An IPv6 Architecture for Cloud-to-Vehicle Smart Mobility Services over Heterogeneous Vehicular Networks

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***Abstract*—In this paper, we provide the specification of a cloud-initiated Point-of-Interest (PoI) application, and illustrate its requirements for a convergence between IPv6 mobility management and Dedicated Short Range Communications (DSRC) geographic services. We propose to extend a flat IPv6 mobility management architecture with a new functional block, namely LIMME (Location & Infrastructure Mobility Management Entity), composed of three key functions: a Location Manager (LM) acting as location anchor point for cloud-based services, a Geographic Mobility Management (GMM) function acting as location proxy for the LM and handling IPv6 mobility, and an Infrastructure Node selector, which selects a route based on geographical data and local infrastructure node conditions. As a proof-of-concept, we implemented these extensions on the iTETRIS ITS simulation platform and illustrated their benefits in enhanced IPv6 mobility management and traffic offloading.**

I. INTRODUCTION

Connected vehicles in smart cities of the future are envisioned to provide passengers with a wide range of services to facilitate their traveling experience. Such services will range from safety warnings and traffic information to mobility and comfort (infotainment) applications. In order to be able to host such services reliably, two basic requirements need to be fulfilled: *continuous connectivity between vehicles (V2V) and the Cloud (V2C)* and *efficient data load management*. To satisfy those two requirements, it is necessary to exploit connectivity through Heterogeneous means (e.g. big cells for high connectivity vs small cells for high throughput, or Cellular based 3G/LTE vs DSRC access). Moreover, Infrastructure Nodes (IF-Nodes) connected to vehicles have to be utilized efficiently in order to avoid bottlenecks and to reduce handovers latency. IPv6 is a natural choice to this objective, as it can natively operate over heterogeneous technologies and has a proven record of efficient Internet traffic flow management.

Whereas some cloud-based services could generate intensive traffic streams (CCTV, major software updates, voice), most of the cloud services for smart mobility will bear resemblance with MTC (Machine-type communications): low individual volume, periodic traffic, large *aggregated* traffic to a large amount of vehicles. The two major differences from traditional MTC are first that such cloud-based services will generate *downlink traffic* rather than uplink, and second that these services will have a limited geographical scope. The connectionless character of such services sets the ground for creating flexible and transparent traffic offloading mechanisms among the IF-Nodes which can provide Internet access to the vehicles.

In this context, IPv6 mobility management solutions through Heterogeneous Networks need to be adapted. First, the convergence of DSRC and cellular technologies require an adapted IPv6 addressing scheme. Unlike cellular technologies, vehicles may be simultaneously connected to several Roadside Units (RSUs). Considering RSUs acting as IPv6 routers [1] creates the necessity of concurrently handling multiple vehicles IPv6 addresses (associated with multiple technology interfaces) and makes hierarchical IPv6mobility management (e.g. [2], [3]) solutions inefficient.

Second, hierarchical IPv6 mobility management functions are designed to optimize handover for connections that need to remain active for long intervals. Multipath TCP (MP-TCP) [4] is another approach to manage handovers and handle traffic offloading among its active flows efficiently. In [5] and [6], MP-TCP is proposed for vertical handovers among distinct technology interfaces. Yet, both hierarchical IPv6 Mobility Management and MP-TCP have been designed for cases when the active connection is long enough to justify handling handovers or maintaining multiple paths to the destination host. This does not hold for POI (MTC-like) traffic, where we are rather dealing with small bursts, as mentioned before. As a result, applying these approaches for POI traffic implies generating redundant overhead and signaling delay for short effective communication time. On the other hand, the fact that each vehicle can be accessible through multiple IF-Nodes at the same time broadens the capabilities for optimal per-packet dynamic traffic offloading among the IF-Nodes. In this context, the availability of updated geo-based information related to the vehicles can be of significant importance for this process.

Flat IPv6 architectures (e.g. Distributed Mobility Management (DMM) [7], Proxy DMM[8]) aim to overcome the weaknesses of architectures organized in multiple routing hierarchical levels (i.e. signaling overhead with centralized mobility anchor, non-optimal routing), by increasing direct communication among peers residing in the same geographical area [9]. However, such architectures are optimized for traffic initiated by the mobile node. Cloud-based services initiate traffic from the cloud, and the absence of a centralized *Home*

Agent makes it difficult for cloud services to efficiently locate the target MN.

In this paper, we propose an extension to flat-based IPv6 mobility management architectures to be adapted to cloud-initiated services over heterogeneous IF-nodes. We first formulate the specifications of a Point-of-Interest (PoI) application, periodically transmitting personalized information (e.g. public transportation info, car sharing, advertising and booking parking places and/or Electronic Vehicle charging spots etc.) to target vehicles. We then describe the new functions required to handle this application, namely LIMME *Location and Infrastructure Mobility Management Entity*, residing at the network Edge and consisting of three blocks: a Geographic Mobility Management (GMM) module, a location database mapping the MN IDs to the last known geographic locations and IPv6 address. Finally, an *IF-Node selector* to provide traffic offloading and optimize the communication capacity. As proof-of-concept, we implemented the required modules and extensions on the iTETRIS simulation platform [10] and illustrated their role in improved IPv6 mobility management over heterogeneous vehicular technologies.

The rest of the paper is organized as follows. In section 2, we show the logic of our Point of Interest Application. In section 3, we discuss the requirements of the service. In section 4, we present our Network Architecture and its benefits. In section 5 we introduce the iTETRIS Architecture and the required extensions in Network Simulator (NS-3). In section 6, we show our proof-of-concept results on a basic scenario and in section 7 we highlight the conclusions of this work and our future steps.

II. THE POINT OF INTEREST CLOUD APPLICATION

The Point of Interest Application aims at providing an example of regional infotainment services which are offered to the set of vehicles entering the given region. The driver has the option to accept or decline the offered service and, once he accepts it, he starts receiving the data of this service periodically until he gets out of the region or he decides to stop the service.

This simple functionality is based on the exchange of three different types of messages between the Vehicles and the Infrastructure nodes (Wave RSUs or Cellular Base Stations):

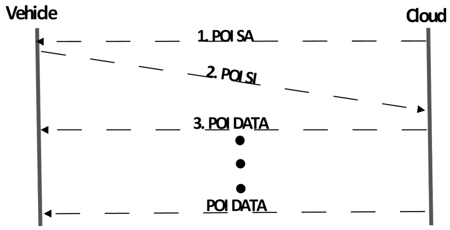

Fig. 1: POI App messages exchange

- **POI Service Advertisements (POI SA):** As the term indicates these messages are broadcasted periodically by the Infrastructure nodes (IF-Nodes) which cover a target geographical area, in order to advertise the offered service to the passing vehicles.
- **POI Service Interest (POI SI):** These Unicast messages are generated from the vehicles as a result of the reception of the Service Advertisements in order to subscribe to the specific service.
- **POI Service Data (POI DATA):** After receiving the Service Interest from a given vehicle, the Cloud starts generating Unicast Data messages for the subscribed vehicle periodically.

III. POI SERVICE REQUIREMENTS

POI services constitute a family of applications which balance between their usefulness in a local scope and their need for Internet connectivity. We will now introduce the requirements of our envisioned service (Fig.2).

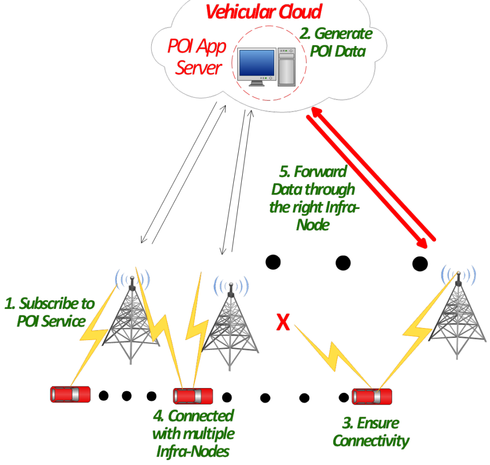

Fig. 2: POI service requirements

1) **On-demand service provision**. The vehicle will trigger the transfer of periodic service data by indicating to the Cloud its interest for the service.
2) **Periodic but independent data transmissions from the Cloud**. No need to provide support for continuous sessions and maintain active routes open is needed and, as a result, no need for traditional means of handovers. Thus, the traffic type resembles M2M but it comes from the Cloud not from the connected vehicles.
3) Our basic performance criterion is to **maintain connectivity** through some IF-Node during any data transfer.
4) **Vehicles can be connected to multiple IF-Nodes** even through the same technology interface (DSRC allow this, as the mobile nodes do not have to be part of a Basic Service Set (BSS)). As a result, vehicles can have multiple IPv6 addresses per interface at the same time.
5) Cloud to Vehicle (C2V) **traffic should be forwarded through the most appropriate IF-Node**, in terms of optimizing traffic load management.
6) **Localization services should converge with IPv6 operations** in order to provide IPv6 addressing and scalable Mobility Management services.

Concerning IF-Node selection at the downlink, it should be based on Lightweight local (channel load, CQI) or geographic (location, distance) metrics at IF-Nodes, rather than on testing single links quality between the IF-Nodes and the attached vehicles (changing very frequently with mobility, requires signaling overhead). Finally IPv6 Mobility Management should avoid the inefficiencies of centralized approaches such as MIPv6 [3] and Proxy MIPv6 [2] (e.g. long routing paths, signaling overhead, scalability issues etc.). The use of independent sessions implies that a **Distributed Mobility Management (DMM)-like approach** is more appropriate [9], [7].

IV. NETWORK ARCHITECTURE

Based on the aforementioned requirements, we need a mechanism to select the best IF-Node for the downstream traffic from the Cloud, as well as a function which complements IPv6 addressing with location services in order to ensure IPv6 connectivity from the Cloud. In this context, our Architecture introduces the Location Infrastructure and Mobility Management Entity (LIMME), a new block which is located at the Edge of the Network, directly connected with the IF-Nodes of a given region where the POI service is offered. As the name indicates, this entity performs three basic functions namely, **Location Management**, **IF-Node selection** for data forwarding and **IPv6 Geographic Mobility Management (GMM)**. A high level view of these functions and the way they interact to handle cloud-originating IPv6 traffic efficiently is shown in Fig. 3. IPv6 GMM provides the Location Management block with updated **Geographic Address Set (GAS)** information for the subscribed vehicles. This information is then queried by the IF-Node selector, based on the destination vehicle's IPv6 Home Address (HoA) [1] and utilized on the data plane to route IPv6 traffic through the appropriate IF-Node. We will now describe the roles of the separate LIMME functions in more detail.

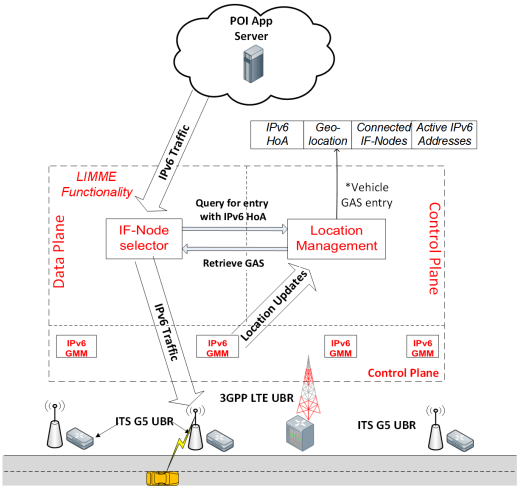

Fig. 3: POI App supporting Architecture

A. *Location Management*

The role of the Location Management function is to ensure that every subscribed vehicle can be tracked and accessed by LIMME through the IF-Node to which it is connected.

For DSRC, this functionality can be based on periodic Beacons broadcast by the vehicles via their C2C stack [2], where they report their geo-location to their neighbors (other vehicles and RSUs). Upon subscription to the POI Application, vehicles Location Updates (LUs) are periodically communicated to LIMME through their neighboring RSUs (see (c) and (g) in Fig. 4). LIMME's Location Management block then updates its database with the vehicle's most recent GAS information. As shown in Fig. 3, GAS includes information about: the vehicle's location, its IPv6 HoA, its neighbor IF-Nodes (location, IPv6 address), as well as its active IPv6 addresses. As we will show next, these addresses are obtained through the interaction with the IPv6 GMM block.

For Cellular coverage, location management can be based on Base Stations reporting the attached vehicles which are registered to the service. Although precise geographical information about the vehicle cannot be extracted in this case, this report is adequate to indicate to LIMME that the subscribed vehicle is reachable through cellular infrastructure.

As depicted in Fig. 3, Management plane traffic (i.e. Location Updates) is in the uplink between the IF-Nodes and the Location Management. Given that such information is useful only for vehicles which have subscribed to the given regional service, the transferred information will concern those vehicles only, thus limiting the traffic on the uplink. This approach has also a low overhead, as the limited geographical scope of the service implies that only a limited set of IF-Nodes is expected to update MN locations at a time.

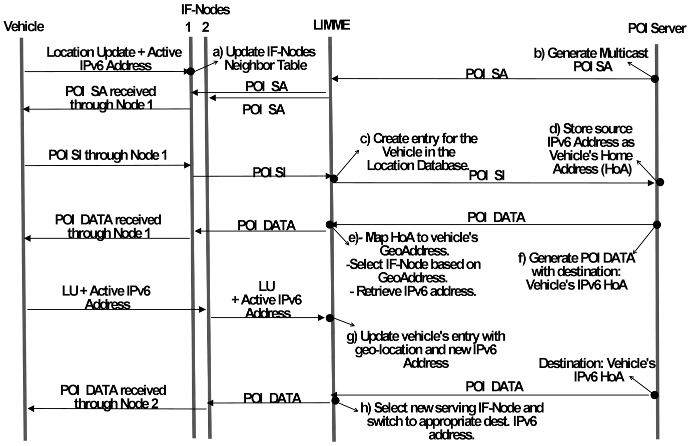

Fig. 4: LIMME Functionality

B. *IPv6 Geographic Mobility Management (GMM)*

The role of the IPv6 GMM function of LIMME is to extend the access to the vehicle nodes, from the Cloud at any point in time.

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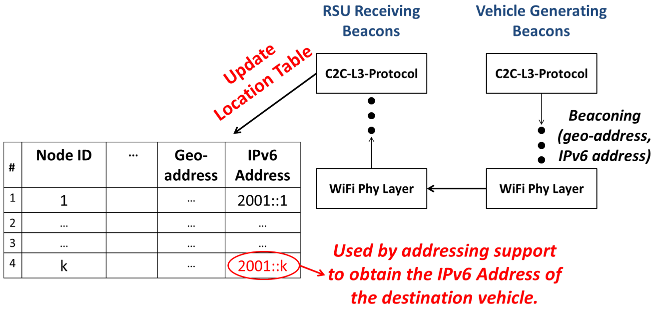
[1] By IPv6 HoA we indicate the initial IPv6 address with which the vehicle is subscribed to the service.

[2] C2C stack refers to the ETSI Geo-networking non-IP stack.

In our Architecture, every RSU or Cellular Base station acts as an IPv6 router which advertises its prefix and allows each passing by vehicle to autoconfigure a new global IPv6 address [11]. In that sense the Architecture is flat and it bears similarities with DMM [7]. In order to ensure connectivity with the Cloud, we extend our Location management function with IPv6 addressing support capabilities.

For DSRC this task is done in two steps. The first step concerns the Vehicle to IF-Node (V2I) plane and it dictates that the Location Management Beacons should be enriched with IPv6 addressing information. In this way, every IF-Node receiving Beacons can obtain IPv6 reachability information about the neighbor vehicles (see (a) from Fig. 4).

To this direction, we suggest an extension which is based on the operation of the C2C stack (Geonetworking). Every node keeps a location table where it stores the information provided by the Location Management beacons about the other nodes. We suggest the enhancement of this information with the IPv6 addresse(s), attributed to the DSRC interface of each transmitting vehicle, as shown in Fig. 5.



#	Node ID	…	Geo-address	IPv6 Address
1	1		…	2001::1
2	…		…	…
3	…		…	…
4	k		…	2001::k

Fig. 5: IPv6 address retrieval through the C2C stack

The second step refers to the Infrastructure-to-LIMME plane and it is common among DSRC and cellular IF-Nodes. Based on this, every GAS update in LIMME's Location Management block includes IPv6 addressing information about the vehicle (see (g) from Fig. 4).

C. IF-Node selection

The IF-Node selection block is responsible for choosing the most appropriate IF-Node for a given POI Data transmission.

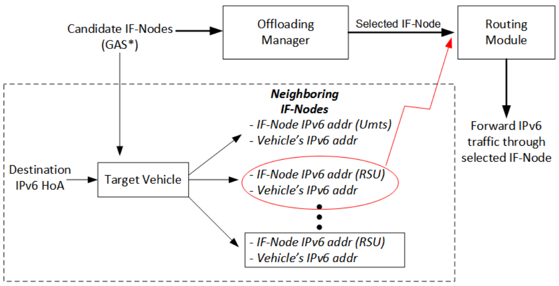


Fig. 6: IF-Node selection functionality

Figure 6 depicts the flow diagram for IF-Node selection. GAS information provided through the interaction with the Location Management Block specifies the set of candidate IF-Nodes to route the traffic through at each transmission. The Offloading Manager then picks the best candidate based on geographical context information retrieved through GAS (see (e) and (h) from Fig. 4), as well as other information provided by the IF-Nodes of the Application region. Such information can consider the minimum distance of the vehicle from the IF-Nodes of the area, as well as metrics extracted by the IF-Nodes (e.g. channel load for DSRC, Channel Quality Indicators (CQI) for cellular etc.), without the need of any additional management plane signaling which could create overhead.

The role of the routing module is to forward the traffic through the selected IF-Node, by mapping the vehicle's IPv6 HoA to the one with which it is accessible through the selected IF-Node (see (e) and (f) from Fig. 4).

V. IMPLEMENTATION

We extended iTETRIS vehicular simulation platform to support our suggested Architecture and our POI Application logic. As proof of concept, we implemented the LIMME functionality and the POI Application on a synthetic scenario.

A. *iTETRIS Simulator and Contributions*

iTETRIS [10] is a platform for vehicular communication simulations which permits to define large scale realistic road and network traffic scenarios and simulate them through the integrated Network Simulator NS-3 [12], the road traffic simulator SUMO [13] and an application module. One of the main assets of iTETRIS is that it provides, through its control system (iCS), the capability of bidirectional interactions between its Network and Mobility Simulator. The application block specifies the logic of different smart mobility applications.

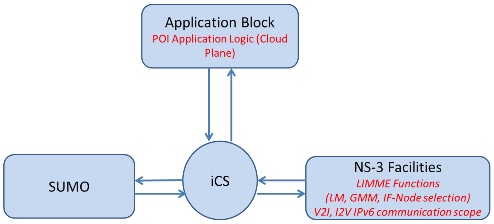


Fig. 7: Placement of Architecture and POIApp modules in iTETRIS

In Fig. 7 we summarize the placement of our extensions within the iTETRIS simulator. In the Application block we implemented the POI Application logic discussed in II. In this context, the Application Block represents the Cloud plane for our simulations. In the NS-3 block, we implemented all the IPv6-related communication extensions needed to support our Architecture.

B. *NS-3*

iTETRIS uses an extension to the standard version of NS-3, which supports a socket interface with iCS, and includes an ETSI compliant ITS-G5A interface and an implementation of the geonetworking (C2C) stack, compliant with the ETSI Architecture [14]. Figure 8 summarizes the ITS-related extensions, including the extended functionalities for LIMME.

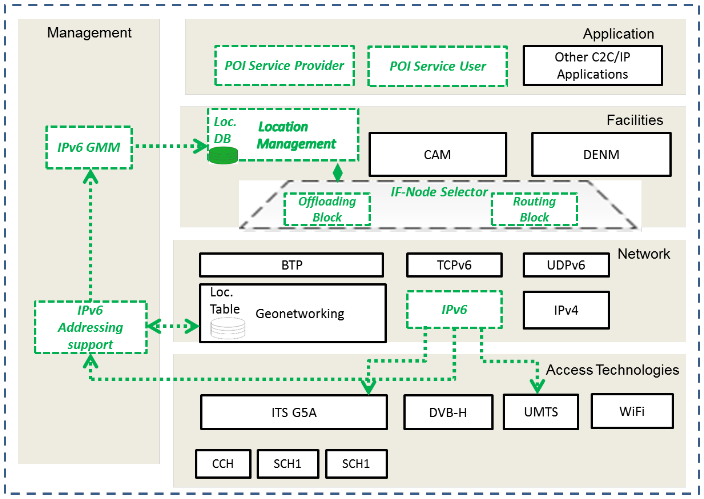


Fig. 8: NS-3 ITS extensions

1) Network block contributions: We extended the iTETRIS version of NS-3 with an IPv6 stack, which can ensure traffic offloading between cellular and DSRC communications, in a transparent way to the Cloud-based POI Application. In this context we had to extend the DSRC equipped nodes (i.e. vehicles and RSUs) with IPv6 addressing and routing capabilities, in the way that we described in section IV-B.

2) Facilities and Management block contributions: These two blocks were extended to implement the functionality of the LIMME entity. Particularly, they are responsible for retrieving GAS information about the target vehicles, selecting the most appropriate IF-node for each POI DATA transmission and providing IPv6 reachability towards the target vehicle through the selected IF-Node. The extensions pertain also to IPv6 interoperability with the Management functions of different technology interfaces (i.e. DSRC, UMTS).

VI. SIMULATION RESULTS

For our simulations we launch an urban scenario where vehicles equipped with both UMTS and DSRC interfaces cross a straight road 1km long covered by 1 UMTS BS, which complements the coverage of 2 RSUs that provide only partial coverage in the area (Fig. 9). In this region the POI service is available through the residing IF-Nodes and for every vehicle that is subscribed to the service, autonomous POI Data are generated from the Cloud.

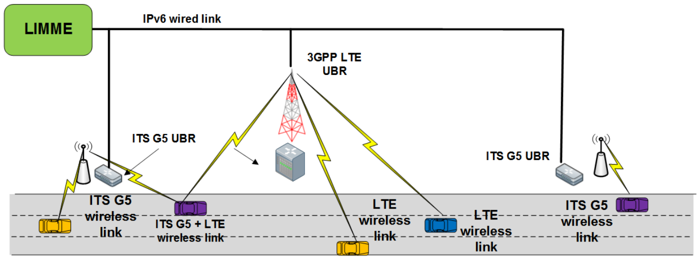


Fig. 9: Heterogeneous scenario

The selection among different technologies and IF-Nodes to forward the C2V traffic through is done by the LIMME, based currently on the following algorithm:

Algorithm 1 IF-NODE SELECTION

```
Retrieve set of neigbor IF-Nodes
if (#of IF-nodes == 1) then
    Select this node
else if (#of IF-nodes > 1) then
    if (All IF-Nodes are of the same techno) then
        Select the one with minimum Euclidean distance from the vehicle
    else
        Select the RSU with minimum Euclidean distance from the vehicle
    end if
end if
```

The capacity of cellular networks strongly depends on the number of connected nodes. In this context, the aim of traffic offloading is to maintain this capacity functional, regardless of the node density. In the following, the impact of vehicle density is evaluated. Our performance metrics are: the POI DATA Packet Delivery Ratio (PDR) and the Average Delivery Delay (ADD).

We introduced vehicle fleets of 5, 10, 20 and 30 vehicles for an Heterogeneous (2 DSRC RSUs, 1Umts BS available) and an Homogeneous scenario (2 DSRC RSUs available). The set of the simulation parameters is summarized in table I.

Parameters	Values
Number of Vehicles	5,10,20,30
Number of Umts BS	1
Number of RSUs	2
RSU Inter-Distance	350 m.
Packet Size	1000 Bytes
Number of Umts BS	1
Vehicular Speed	20 m/sec
Packet Generation Rate	1 pack/sec/vehicle
Data Rate on ITS-G5	6 Mbps
POI Penetration	100 %
ITS G5 Penetration	100 %

TABLE I: Vehicular Density simulation parameters

The obtained results are depicted in Fig. 10 and 11. In terms of PDR, we can see the benefit of using Heterogeneity, as the performance for the respective scenario is constantly above the Homogeneous one. This is explained by the full communication coverage provided when the Umts BS is present. However, we notice that there is significant performance degradation for the Heterogeneous case, as we increase the number of vehicles. This is due to the limited number of data flows that are allowed to run concurrently within a Umts Base station. Particularly, as we increase the number of vehicles, we also increase the number of flows that should be supported from the Umts BS. However, due to a limit on the amount of data flows that can be handled concurrently by the BS, only a portion of vehicles can receive messages through the Umts interface. On the other hand, for the Homogeneous case the performance is stable for 10,20 and 30 vehicles, while quite improved for 5 vehicles.

In terms of ADD, we can once again view the impact of Umts configuration restrictions in the curve of Heterogeneous scenario of Fig. 11. Particularly, the percentage of total

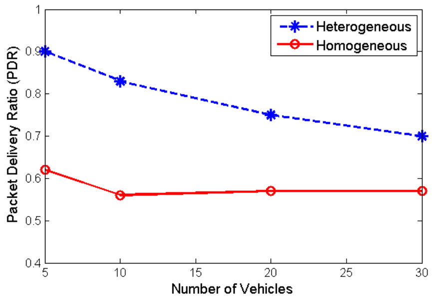


Fig. 10: Vehicle density vs overall Packet Delivery Ratio

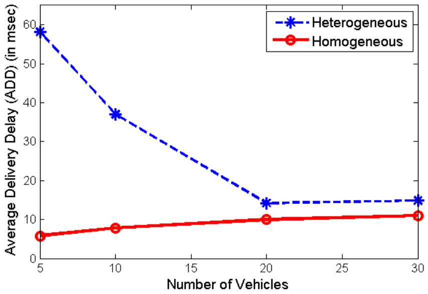


Fig. 11: Vehicular density vs Average Delivery Delay

message receptions through Umts interface is decreased as we increase the number of vehicles and the respective percentage for DSRC Interface is increased instead. As a result, this has an impact on the ADD which converges more to RSU Delivery Delay times (lower) than to Umts ones (higher). For the Homogeneous scenario (pure DSRC) on the other hand we can view a normal behavior, where the Average Delivery Delay is slightly increased as we increase the vehicle density.

Despite the limits resulting from the restrictions in the configuration of UMTS, it is still obvious that increasing vehicular density reduces the performance of the PoI, in particular when using cellular networks. This further justifies why to rely on multiple RSUs to off-load exceeding traffic to vehicles, which would require investigations on metrics and triggers to decide when, and which flows should be off-loaded.

VII. CONCLUSIONS - FUTURE WORK

In this paper, we proposed an IPv6 architecture for Cloud to Vehicle downstream services. This architecture is based on the convergence of geo-localization mechanisms with IPv6 addressing for ensuring reachability and traffic off-loading from the Cloud through optimal infrastructure node and technologies. From an IPv6 mobility management perspective, the IPv6 mobility management functions are located at the Network edge in order to better handle multiple IPv6 addresses identifying the same vehicle. But considering Cloud-initiated traffic, this architecture has been extended with a Geographic Mobility Management, where an entity called LIMME is in charge of identifying the optimal IF-Nodes to reach a particular vehicle. We implemented this Geographic Mobility Management architecture on the iTETRIS ITS simulation platform and illustrated its traffic offloading capabilities in a proof-of-concept.

In our future work, we will further enhance the IF-Node selection criteria, by integrating channel quality metrics, such as channel load for DSRC or CQI for LTE. We will also validate the proposed mobility management architecture at a larger scale, both in terms of vehicles and in terms of traffic volumes originated from the Cloud. Furthermore, we will evaluate the performance of our Architecture by comparing it with other IPv6 Mobility Management schemes.

VIII. ACKNOWLEDGMENTS

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