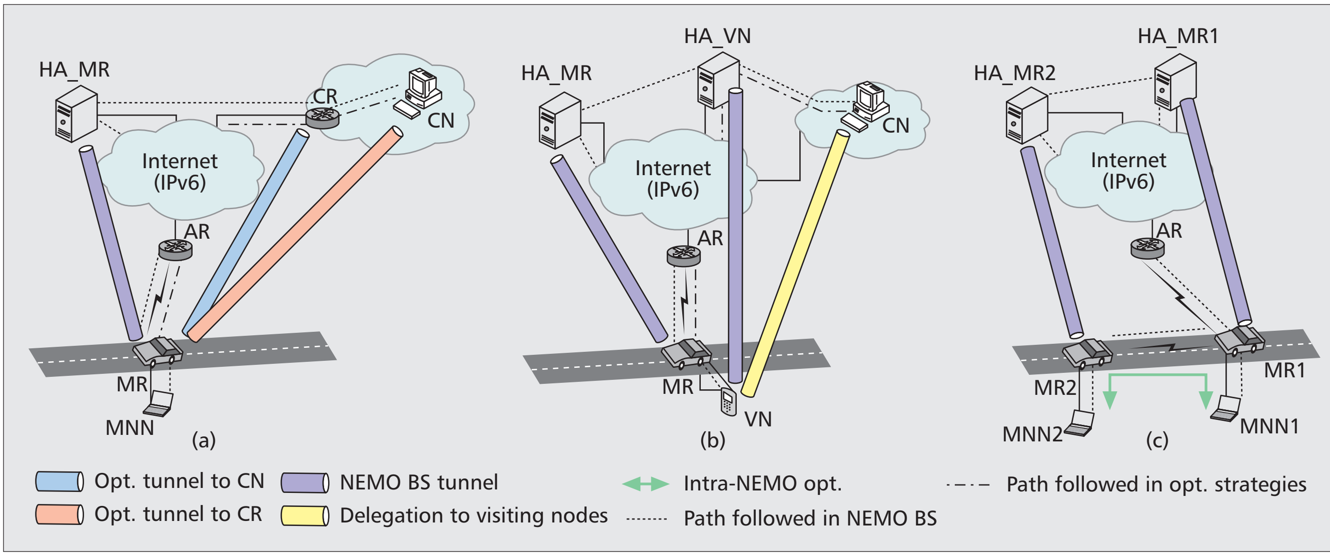

Figure 3. *Optimization of routes to reach the CN in single-hop communications.*

al, suboptimal paths to the CN result in increased packet overhead, and longer processing and end-to-end delays. Solutions that address the above mentioned issues for single-hop connections are described later in this section.

On the other hand, although multihop connections are technically possible, not only do they require nested configurations in NEMO-enabled vehicular networks, but they are also unlikely to happen due to the following reasons:

- Given vehicles' high mobility, multihop paths are of short duration (WiFi experiments in urban and freeway scenarios and analyses from simulated vehicular networks indicate a range between 10 and 40 s for contact duration between two moving vehicles [6, 7]).
- A vehicle is restricted in configuring IP addresses from another vehicle's IP prefix when they both belong to different administrative domains.

Instead of having vehicles configuring IP addresses from other vehicles, in multihop scenarios it is more feasible for MRs to use ad hoc routing in a sub-IP layer in order to obtain IP addresses directly from the AR.

Single-Hop Connections between VCN and Fixed Network

The strategies in this category aim at avoiding the MR-HA tunnel. These strategies are illustrated in Fig. 3 and described below.

Tunnel Establishment to CN — This strategy resembles the RO technique used in MIPv6, with a tunnel established between MR and CN. The requirement in this case is for the CN to support NEMO BS. The approach is especially useful when MNNs in the same mobile network communicate with only a few CNs. MIRON [4] is an example of this strategy. This optimization method is offered to those MNNs that have no mobility protocol running on their own. Although the solution was evaluated with fixed nodes, it can be employed in vehicular scenarios. Results for delay-sensitive applications demonstrated a 5 percent reduction in packet overhead and nearly 50 percent increase in throughput.

Tunnel Establishment to Correspondent Router — In this strategy, the closest router to the CN (i.e., the correspondent router [CR]) sets a binding entry with the MR's information. The duties of the HA are then shifted to the CR. By assuming that traffic always traverses the CR, the path MR-CN is optimized. An additional procedure to locate the CR becomes necessary in order to establish the optimized tunnel. ONEMO [8] is a solution based on this strategy. The MR discovers the CR by sending a CR Discovery Request message to an anycast address derived from the CN's network prefix. Once the optimized tunnel is established, all the mobile network traffic bypasses the HA. The solution was tested in vehicular scenarios with TCP traffic and demonstrated a 44 percent reduction in RTT and 6 percent increase in throughput.

Delegation to Visiting Nodes — In this strategy, every mobility-capable MNN (i.e., the visiting node [VN]) configures a topologically valid CoA and activates its own RO using MIPv6. The MR forwards the packets coming from the visiting node to the AR without using the bidirectional tunnel to the HA_MR. By surpassing the HA_MR and HA_VN, the path between the VN and the CN is therefore optimized. An additional prefix delegation mechanism is required for the VN to be able to configure a valid CoA. An alternative mode of operation of MIRON [4] uses the above mentioned strategy. When the mobile network contains visiting nodes, they use address delegation with network access authentication to manage their own route optimization procedure in a secure manner.

Intra-NEMO Optimization — This strategy aims to establish a direct path between MNN and CN when they are connected to the same

AR. By adopting this strategy, packets can be delivered with no use of resources from the fixed network. Usually, direct paths in the ad hoc network are established by a MANET routing protocol. Furthermore, there is a family of solutions—the so-called MANEMO—that explores the cooperation of MANET routing and NEMO.

Solutions in [5, 9] exemplify this strategy. Both are designed for vehicular scenarios and use Optimized Link State Routing Protocol (OLSR) to learn routes in the ad hoc network. They use a policy-based routing mechanism at the MR to select a NEMO path or a MANET path. Criteria such as bandwidth and RTT are used to select the optimal path. The testbeds of both solutions involved moving vehicles. Results in [9] showed an improvement in path selection based on available bandwidth for UDP traffic. Accordingly, in [5] the experiments demonstrated a 26 percent reduction in total RTT.

Another example is provided in VARON [10]. This solution aims to improve the delay and throughput for intervehicle communications while providing security. When the RO is activated, it establishes a path using the ad hoc routing protocol (ARAN) and performs a secure hop-by-hop binding procedure that uses cryptographically generated addresses. Simulation results from a vehicular environment showed that the TCP throughput of VARON does not improve for sparse scenarios, but outperforms by up to four times that obtained by NEMO BS in dense scenarios.

Multihop Connections between VCN and Fixed Network

What is intended by techniques in this category is that packets coming from nested MRs do not suffer from extra encapsulations at intermediate MRs, so the pass through multiple HAs before reaching the CN is avoided. As mentioned before, the use of sub-IP ad hoc routing is a more feasible way to address this issue if a multihop path is established to reach the fixed network. This strategy is illustrated in Fig. 4 and explained as follows.

MANEMO — In case of packets coming from nested MRs and destined to external nodes, ad hoc sub-IP routing is used to forward IP packets through the multihop path in such a way that it creates a virtual link between the vehicle and the AR without processing of IP headers at intermediate vehicles. The packets are then forwarded from the AR to the proper HA and then delivered to the CN. For packets destined to nodes in the same ad hoc network, the intra-NEMO strategy described earlier is employed.

A MANET-centric solution that applies NEMO in VCN is presented in [11]. To eliminate the nesting problem, the scheme uses sub-IP geographic routing. Once a nested MR encapsulates a packet, the sub-IP layer builds a geo-header pointing to the AR. This geo-header is used to forward the packet until the AR is reached. Consequently, from the IP layer's perspective, the nested configuration is hidden, emulating a direct link between the AR and the nested MR.

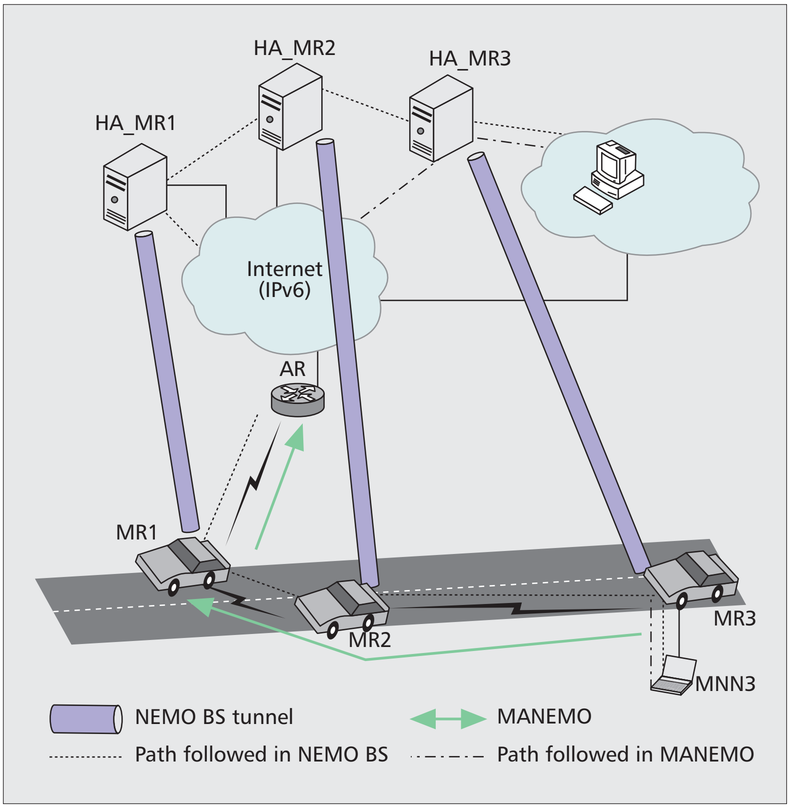

Figure 4. *Optimization of routes to reach the CN in multi-hop communications.*

Contrast of the Different RO Solutions and Discussion

A qualitative comparison of the surveyed works is presented in Table 1. Here, we discuss how those solutions address the specific requirements identified in VCNs.

Most of the RO solutions combine several strategies to achieve optimization of NEMO. In general, all of them meet the requirement of improving network performance metrics such as end-to-end delay and packet efficiency. Nonetheless, there are also trade-offs, specially in adaptability and processing delay. To focus on requirements mentioned earlier, the solutions greatly differ from one another in the level at which those requisites are met.

One of the issues affecting most of the RO solutions relates to privacy protection. The ones that require the intermediate MRs to inspect or modify the BU signaling, or propagate unprotected MNPs outside of the mobile network do not fulfill this requirement. A good example of MNP protection is provided by [4, 10]. Moreover, the MNP ownership has to be validated, and the strategies based on optimization to the CN/CR do not have the mechanisms to do such validation. Given that a vehicular scenario is formed by independent vehicles acting as mobile networks, it is very important to guarantee that no entity can use others' MNPs to impersonate them. On the other hand, in terms of separabili-

Solution	RO strategy	Nested NEMO opt.	MR-CN external opt.	V2V opt.	Separability	Security	Multihoming	Addressing management	Signaling load
ONEMO [8]	Proxy-MR, tunnel to CR	Yes	Yes	Yes	No	No	Supports mCoA configuration	Same as NEMO BS with TLMR's CoA announced to child-MRs	Independent of nesting level
MIRON [4]	Tunnel to CN, deleg. to visiting nodes/MR	Yes	Yes	No	Not restricted	Yes	Not restricted	Valid CoA delegation to MRs using PANA and DHCPv6	Grows linearly with # of opt. (independent of level of nesting); generated by addr. deleg. mechanism for VMN/nest. scenarios.
Converged MANEMO [9]	Intra-NEMO opt., MANEMO	Yes	No	Yes	Yes	No	Yes	MNP announced in OLSR	Independent of nesting level
Geo VANEMO [11]	MANEMO	Yes	No	Yes	Not restricted	No	Not restricted	MNPs announced to the routing protocol	Independent of nesting level; extra tunnel at the sub-IP layer
VARON [10]	Intra-NEMO opt.	No	No	Yes	Not restricted	Yes	Yes	MNPs announced to the routing protocol	Generated by the cryptographic system
Simultan. MANEMO [5]	Intra-NEMO opt.	No	No	Yes	Yes	No	Yes	MNPs announced to the routing protocol, mCoA support.	Generated by high frequency of OLSR messages

Table 1. *Comparison of optimized network mobility solutions for VCN.*

ty and multihoming, many of the presented solutions could easily be adapted to support multiple CoA registrations, and thus fulfill those requirements. In [5], for example, that extension is already included and the solution is evaluated using multiple active egress interfaces.

Solutions that determine the CN's location by means of topological or geographical information have been shown to be able to use better paths. Therefore, with the use of georouting, solutions may react faster to topology changes and may exchange IP-related signaling with the AR (e.g., router advertisement messages) regardless of network configurations. Moreover, given the geographic features available in VCNs, one would expect that solutions based on intra-NEMO and MANEMO strategies would become natural for vehicular scenarios.

Finally, although proposals to establish a distributed system of HAs exist (Global HA-HA protocol, draft-wakikawamext-global-haha-spec-01.txt [2]), none of the solutions that traverse at least one HA evaluate their performance by selecting the closest HA. If this were achieved, a more optimized route could be used (the MR-HA distance is reduced), and the solution could be more reliable and robust.

NEMO BS in Heterogeneous Vehicular Access Networks

A vehicle equipped with different radio interfaces may connect, sequentially or simultaneously, to dissimilar access networks. At first, NEMO BS was defined to register one single CoA with the HA, which was preventing the possibility to have more than one connection to different IP networks in the mobile network. However, a new standard named Multiple Care of Address Registration has been adopted to fix this problem (RFC 5648 [2]). An analysis of multihoming in network mobility support can be found in RFC 4980 [2].

The architecture of different access technologies is not yet transparent for the adoption of NEMO BS. A gap exists between some network architectures, such as LTE, and the entities defined by NEMO BS to provide IP mobility. In draftperkins-mext-hatunaddr [2], the author proposes to modify the HA so that the control plane and data plane are split to match the fourth-generation (4G) protocol elements. However, adoption of network-based protocols such as Proxy Mobile IPv6 (RFC 5213 [2]) is more likely to happen among LTE vendors, since this could simplify the stack of protocols at the MR while retaining full control of the IP mobility at the operator [12]. Whether using host-based mobility with NEMO BS or network-based mobility with Proxy MIPv6, roaming through heterogeneous networks is still challenging in terms of reducing the handover delay and improving the performance perceived by users moving at vehicular speeds. An example of different handoff techniques that address these problems and target vehicular mobility in multitier multihop wireless mesh networks is presented in [13].

In the following section, we outline open research issues for IP mobility in VCNs and provide some examples of ongoing research in this regard.

Open Research Issues

Anchor Point Location for VCN

Given the wide extensions in which VCNs are deployed, the vehicle's home network becomes a relative concept, which makes it difficult to indicate what the best location for the HA is. Proposals such as the aforementioned Global HA-HA protocol are more suitable for VCNs, since they allow the geographical distribution of HAs. Moreover, although the NEMO standard includes a modified version for dynamically discovering the HA address (DHAAD), this mechanism is designed only for environments in which security is not a requisite (draft-dupont-mextdhaadharmful-00.txt [2]). Therefore, further studies on these aspects are also required. An interesting paradigm shift is presented in [12], in which the vehicle's home network is matched with the visited access network's administrative domain, and network-based mobility (based on Proxy MIPv6) is used instead of NEMO BS.

USE OF GEOGRAPHIC INFORMATION IN RO

One salient characteristic of VCNs is that they are rich in geographical features. Beacons transmitted by OBUs carry information such as location, direction, speed, and acceleration. Such information is used by novel routing protocols that forward packets based on geographical locations, and that have been proved to fit well in vehicular scenarios. However, it is also possible to explore the utilization of this information to benefit handover events and RO for IP mobility. The prediction of handover events, based on mechanisms that integrate probabilistic methods and location information, could boost the mobility performance of IP mobility solutions.

SECURITY AND PRIVACY

This is still a pending requisite to be addressed by many IP mobility and RO solutions. Current standards rely on IPSec for security, but there have been reports by vendors and implementors about implementation and interoperability issues of IPSec in MIPv6/NEMO BS.[4] Moreover, many IP mobility and RO solutions neglect the processing delay and overhead caused by IPSec, even though the mechanism is defined as mandatory. Therefore, it is necessary, on one hand, to evaluate more solutions that actually implement IPSec as part of the mechanism and, on the other hand, to explore alternative security mechanisms that could motivate the rapid deployment of IP mobility in VCNs.

Finally, all ownership authentication for network prefixes, privacy protection, and confidentiality of the information needs to be further explored in V2I and V2V scenarios [14].

ROLE OF VEHICULAR MOBILITY MODELS IN RO

Simulation tools are a popular and cost-effective option for the evaluation of new protocols in VCNs. Different mobility models that resemble the behavior of vehicles in highways and urban scenarios are currently integrated in the simulation phase. However, it is important to determine the extent to which the mobility model affects the results obtained by simulations. Studies have shown that different mobility models lead to dissimilar network protocols' performance [7]. If a real testbed is not available, more realistic mobility models should be employed at the moment of evaluation of new IP mobility and RO solutions.

ADDRESSING ALLOCATION SCHEME

NEMO BS allows for two different forms of MNP registration:

- Implicit, in which both the MR and HA know beforehand the assigned MNP
- Explicit, in which the MR explicitly sends the MNP in the BU

However, the VCN may involve millions of nodes, and static configuration does not escalate in such large-size networks. A protocol to dynamically assign MNP to mobile networks has recently been approved to become an RFC (draftietf-mext-nemo-pd-07 [2]), and its impact on the security aspect and route optimization mechanisms needs to be further studied. Furthermore, the integration of geographic addresses and IPv6 is another challenge to be addressed. Some advances on this topic are presented in [15].

IMPACT OF VCN MARKET PENETRATION

VCNs rely on the deployment of in-vehicle and on-road communications equipment. The pace at which the equipment penetrates the market will highly affect the performance of the IP mobility solutions, which employ anchor points located on the infrastructure side. Therefore, network-wide connectivity plays an important role in the solutions' performance. Moreover, the distribution of equipped vehicles could be highly variable even for a contained geographic area. In the hypothetic case that all new vehicles were fully equipped for VCN, they would be mixed with the existent fleet of vehicles that, in contrast, will follow a slow and gradual adoption process [16]. Therefore, IP mobility solutions should handle the different market penetration rates of VCN equipment over the short, medium, and long terms.

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CONCLUSION

This article has identified several design challenges and special requirements for network mobility support in VCNs. It has also provided qualitative comparisons of the strategies and solutions proposed to date to optimize the performance of NEMO BS in vehicular scenarios and outlined some of the main open research challenges related to the IP mobility problem in VCNs. Possible approaches to address these challenges and the related ongoing research have been discussed.

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Biographies

SANDRA CÉSPEDES (slcesped@@bbcr.uwaterloo.ca) received B.Sc. (Hons. 2003) and Specialization degrees in telematics engineering and management of information systems (2007) from Icesi University, Colombia. She worked as a lecturer and researcher at Icesi University in 2005–2008, and currently is working toward her Ph.D. degree with the Department of Electrical and Computer Engineering at the University of Waterloo, Canada. Her current research interests include mobility management, wireless network routing, and vehicular ad hoc and sensor networks

XUEMIN (SHERMAN) SHEN [M'97, SM'02, F'09] (xshen@bbcr.uwaterloo.ca) received a B.Sc. (1982) degree from Dalian Maritime University, China, and M.Sc. (1987) and Ph.D. degrees (1990) from Rutgers University, New Jersey, all in electrical engineering. He is a professor and University Research Chair, Department of Electrical and Computer Engineering, University of Waterloo. His research focuses on mobility and resource management, UWB wireless networks, wireless network security, and vehicular ad hoc and sensor networks. He served as an Area Editor for *IEEE Transactions on Wireless Communications* and Editor-in-Chief for *Peer-to-Peer Networks and Applications*. He is a Fellow of the Engineering Institute of Canada, a registered Professional Engineer of Ontario, Canada, and a Distinguished Lecturer of the IEEE Communications Society.

CHRISTIAN LAZO-RAMIREZ (clazo@inf.uach.cl) received a Ph.D. in telematics engineering from the Universidad de Vigo, Spain (2008). He is an auxiliary professor in the Department of Computer Science at the Universidad Austral de Chile (UACH), Valdivia. His research interests are in the field of new-generation networks, ad hoc and sensors networks, IP protocols in heterogeneous mobile communications, and the Internet of Things.