AnaVANET: An Experiment and Visualization Tool for Vehicular Networks

Manabu Tsukada[1](✉), José Santa[2,3], Satoshi Matsuura[4],
Thierry Ernst[5], and Kazutoshi Fujikawa[4]

[1] INRIA Paris - Rocquencourt, Le Chesnay, France
manabu.tsukada@inria.fr, tsukada@hongo.wide.ad.jp
[2] University Centre of Defence at the Spanish Air Force Academy, San Javier, Spain
[3] University of Murcia, Murcia, Spain
jose.santa@cud.upct.es, josesanta@um.es
[4] Nara Institute of Science and Technology, Nara, Japan
matsuura@is.naist.jp, fujikawa@itc.naist.jp
[5] CAOR Lab, Mines ParisTech, Paris, France
thierry.ernst@mines-paristech.fr

Abstract. The experimental evaluation of wireless and mobile networks is a challenge that rarely substitutes simulation in research works. This statement is even more evident in vehicular communications, due to the equipment and effort needed to obtain significant and realistic results. In this paper, key issues in vehicular experimental evaluation are analyzed by an evaluation tool called AnaVANET, especially designed for assessing the performance of vehicular networks. This software processes the output of well-known testing tools such as *ping* or *iperf*, together with navigation information, to generate geo-aware performance figures of merit both in numeric and graphical forms. Its main analysis capabilities are used to validate the good performance in terms of delay, packet delivery ratio and throughput of NEMO, when using a road-side segment based on IPv6 GeoNetworking.

Keywords: Vehicular Ad-hoc Networks · Experimental Evaluation · Wireless Multihop Communication · Network Mobility · Visualization Tool

1 Introduction

Vehicular networks are essential for Intelligent Transportation Systems (ITS) to optimize the road traffic and achieve safe, efficient and comfortable human mobility. Essentially, there are two main communication paradigms in vehicular communications, vehicle to vehicle (V2V) and vehicle to infrastructure (V2I), depending on whether the communication is performed directly between vehicles or using nodes locally or remotely installed on the road infrastructure.

When the V2V paradigm is considered, the research field is commonly called Vehicular Ad-hoc Networks, or VANET. Although there are a lot of works related

V.C.M. Leung et al. (Eds.): TridentCom 2014, LNICST 137, pp. 126–135, 2014.
DOI: 10.1007/978-3-319-13326-3_13

to VANET applications and basic research at physical, MAC and network layers, there is a significant lack of real evaluation analysis in this field, due to cost and effort implications. A number of experimentation works and supporting tools should be improved in the short term, in order to give real evidences to car manufacturers and road operators of the benefits of vehicular communications.

Conventional network measurement tools (e.g. *iperf*, *ping* or *traceroute*) assume fixed networks and assess network performances in a end-to-end basis. However, under dynamic network conditions such as in the vehicular networks case, it is difficult to measure detailed status of networks by using solely these tools, because vehicles are always changing their location and the performance of wireless channels fluctuates. In order to solve these issues, we have developed a packet analysis and visualization tool called AnaVANET [1], which considers the peculiarities of the vehicular environment for providing an exhaustive evaluation software for outdoor scenarios. Both V2V and V2I networks can be efficiently analyzed, thanks to the integrated features for collecting results, post-processing data, generate graphical figures of merit and, finally, publish the results in a dedicated web site (if desired).

The rest of the paper is organized as follows. Section 2 introduces the readers about the network layer protocols in vehicular networks experimentation. Then, the issues and requirements for evaluating vehicular networks are listed in Section 3. The evaluation methodology desired in this frame is described in Section 4 and, as a result of our analysis, the design and implementation of the AnaVANET evaluation tool is detailed in Section 5, together with a reference evaluation of a network testbed using the tool in Section 6. Finally, Section 7 concludes the paper summarizing the main results and addressing future works.

2 Network Protocols in Vehicular Networks

Network protocols in vehicular networks can be classified in infrastructure-less scenarios, i.e. V2V, and infrastructure-based scenarios, i.e. V2I, as showed in Fig. 1.

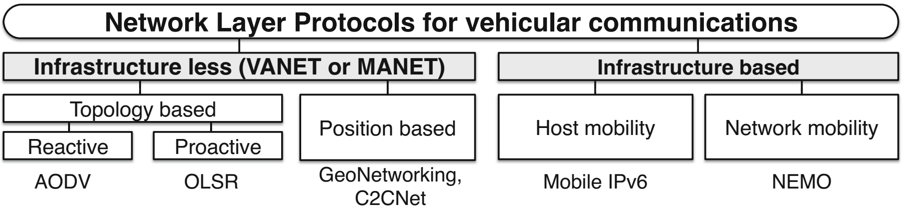

Fig. 1. Network Protocols in vehicular networks

The infrastructure-less scenario is well-known by the research area of VANET or Mobile Ad-hoc Networks (MANET). These approaches are designed to enable

---

[1] http://anavanet.net/

wireless communications in dynamic topologies without any infrastructure. Routing protocols here are further classified as *topology-based* and *position-based* routing protocols. Topology-based protocols were divided into two main branches by the IETF MANET working group: *reactive*, where nodes periodically exchange messages to create routes (*e.g.* AODV [1]), and *proactive*, in which control messages are exchanged on demand when it is necessary to reach a particular node (*e.g.* OLSR [2]).

Unlike topology based routing, position based routing does not need to maintain part of the network structure in order to forward packets towards the destination node. When routing packets based on position, nodes forward the packets with the aim of reaching the nodes within a geographical location. Thus, position based routing can eliminate the problem that appears in topology based protocols when routes become quickly unavailable in high mobility scenarios. In Greedy Perimeter Stateless Routing (GPSR) [3], for instance, the intermediate nodes make a decision based on the destination position and neighbor positions. The Car-to-Car Communication Consortium (C2CC) also specified the C2CNet protocol, which was later enhanced by the GeoNet project to support IPv6. Within the ITS standardization domain, GeoNetworking [4] is being completed by ETSI at the moment, integrating several geo-aware strategies to better route packets in vehicular networks.

On the other side, infrastructure-based protocols have been focused on the global connectivity of nodes to the Internet. Mobile IPv6 [5] solved the mobility problem for mobile hosts and, later, Network Mobility Basic support (NEMO) [6] provided a solution for the mobility of a whole network (e.g. a vehicle or bus), which has been recommended by the ISO TC204 WG16 to achieve Internet mobility for vehicles.

3 Issues and Requirements for VANET Evaluation

Using multi-hop and dynamic routing strategies presents a challenge in the evaluation of vehicular networks. Common end-to-end evaluation tools such as *ping6* and *iperf* are useless to track the effect of route change, because they are unaware of the path taken during a communication test. An additional lack of these tools is the possibility to measure the performance of hop-by-hop links, since the study is carried out end-to-end. Also, geographical and external factors such as nodes position, distance between nodes or obstacles are not linked with network performance figures of merit.

With the aim of summarizing these main requirements when evaluating multi-hop vehicular networks, the next needs are found essential by the software tools used in experimental campaigns for evaluating both V2V and V2I:

Path detection. The topology of a vehicular network with dynamic routing changes frequently as vehicles move, and the communication path is changed accordingly. Thus, the tool should take note of the communication path used in every moment.

Communication performance in links. Once the communication path is tracked, the tool should measure the performance in a link-by-link as well as end-to-end basis.

Geographical awareness. The network performance in a link depends on various geographical factors, such as the distance between the nodes, the movement speed and direction, and the existence of obstacles in the communication link. Thus, the evaluation tool should take the above geographical factors into account.

Intuitive visualization. Performance figures of merit and environmental information should be shown together in a synchronized way, and the spatio-temporal data series should be available in post process to play them at different speeds, stop when desired, or replayed freely as he or she wants.

Independence from network protocols. Given the various network layer protocols in vehicular communications, the evaluation tool should be independent from the one chosen.

Independent from devices. Since the configuration of vehicle and infrastructure devices may differ, the evaluation tool should not rely on any specific device functionality.

Adaptation to various scenarios. The software evaluation tool should accommodate to all possible communication scenarios (moving or static, urban or highway, etc.).

Easiness for data collection. Since a lot of experiments could be needed in a extensive campaign, the easiness of gathering data and deploying software modules in devices is essential.

As it is later described, the evaluation tool presented in this work (AnaVANET) copes with the previous requirements.

4 Evaluation Methodology

The evaluation goals are to analyze which *testing conditions* affect which *data flows or network protocols*. For achieving this end it is necessary to design a proper evaluation methodology. Within it we should consider the tendency of results by repeating tests with the same settings or varying parameters under study, such as the network protocol, the mobility of nodes or the data volume. The overall analysis should be supported by a proper evaluation tool, such as the later presented **AnaVANET**. This section details both the testing conditions and the possible routing protocols to consider, as it is summarized in Fig. 2, by introducing the concept and presenting our real use case for testing the performance of NEMO over IPv6 GeoNetworking.

4.1 Testing Conditions

Testbed Platform. The testbed used for the evaluation of a network architecture should be carefully chosen to implement most relevant nodes in real software

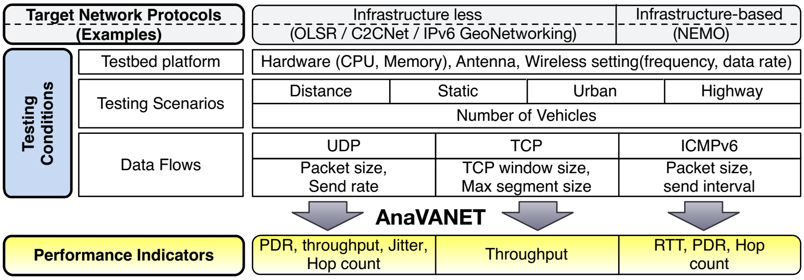

Fig. 2. Evaluation Methodology

and hardware. In vehicular communications, this is extremely important, since a good deployment could be needed in case of testing V2V multi-hop networks.

In our particular case, the testbed comprises a set of four vehicles and two roadside stations, as illustrated in Fig. 3. Each vehicle is equipped with a mobile router (MR), with at least two interfaces: an Ethernet link to connect mobile network nodes (MNNs) within the in-vehicle network, and a wireless adapter in ad-hoc mode used for both V2V and V2I communications. On the roadside, access routers (ARs) are prepared to be fixed on the top of a building or any other elevated point near the road. Each one provides two interfaces: an Ethernet link for a wired Internet access, and a wireless adapter in ad-hoc mode to connect with vehicles in the surroundings. At a backend point in the Internet, a home agent (HA) is installed to support Internet mobility of MRs by using NEMO.

Among the various testbed conditions, the hardware specification (CPU, memory, etc), antenna and wireless settings are important factors for the evaluation, since they will highly affect the results. In our case, MRs are Alix3d3 embedded boxes provided with a Linux 2.6.29.6 kernel. Each MR has a mini-pci wireless card Atheros AR5414 802.11 a/b/g Rev 0, and an antenna 2.4GHz 9dBi indoor OMNI RP-SMA6 is used. The frequency used has been 2.422Ghz and the data rate has been fixed to 6 Mbits/s.

Testing Scenarios. Fixing the evaluation scenarios beforehand is essential in the planning of a testing campaign. In general, the main factors that determine the possible scenarios are:

Mobility. Static scenarios can be chosen to test the network operation in a controlled way, but also dynamic ones can be used in a realistic evaluation. A dynamic scenario is considered in our case.

Location. The place in which the tests are carried out impacts on the network performance, due to signal propagation blockage issues above all. In our case a semi-urban scenario is used within the INRIA-Rocquencourt installations.

Number of vehicles. The number of hops between the source and the destination vehicles affect the communication delay and the higher probability of packet looses, due to route changes or MAC transmission issues. Up to four vehicles are considered in our case.

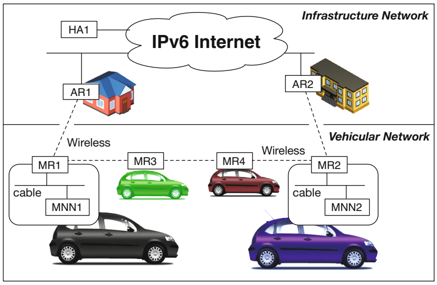

Fig. 3. Network Configuration

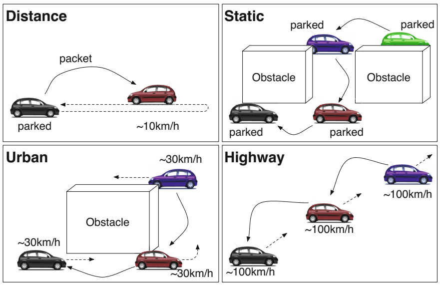

Fig. 4. Movement Scenarios

As summarized in Fig. 4, testing scenarios have been divided into urban and highway; mobility has been set to static, urban-like speed, and high speed.

4.2 Data Flows and Performance Indicators

A number or protocols and data flows can be set for evaluations, however, only the most representative and more used in the literature should be considered to study concrete performance indicators. For instance, in our case UDP, TCP and ICMPv6 are used to measure the network performance between two communication end-nodes (MNN to MNN) mounted within two vehicles:

UDP is a connection-less unidirectional transmission flow. The traffic is generated by *iperf* in our case. It is considered that with UDP the performance indicators under consideration can be the packet delivery ratio (PDR), throughput and jitter.

TCP is a connection-oriented bidirectional transmission flow. This traffic is also generated by *iperf* in our case. The performance indicator under consideration here has been the maximum throughput.

ICMPv6 is a bi-directional transmission flow. The traffic is generated by *ping6* in our case. The performance indicator under consideration can be the road trip delay time (RTT) and PDR.

5 System Design and Implementation of AnaVANET

AnaVANET (initially standing for Analyzer of VANET) is an evaluation tool implemented in Java to assess the performance of vehicular networks. It takes as input the logs generated by the *iperf*, *tcpdump* and/or *ping6*, together with navigation information in NMEA format, to compute the next performance metrics: network throughput, delay, jitter, hop count and list of intermediate nodes in the communication path, PDR end-to-end and hop-by-hop, speed, and instantaneous position.

AnaVANET is put in the context of the evaluation scenario described in the previous section in Fig. 5 , showing also the main inputs and outputs of the tool.

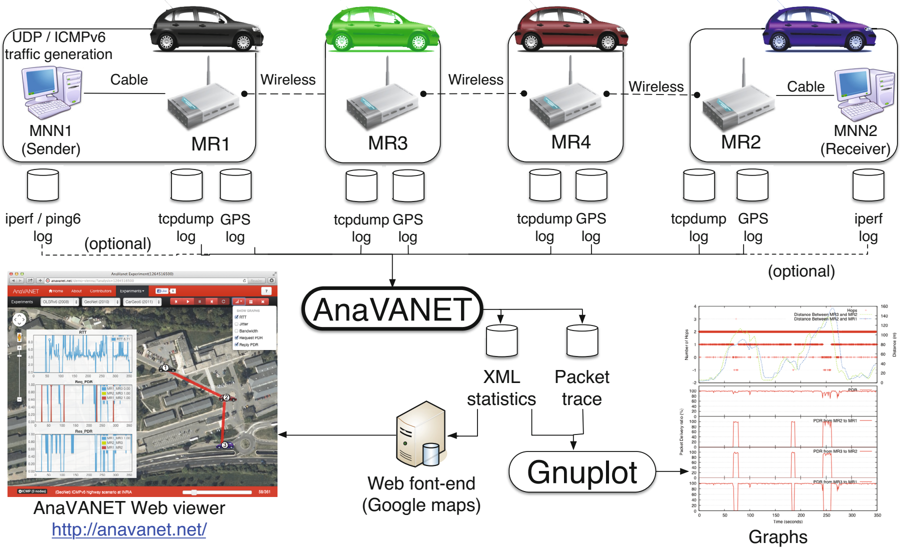

Fig. 5. Overview of AnaVANET

The sender MNN (left most vehicle) is in charge of generating data traffic, and both the sender and the receiver (right most vehicle) MNNs record a high level log, according to the application used to generate network traffic (*iperf* and *ping6* for the moment). All MRs record information about forwarded data packets by means of the *tcpdump* tool, and log the vehicle position continuously. All this data is post-processed by the AnaVANET core software and then analyzed. The tool traces all the data packets transmitted from the sender node to detect packet losses and calculate statistics for each link and end-to-end, and then merge all these per-hop information with transport level statistics of the traffic generator. As a result, AnaVANET outputs an XML file with statistics on a one-second basis, and a packet trace file with the path followed by each data packet.

Once generated, performance metrics can be graphically showed through plots generated by *gnuplot* and a website where all tests are available. The screenshot of the website is shown in left bottom of Fig. 5. Accessing the website one can replay the tests on a map to see momentary figures of merit.

On the map, the position and movement of the vehicle are depicted with the speed of each vehicle and the distance between them. The transferred data size, bandwidth, packet loss rate, RTT and jitter, for each link and end-to-end are displayed. The network performance is visualized by the width of links and the colors used to draw them.

6 Evaluation of NEMO over IPv6 GeoNetworking

Early versions of AnaVANET were designed for evaluating infrastructure less network protocols, as used in our previous works for analyzing OLSR in vehicular environments [7] and later tests of IPv6 over C2CNet [8] in the FP7 GeoNet project.

The current version of AnaVANET can also analyze infrastructure-based network protocols such as NEMO. In this section, we report a summary of the results collected in the evaluation of NEMO over IPv6 GeoNetworking when a vehicle connects with a node located in the Internet using two roadside units as access routers. The *umip.org*[2] implementation of NEMO is used and the *cargeo6.org*[3] software is used for IPv6 GeoNetworking. ICMPv6 and UDP evaluations in handover scenarios were performed at INRIA Paris-Rocquencourt campus with the two ARs previously presented in the testbed description. The speed of the vehicle was limited to less than 15 km/h, like in a low mobility urban scenario. The reader can directly click in Fig. 6 - Fig. 9 to see the correspondent result in the AnaVANET web viewer, to further perceive the details of the gathered results.

ICMPv6 echo requests (64 bytes) are sent from the MNN to a common computer located in the wired network twice in a second, which replies with ICMPv6 echo replies. The results collected in the ICMPv6 tests are plotted in Fig. 6. The lower part shows the itinerary of the vehicle and the locations of AR1 and AR2 on the map, whereas the upper part shows the RTT, the packet loss and the result of the mobility signaling. The X-axis and the Y-axis of the upper part are the latitude and the longitude of the vehicle, corresponding to the road stretch indicated in the lower part of the figure. When either the request or the reply is lost, the RTT is marked with a zero value and, at the same time, a packet loss is indicated. A binding registration success is plotted when the NEMO binding update (BU) and the corresponding binding acknowledgment (BA) are successfully processed. On the contrary, if either of them is lost, a binding registration fail is plotted at the position.

Fig. 7 shows the same results of the test, but referred to the test time. The upper graph shows the RTT and the distance to the two ARs; the middle one shows the PDR obtained with the two ARs; and, finally, the lower plot shows the status of the NEMO signaling. A NEMO success means that the binding registration has been successfully performed, and a fail indicates that either the BU or the BA has been lost.

The results collected in the UDP tests are plotted in Fig. 8. UDP packets are sent from the MNN to the wired node at a rate of 1 Mbps and a length of 1250 bytes. The lower part of the figure shows the itinerary of the vehicle, and the upper part corresponds to the PDR obtained with the ARs and the binding registration results, as in the previous case. The road stretch is the same one used above, but the vehicle moves on the contrary direction in this case.

In the time-mapped results showed in Fig. 9, the upper graph shows the UDP throughput from the MNN to the wired node, the middle part shows the PDR to the two ARs, and the lower plots the status of the NEMO signaling. Success of NEMO status means that the binding registration is successfully performed and Fail means that either the BU or the BA is lost.

---

[2] http://umip.org

[3] http://www.cargeo6.org

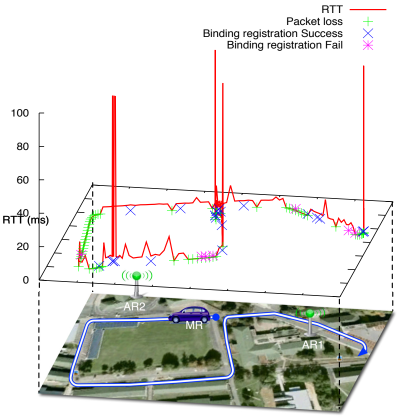

Fig. 6. Map-based RTT, Packet Losses and Mobility Signaling of ICMP evaluation in a handover scenario

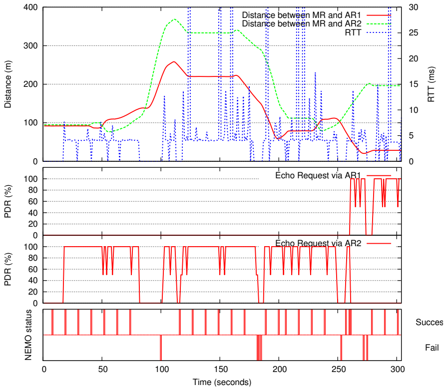

Fig. 7. RTT, Packet Loss and Mobility Signaling of ICMP evaluation in a handover scenario

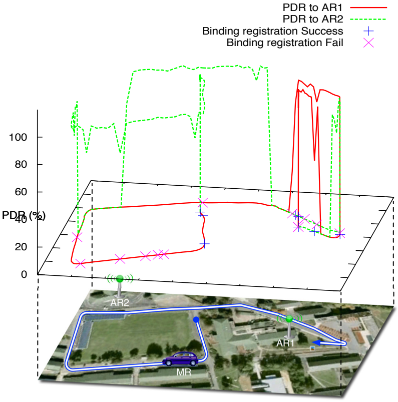

Fig. 8. Map-based PDR of UDP evaluation using NEMO over IPv6 GeoNetworking

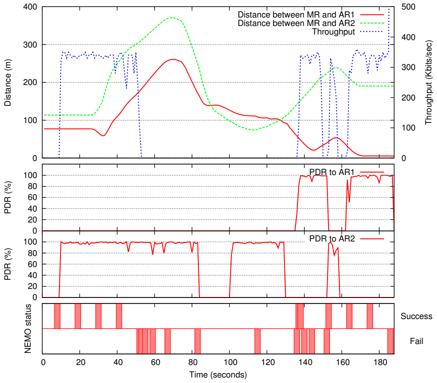

Fig. 9. PDR of UDP evaluation using NEMO over IPv6 GeoNetworking

7 Conclusions and Future Work

The paper has presented the peculiarities of evaluating vehicular networks experimentally, through presenting the most used protocols and detailing the needs of the software tools to be used for this task. After that, the importance of the testing methodology is described, and a reference design of a vehicular network evaluation is used to exemplify it. The testbed design and implementation, testing scenarios, routing protocols and data flows, are found essential to be fixed beforehand to avoid improvisation during the testing campaign. The AnaVANET platform is then presented as an efficient evaluation software to process the data gathered by common testing tools, and then generate lots of performance indicators of the trials. The capabilities of AnaVANET are exploited in a novel evaluation of NEMO over IPv6 GeoNetworking, using the tool to gather RTT, PDR and channel throughput information. The results reveal that mobile IPv6 connectivity can be maintained in a V2I case using GeoNetworking over WiFi to pass NEMO IPv6 traffic between vehicles and infrastructure.

Our future work includes, first, a link layer extension of the system to analyze the channel quality (RSSI), load ratio and coverage map. Second, it is considered the support for multicast data flows, since it is essential for the dissemination of events in vehicular networks. Third, we plan to evaluate a real application developed for cooperative ITS.

Acknowledgments. This work has been sponsored by the European 7th FP, through the ITSSv6 (contract 270519), FOTsis (contract 270447) and GEN6 (contract 297239) projects, and the Spanish Ministry of Science and Innovation, through the Walkie-Talkie project (TIN2011-27543-C03).

References

1. Perkins, C., Belding-Royer, E., Das, S.: Ad hoc On-Demand Distance Vector (AODV) Routing. RFC 3561 (Experimental) (July 2003)
2. Clausen, T., Jacquet, P.: Optimized Link State Routing Protocol (OLSR). RFC 3626 (Experimental) (October 2003)
3. Karp, B., Kung, H.T.: Gpsr: Greedy perimeter stateless routing for wireless networks. In: 6th Annual International Conference on Mobile Computing and Networking, MobiCom 2000, Boston, Massachusetts, USA, August 6-11, pp. 243–254. ACM / IEEE (August 2000)
4. Intelligent Transport Systems (ITS); Vehicular Communications; Part 4: Geographical Addressing and Forwarding for Point-to-Point and Point-to-Multipoint Communications; Sub-part 1: Media-Independent Functionality, ETSI TS 102 636-4-1 V1.1.1 (June 2011)
5. Perkins, C., Johnson, D., Arkko, J.: Mobility Support in IPv6. RFC 6275 (Proposed Standard) (July 2011)
6. Devarapalli, V., Wakikawa, R., Petrescu, A., Thubert, P.: Network Mobility (NEMO) Basic Support Protocol. RFC 3963 (Proposed Standard) (January 2005)
7. Santa, J., Tsukada, M., Ernst, T., Mehani, O., Gómez-Skarmeta, F.: Assessment of vanet multi-hop routing over an experimental platform. Int. J. Internet Protocol Technology 4 (2009)
8. Tsukada, M., Jemaa, I.B., Menouar, H., Zhang, W., Goleva, M., Ernst, T.: Experimental evaluation for IPv6 over VANET geographic routing. In: IWCMC 2010: Proceedings of the 6th International Wireless Communications and Mobile Computing Conference, pp. 736–741. ACM (2010)