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***Abstract*—The combination of geographic-based routing protocols (GeoNetworking) and IPv6 NEtwork MObility (NEMO) into a single communication architecture (IPv6 GeoNetworking) is key in Vehicular Ad-hoc Networks (VANET). While NEMO manages Internet access and session continuity between the vehicle and the Internet, geographically based data forwarding allows an efficient dissemination of the information between vehicles and the infrastructure. In this paper, we refer to the basic scenarios that led to the design of the IPv6 GeoNetworking architecture in the context of the GeoNet project. A prototype implementation of the modules that couple these two technologies is described, in particular the adaptation of IPv6 and C2CNet, a layer that ensures the geographic capabilities. Results of a light experimental performance evaluation are reported.**

I. Introduction

Intelligent Transportation Systems (ITS) gained a lot of attention in the past few years. New access technologies (i.e. 802.11p) saw the light in order to meet Vehicular Ad-hoc NETworks (VANET) needs such as highly dynamic topologies. Moreover, promising road safety, traffic efficiency and infotainment services have to rely on a network layer that could cover most of the communication scenarios and types which is a challenging target in VANETs. Vehicles are expected to transmit information to the surrounding vehicles as well as to the infrastructure and peers reachable in the Internet. This requires, on one hand, specific routing mechanisms to disseminate efficiently critical information in their direct surrounding and on the other hand the capability to maintain permanent Internet connectivity. Regarding the first point, location capabilities such as the Global Position System (GPS) have to be deployed in order to distribute data based on geographic routing decisions. For continuous Internet reachability, which is highly required for value-added services and usual Internet applications, IPv6 mobility support functions such as NEMO Basic Support (RFC 3963) are required. In this scope, coupling VANETs geographic-based routing (GeoNetworking) and NEMO into a single communication architecture supporting both scenarios is key. A mobile router embedded in the vehicle could then be used to maintain Internet connectivity for all in-vehicle nodes (navigation system, PDAs, etc.) while a VANET geographic routing protocol would allow communication with neighbor vehicles.

A few recent studies have dealt with the combination of VANET routing protocol together with NEMO. A mobile gateway allows the in-vehicle nodes reachability using a permanent prefix assignment. [1] explains how a mobile gateway could maintain multiple paths to the Internet and to the destination using a mobile ad-hoc (MANET) routing protocol and lists the advantages of using MANET and NEMO converged communication that allows fault tolerance and scalability. [2] presents experimental results of the cited concept by testing the simultaneous use of OLSR as a MANET routing protocol and NEMO in a vehicular communication through several access technologies and using specific routing policies. [3] analyses the requirements of an efficient communication in which NEMO complies with VANETs and points out the advantages of a MANET-centric approach that includes a reactive mechanism that manages the MANETs routes and can switch back to a NEMO route. In addition to the research studies, worldwide, many organizations and consortia work on the design of a communication architectures that consider NEMO as a protocol running on top of a VANET routing layer, for instance the ITS station architecture commonly specified by ETSI TC ITS [4] and ISO TC204 [5] and partly implemented in the CVIS project [6].

Among the above cited work and studies, few real experiments that couple NEMO and geographic-based routing decisions have been performed. This was actually achieved in the context of the GeoNet european project which specified and implemented a communication architecture combining IPv6 and GeoNetworking (IPv6 GeoNetworking) [7].

This paper thus presents work performed in the GeoNet project. Section 2 presents the reference architecture contributed by GeoNet. Section 3 explains the design and the implementation of the system. Section 4 reports the results of the experimental performance evaluation tests realized in our testbed. The last section summarizes and concludes this paper.

II. Reference system and architecture

Safety and non-safety applications should rely on a single communication architecture that is expected to provide both

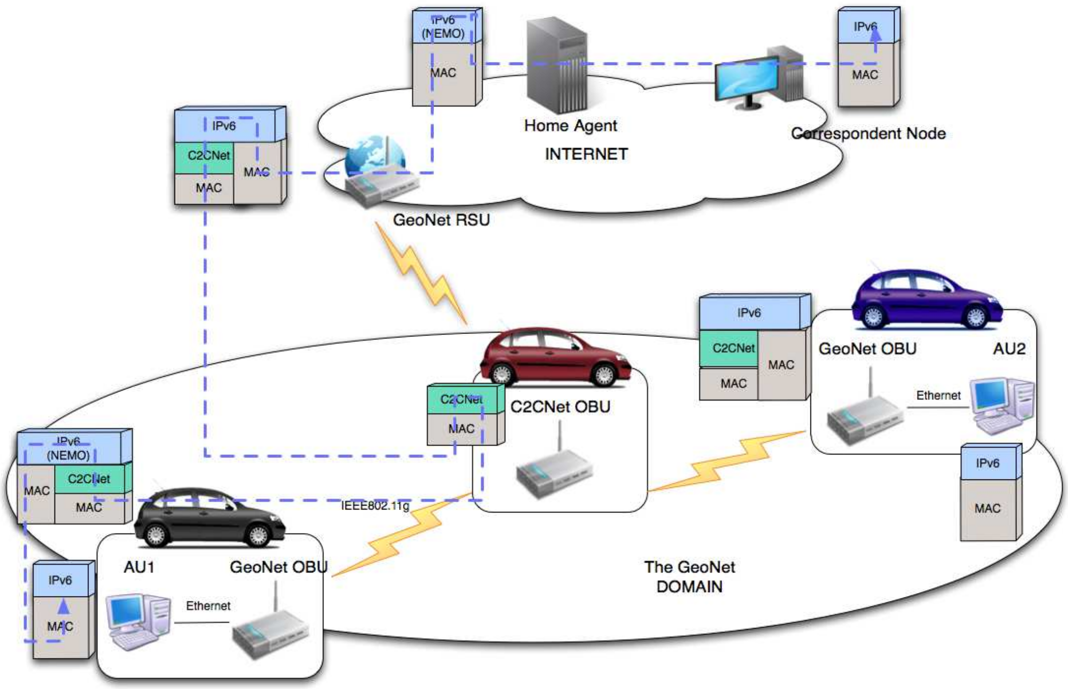

Fig. 1. Reference scenario and architecture

geographic-based routing functionalities and a continuous Internet connectivity. The standardization community, such as ETSI Technical Committee for Intelligent Transport Systems (ETSI TC ITS) in Europe is defining an ITS communication architecture (known as the ITS station architecture, developed in cooperation with ISO TC 204) which covers most of the communication scenarios. Especially when the vehicle has to communicate with the infrastructure compulsorily. Particularly, the GeoNet european project[1] focused on such communication scenarios including the infrastructure. It aimed at combining Internet Protocol Version 6 (IPv6) features with geographic routing capabilities for VANETs into a single communication stack, referred to as IPv6 GeoNetworking and detailed in [7]. [8] provides further information on the motivation for combining IPv6 with GeoNetworking.

As a part of the IPv6 GeoNetworking architecture, the C2CNet layer capabilities, designed in the frame of the Car-to-Car Communication Consortium[2] (C2C-CC) are combined with IPv6 in order to enable Vehicle-to-Vehicle, Vehicle-to-Infrastructure and Internet-based communication. Three types of nodes are considered in the architecture: GeoNet OBU embedded in the vehicle, GeoNet RSU (Access Routers) deployed on the roadside infrastructure and other IPv6 nodes running GeoAware applications. Only GeoNet OBU and GeoNet RSU comprise the C2CNet layer capabilities; they are forming a GeoNet domain, that may comprise nodes implementing the C2CNet layer capabilities but not IPv6 (C2CNet nodes). The GeoNet OBU (On Board Unit) is an IPv6 Mobile Router (MR) connecting the in-vehicle network to other vehicles, the roadside infrastructure or the Internet. The GeoNet RSU (Road Side Unit) is an IPv6 Access Router (AR) connected to the roadside infrastructure network and providing Internet access to the OBUs in its communication range.

In this paper, we consider two basic scenarios. The first one is when classic Internet services (e.g. infotainment, video-on-demand or weather status information) are used. In this case, the vehicle has to communicate with some stationary nodes in the Internet. As shown in Fig.1, the packets are sent from the IPv6 node attached to the GeoNet OBU. The OBU implements NEMO Basic Support (NEMO BS) to maintain its reachability in the Internet when moving from one network to another. By means of the Neighbor Discovery Protocol [9], the GeoNet OBU can select the access router to which it has to deliver each packet destined to the Internet. The packets are then forwarded on the C2CNet link. Intermediate C2CNet nodes relay the packet at the C2CNet layer until it reaches the GeoNet RSU (next IP hop from the GeoNet OBU) which forwards them to the Home Agent (HA). The HA routes them to the destination node. In the second scenario, a vehicle is expected to send alerting messages to other surrounding vehicles whenever it detects a road traffic hazard. One of the common cases to consider, is when the vehicle has no reachability with other vehicles. In this case the safety information has to be sent through the infrastructure to a control center or directly to the other vehicles belonging to the same geographic area (i.e. the same highway). The following sections give more details

[1]EU FP7 GeoNet european project: http://www.geonet-project.eu
[2]C2C-CC: http://www.car-to-car.org

about the C2CNet layer functions, The NEMO BS and the Neighbor Discovery Protocol.

A. The C2CNet layer concept

C2CNet is a communication layer that enables geographical addressing and routing. C2CNet includes position-based routing mechanisms adapted to vehicular communications. The Greedy Perimeter Stateless Routing (GPSR) [10] algorithm has been adopted. It benefits from the reactive approaches of GeoRouting in wireless networks where the route determination is initiated on demand. GPSR is based on the greedy forwarding decisions using only information about immediate neighbors in the network topology. C2CNet defines a new network header (see Fig.2) which carries the C2C identifier (C2CNet ID) of the source and the destination and their geographic locations. Each node in the vehicular ad-hoc domain is addressed by a unique C2CNet ID that it exchanged between one vehicle and its neighbors. Thus, the routing decision is based on geographic location of communication peers, source, destination and intermediary nodes.

Fig. 2. GeoNet packet encapsulation

B. Network mobility support using NEMO Basic Support

NEMO Basic Support allows on one hand all IPv6 nodes deployed in an in-vehicle network to be reachable at a permanent address, and on the other hand maintains Internet connectivity and open sessions over subsequent points of attachment to the network. Since a vehicle may have Application Units (i.e. IPv6 in-vehicle network nodes or MNNs in NEMO jargon) attached to the GeoNet OBU, network mobility support is essential. The GeoNet OBU is serving as an Pv6 Mobile Router (MR) and manages mobility of the entire in-vehicle network. MNNs can benefit from this feature without any specific support, which means that any node equipped with an IPv6 stack can be attached in the in-vehicle network and engage into Internet-based communications. In order to be reachable at a permanent address, an address configured from a common prefix (MNP) must be allocated to the MR and on all its attached nodes. This is where the operation of NEMO Basic Support takes place. The MR is sending a message (Binding Update registration) to its Home Agent (HA) located in the home network. This message contains the transient address (Care-of Address, abbreviated to CoA) configured on the egress interface of the MR, therefrom instructing the HA to redirect to the CoA all packets addressed to an address part of the MNP. As a result of the Binding Update registration, the HA and the MR establish a NEMO IP-in-IP tunnel in which all packets between a MNN and their correspondents in the Internet (CNs) are encapsulated. This tunnel has to be updated each time a new CoA (with global reachability) is configured on the egress interface.

C. The Neighbor Discovery Protocol in GeoNet

Each C2CNet egress interface of a GeoNet OBU (MR) or a GeoNet RSU (AR) must be configured with two different IPv6 addresses: a link-local address and a global address. All GeoNet nodes attached to the same IPv6 C2CNet link should be reachable using both addresses. The global address must be used when trying to reach other nodes not directly attached to the C2CNet link (i.e. nodes on the global Internet as well as nodes attached to the GeoNet OBUs and GeoNet RSUs). The mechanism used to configure the IPv6 C2CNet egress interfaces of GeoNet OBUs in an automatic way is based on the IPv6 Stateless Address Autoconfiguration protocol specified in RFC 4862 [9]. This protocol basically enables a host to generate its own addresses using a combination of locally available information (interface identifier part of the address) and information advertised by routers (prefixes that identify the subnets associated with a link). The concept used in GeoNet is the same: GeoNet RSUs advertise the prefix information by sending Router Advertisements, and the GeoNet OBUs use that prefix information and their C2CNet IDs, to generate a valid global IPv6 address assigned to the C2CNet egress interfaces. A link-local address is also generated on the C2CNet egress interface, using the same C2CNet interface identifier and the link-local IPv6 prefix (FE80://64). A prefix length of 64 bits is used and thus the length of the C2CNet ID is 64 bits. IPv6 multicast packets produced by Neighbor Discovery, i.e. the all-nodes multicast address (FF02::1) and the all-routers multicast address (FF02::2) are mapped to a geographic area of delivery (GeoDestination) when transmitted to the C2CNet layer. Since Router Advertisements are typical IPv6 multicast packets, they are encapsulated at the C2CNet layer and forwarded as GeoBroadcast within a well delimited geographical area. The GeoDestination of the Router Advertisement is set up at the C2CNet level.

III. Design and implementation

To test our contribution, we have implemented and integrated our work to Hitachi's C2CNet layer which was implemented within the GeoNet project. This C2CNet layer implementation is also used in other research projects, such as PRE-DRIVE C2X [3]. The specifications that have been used as basis in ETSI TC ITS standards are also inline with the V2X standard drafts. In GeoNet, modules and Service Access Points (SAPs) between layers have been defined. In this paper, we focus mainly on the C2C-IPv6 SAP between the IPv6 and C2CNet layers. The whole system is implemented in linux based on the 2.6.29 kernel version. The main modules involved are:

- **The C2CNet module** which implements the geographical routing functionalities as explained in the above section;

[3]EU FP7 Project PRE-DRIVE C2X: http://www.pre-drive-c2x.eu

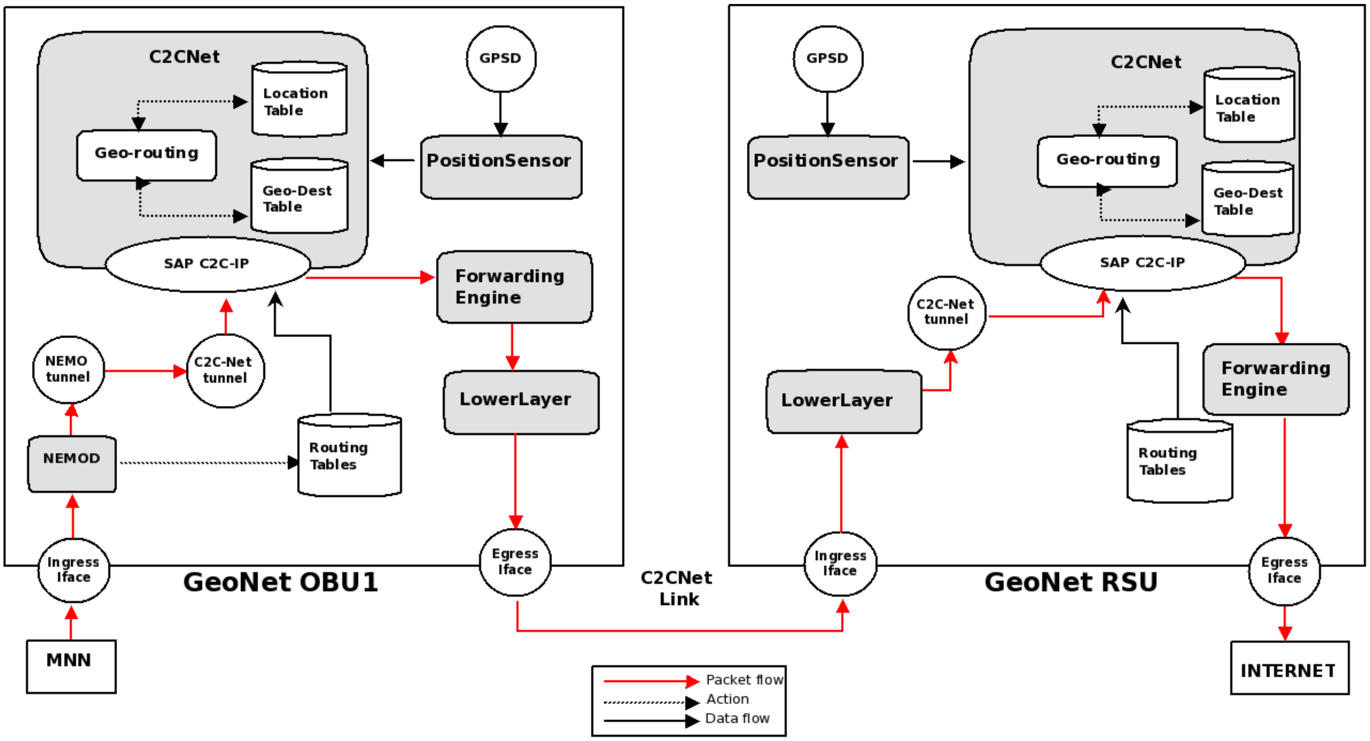

Fig. 3. Implementation of IPv6 over C2CNet

- **The PositionSensor module** which provides geographical coordinates to the On-Board-Unit through GPS;
- **The Lower Layer module** whose role is to adapt the C2CNet to the MAC layer;
- **The Service Access Point between the IPv6 layer and the C2CNet layer** that performs the transmission and the encapsulation of the IPv6 packets through the C2CNet link.

As C2CNet is implemented in the user space, a virtual interface is used to deliver packets from IP layer implemented in kernel space to the C2CNet module. We used the NEPL [11] implementation of NEMO which is installed in OBUs as well as in the Home Agent. The radvd [4] software is installed in both the RSU to enable Router Advertisement in the GeoNet domain and in the OBU to advertise the in-vehicle prefix in the in-vehicle network. We used the madwifi driver for our Atheros cards in the 802.11g standard. Applications providing HMI to the users in the in-vehicle network are running in the nodes attached to the OBU. Once the virtual interface is up, it gets a link local address built from the FE80::/64 prefix and the C2CNet ID of the OBU. A patch is developed for NEMO to allow OBUs to configure their CoA using the C2CNet ID. This implementation is necessary to enable IPv6 address autoconfiguration using the C2CNet ID instead of the MAC address. The Binding Update refresh time is set up to 15 seconds. When RSU sends a Router Advertisement, it uses the multicast address ff02::1 (the all-node link local address). The RA packets are then GeoBroadcasted in an radius area of 500m from the RSU. OBUs receive the RA and update their routing tables setting the link local address of the RSU as a default gateway address. They also autoconfigure their CoA using the prefix advertised in the RA packet. The Correspondent Node traffic is encapsulated first into the NEMO tunnel and then into the C2CNet tunnel. Fig.3 illustrates the internal functioning of the GeoNet implementation. When an Application Unit (AU) sends a packet to the OBU, the NEMO daemon intercepts the packet, encapsulates it into the NEMO tunnel and sends it to the C2CNet virtual interface. The C2CNet layer, listening on the tun0 interface, gets the packet, executes the routing algorithm based on the previous knowledges of its neighbors, decides where to send the packet and then forwards it locally to the lower layer. The lower layer sends finally the packet on the wireless link. A new ethernet type for the C2CNet header is defined to allow its encapsulation into the MAC header.

[4]Linux Router Advertisement Daemon: http://www.litech.org/radvd/

IV. Tests and Evaluation

A. Evaluation environment

IPv6 GeoNetworking is evaluated in the indoor testbed. The indoor test environment is designed to evaluate the pure performance of IPv6 GeoNetworking avoiding interferences due to unexpected radio perturbations and difficulties to trace the movements of the GeoNet OBUs. The scenario is shown in Fig.4. The GPS data is not obtained from actual GPS device but is statically recorded in a configuration file. The advantage of this method is that the same test scenario can be repeated several times with various parameters. The traffic is generated

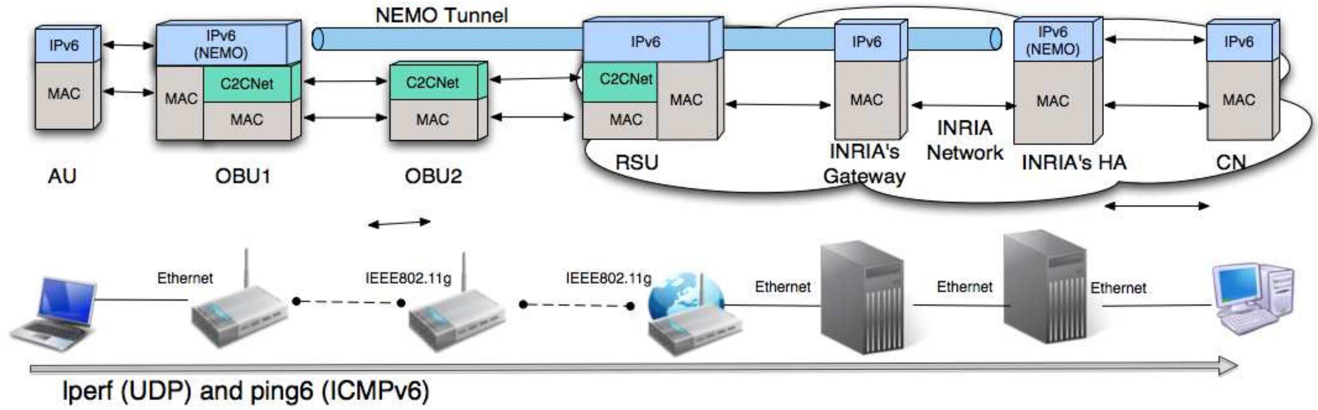

Fig. 4. Network configuration of the indoor test

by the iperf tool. The two communication end-points are one AU attached to the GeoNet OBU that sends the traffic to be evaluated and a Correspondent Node, considered to be located in the Internet. In these tests, packets transit via the Home Agent. We evaluate two types of traffic: i) UDP traffic which is a unidirectional transmission flow from the source to the destination end-nodes where the considered metrics are the packet loss rate and the throughput, and ii) ICMPv6 traffic which is a bi-directional communication flow between the two end-nodes where the considered metrics are RTT and the packet loss rate.

B. Latency evaluation

To evaluate the latency, we measured the Round Trip Time between the two end-points. The AU sends ICPMv6 Request every 0.1 second. The ICMPv6 packet is increased by 20 bytes. The packet size is varying from 20 bytes to 1500 bytes. From the obtained results, we extract the maximum, the minimum and the average RTT as well as the packet loss for each packet size. A previous evaluation of IPv6 over C2CNet is already presented in [12] which doesn't include the use of NEMO. As depicted in Fig.5, we evaluate the average RTT between the Correspondent node and the GeoNet Mobile Router and the packet loss. The maximum RTT is around 110 ms which corresponds to the maximum packet loss (45 percent) for 420 bytes of packet size. As we can see in Fig.5, packets with size exceeding 1300 bytes cannot be delivered by C2CNet due to the MTU of the packet. At the time of writing this paper, the packet fragmentation operation was not yet implemented in the C2CNet layer.

C. Packet delivery ratio and bandwidth evaluation

In this tests, we evaluate the packet loss ratio in a UDP communication. The packet delivery ratio is the percentage of packets arriving at the receiver divided by the packets sent by the sender. The UDP packets are generated in the AU attached to the OBU, sent through the C2CNet link to the HA and finally to the Correspondent Node. The sender sends UDP packets to the receiver with fixed rate. The UDP client

geographical routing.

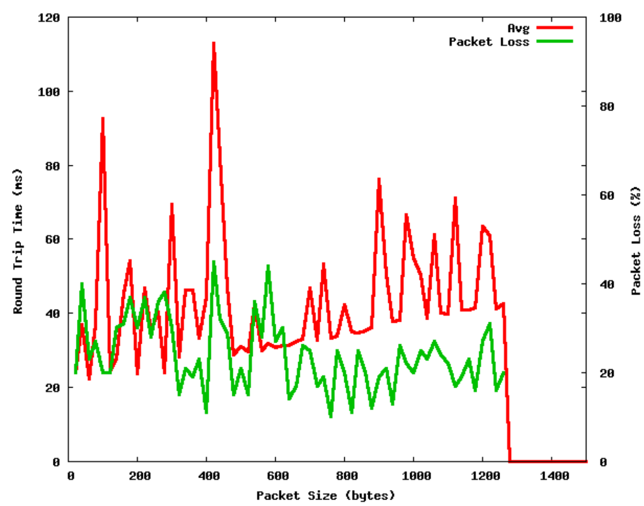

Fig. 5. RTT between AU and CN

and server save the log file traces. After the tests, the log files of both the client and the server are parsed through pointers (the port number) and the packet loss results are plotted. In these tests, the bandwidth is varying from 1 to 6 Mb/s. For each bandwidth value, the read-write buffer is increased from 20 bytes to 1900 bytes. The throughput is shown on the receiver side. As illustrated in Fig.6, when the packet has a small size, the packet delivery ratio is weak. The best values are obtained when the packet size is between 800 and 1300 bytes for the lowest sending rate; when the bandwidth is 1 M and the packet size is 1300 bytes, the packet delivery ratio is almost 100 percent. The maximum throughput is around 2500 Kbits/second. It reaches its maximum when the packet size is 1300 bytes packet. It corresponds to a 5M sending rate.

Fig.7 presents the measured throughput in the network.

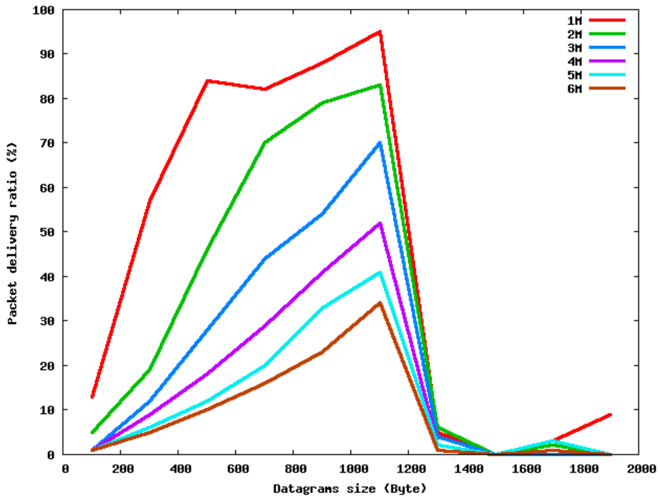

Fig. 6. Packet delivery ratio between AU and CN

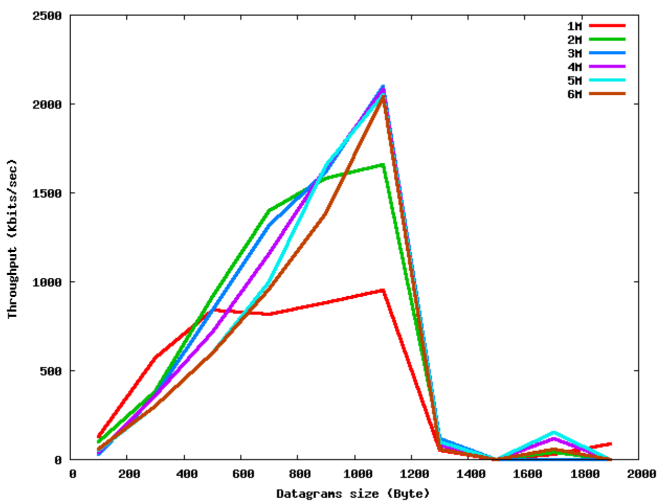

Fig. 7. Network throughput between AU and CN

D. *Result interpretation*

Sub-optimal routing is caused by the packets being forced to pass via the HA. This leads to performance degradation due to increased delay and is undesirable for some applications. Packet Encapsulation of additional 40 bytes header increases packets overhead and may result into packet fragmentation. This turns the results into an increased processing delay for every packets being encapsulated and decapsulated in both the GeoNet OBU and the HA. Bottlenecks in the HA are a severe issue because significant traffic to and from MNNs is aggregated in the HA when it supports several GeoNet OBUs acting as gateways for several MNNs. This may cause congestion at the HA that would lead to additional packet delays, or even packet losses. This issue is subject to bringing further enhancements to this specification (Route optimization solutions) although it is not peculiar to IPv6 GeoNetworking.

V. Conclusion and Future Work

This paper shows how network mobility support capabilities using NEMO Basic Support can be combined with the GeoNetworking capabilities offered by the C2CNET sub-layer. We performed validation tests on our in-door testbed. The results show that a route optimization solution is highly required to resolve the performance issues and bottleneck in the Home Agent. As a future work we plan to conduct field tests with real vehicles and realistic mobility scenarios. Regarding the C2CNet layer implementation, further enhancements are required to avoid the packet processing performance issues.

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