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Towards a Network Management Solution for Vehicular Delay-Tolerant Networks

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Resumo

As redes veiculares foram desenhadas para permitir que os veículos possam transportar dados criando assim um novo tipo de redes, caracterizando-se por dois tipos de comunicação: comunicações veículo-para-veículo (V2V) ou comunicações veículo-para-infra-estrutura (V2I). Redes veiculares intermitentes (do Inglês *Vehicular Delay-Tolerant Networks* - VDTNs) surgiram como uma nova arquitectura de rede de dados onde os veículos são utilizados como infra-estruturas de comunicação. As VDTNs caracterizam-se por serem redes veiculares baseadas no paradigma de comunicações intermitentes. Nas redes VDTN não existe uma ligação permanente extremo a extremo entre o emissor e o receptor. Neste caso, o nó inicial transmite os dados para um nó que esteja junto dele e assim sucessivamente, os dados vão sendo transportados pelos veículos, salto a salto até ao destinatário final.

Esta dissertação centra-se na proposta de uma solução de gestão de rede, baseada no protocolo estandardizado Simple Network Management Protocol (SNMP) para redes VDTN. A solução construída permite controlar uma rede VDTN através de um sistema de gestão de rede (do Inglês *Network Management System* - NMS) com o objectivo de detectar e, se possível antecipar, possíveis erros na rede.

A metodologia de investigação utilizada foi a prototipagem. Assim, foi construído um módulo de gestão de redes para o protótipo laboratorial, chamado VDTN@Lab. O sistema construído inclui uma MIB (*Management Information Base*) que é colocada em todos os nós de uma rede veicular, tanto fixos como móveis. A solução foi construída, demonstrada, validade e avaliado o seu desempenho, estando assim pronta para ser utilizada.

Abstract

Vehicular networks appeared as a new communication solution where vehicles act as a communication infrastructure, providing data communications through vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communications. Vehicular Delay-Tolerant Networks (VDTNs) are a new disruptive network architecture assuming delay tolerant networking paradigm where there are no end-to-end connectivity. In this case the incial node transmits the data to a closed node, the data will be carried by vehicles, hop to hop until the destination.

This dissertation focuses on a proposal of a network management solution, based standard protocol Simple Network Management Protocol (SNMP) to VDTN networks. The developed solution allows control a VDTN netowork through a Network Management System (NMS) with the objective to detect and, if it's possible, anticipate, possible errors on network.

The research methodology used was the prototyping. So, it was built a network management module to the laboratorial prototype, called VDTN@Lab. The system built include a MIB (Management Information Base) placed in all vehicular network nodes. The solution was built, demonstrated, validated and evaluated their performance, being ready for use.

Keywords

Vehicular Communications, Delay-Tolerant Networks, Vehicular Delay-Tolerant Networks, Vehicular Ad Hoc Networks, Network Management, Management Information Base, Simple Network Management Protocol, SNMP, Network Monitoring, Testbed.

Contents

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Acronyms

ADMA	:	Autonomous Decentralized Management Architecture
ASN.1	:	Abstract Syntax Notation
BAD	:	Bundle Aggregation and De-aggregation
BSC	:	Bundle Signaling Control Layer
CPU	:	Central Process Unit
DING	:	Diagnostic Interplanetary Network Gateway
DTN	:	Delay Tolerant Network
GMA	:	GUERRILLA Management Architecture
IBM	:	International Business Machines
IEEE	:	Institute of Electrical and Electronics Engineers
IP	:	Internet Protocol
ITS	:	Intelligent Transport Systems
IVC	:	Intervehicle communications
MAC	:	Media Access Control
MANET	:	Mobile Ad Hoc Network
MIB	:	Management Information Base
MMAN	:	Monitor For Mobile Ad Hoc Networks
MPR	:	Multipoint Relay
MUs	:	Monitoring Units
NHDP	:	Neighbourhood Discovery
NMS	:	Network Management System
OLSRv2	:	Optimized Link State Routing Protocol version 2
PBNM	:	Policy-based network managent
PDP	:	Policy Decision Point
PDU	:	Protocol Data Unit
PEP	:	Policy Enforcement Point
PR	:	Policy Repository
RU	:	RoadSide Unit
SNMP	:	Simple Network Management Protocol
V2I	:	Vehicle to Infrastructure

V2V	:	Vehicle to Vehicle
VANET	:	Vehicular Ad Hoc Network
VDTN	:	Vehicular Delay Tolerant Network
WAVE	:	Wireless Access in Vehicular Environments

1. INTRODUCTION

1.1 Focus

Vehicular Networks and intervehicle communications (IVC) have become increasingly interesting and popular in the research community and automotive industry all over the world. In these networks vehicles are used as a communication infrastructure.

Vehicular networks can be applied in multiple scenarios like urban (where vehicular users can download files from road-side Access Points [1]), multimedia content and commercial applications [2], remote rural and sparse areas [3-6]. They can also be applied in emergency scenarios (a conventional communication infrastructure may not be available and it is necessary a network to establish the communication between emergency services like rescue teams [7, 8].

Vehicular networks are emerging as a new class of wireless network, spontaneously formed between moving vehicles equipped with wireless interfaces. It is a wireless communication between vehicle to vehicle (V2V) and vehicle to roadside infrastructure (V2I).

VANETs are self-organized communication networks build up from vehicles and are characterized by high-speed communication and short time of contact. For communication occur between vehicles and RoadSide Units (RUs), vehicles needs to be equipped with some of radio interface that enables short-range wireless ad hoc networks to be formed [9].

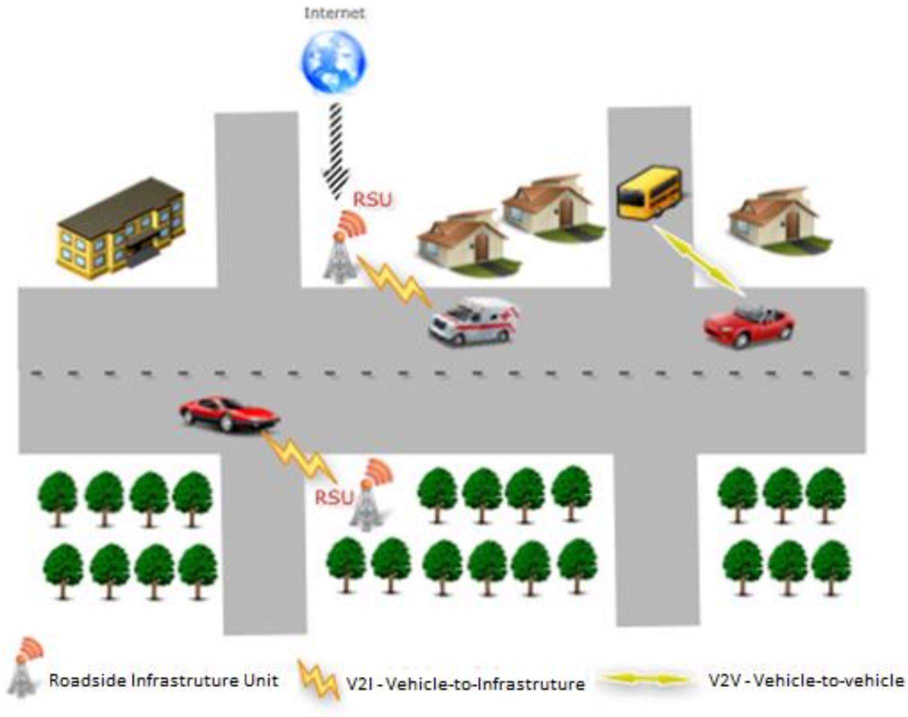

Figure 1 - Illustration of a vehicular ad hoc network (VANET) and the corresponding interactions among nodes.

Vehicular Delay Tolerant Networks (VDTNs) are DTN inspired networks where vehicles act as the communication infrastructure, providing low-cost asynchronous communications. They use the store-carry-and-forward paradigm [10] where vehicles can store information in a buffer and forward packets to destination even in a non end-to-end connectivity. Some of the potential applications for these networks are driving assistance, traffic monitoring, road safety, telemedicine, or even entertainments and multimedia content.

VDTNs are composed by three diferent kinds of nodes, mobile, relay and terminals.

Mobile Nodes (e.g., cars, motorcycles, bus) act as carrier to disseminate information along the network, they are responsible to collect information from terminal/relay nodes and transport that information to destination. Mobile Nodes also can act as terminal nodes. Relay nodes are stationary devices placed in strategic positions in order to download/upload data from/to mobile nodes. Terminal nodes are fixed devices providing connection to end-users.

The VDTN layered architecture [11] assumes an aggregation layer under the network layer, called bundle layer. At the edge of the network, datagrams are aggregated in large size packets, called bundles. VDTNs use out-of-band signaling, based on the separation of control and data planes. An illustration of the VDTN architecture is presented in Figure 2.

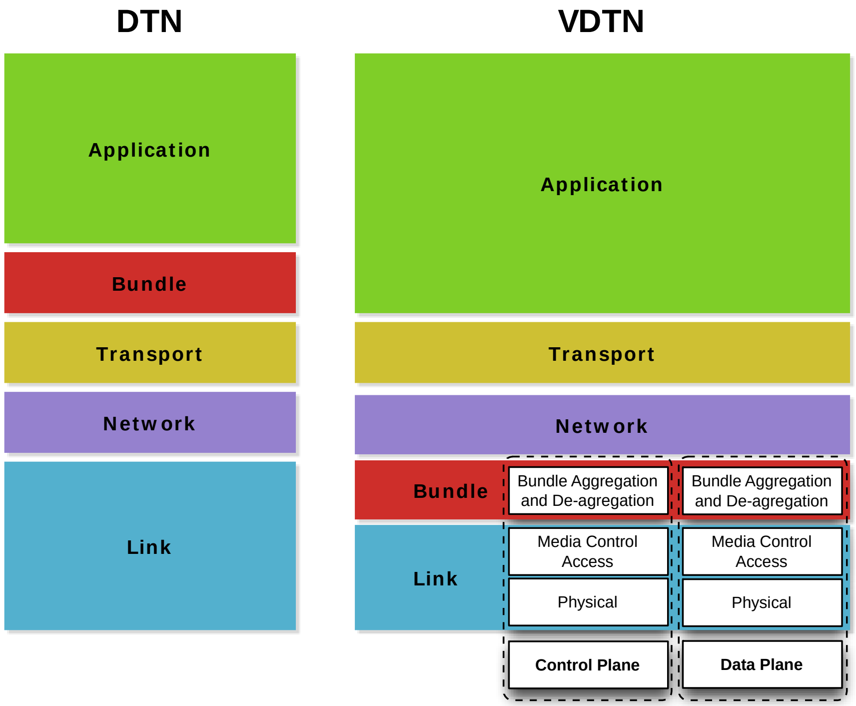

Figure 2 – Comparation between DTN and VDTN layered architectures.

The separation between data and control planes in VDTNs was inspired by the possibility of terminal, relay, and mobile nodes exchange control information at the connection setup phase and each plane may be supported by diferent network technologies. The control plane performs an initial setup, managing the exchange of all necessary information to establish a data connection (executed at data plane). The data plane is responsible for data carrying [11, 12] .

Standard simple network management protocol (SNMP) [13, 14] is widely used networks management and it allows the management information exchange between a network manager and the agents. SNMP is a widely common used protocol for fixed network management (monitoring and configuration). The data are collected by the network management system (NMS) requests to the managed network devices. All objects that can be accessed are described in a management information base (MIB). NMS is responsible to keep the entire network operational, monitoring and controling the network devices.

This dissertation presents a developed application that aims evaluate and control network nodes (terminal, relay and mobile) in a VDTN using SNMP.

1.2 Problem Definition and Objectives

Currently, there is a serious concern by network administrators for keeping a network always operational and functional. SNMP protocol became an excellent option because allows to foresee potencial errors that can occur in a network equipment and interact with them.

The main objective of this dissertation is the proposal, construction, demonstration, and performance evaluation of a network management solution for VDTNs using a standard approach based on SNMP. This application should be capable to communicate with all network nodes by SNMP protocol in order to obtain information about the node state. This information will be analyzed by the developed NMS with the purpose to identify and solve potential anomalies that arise in the network.

To reach this main objective the following intermediate objectives were defined:

- Review the related literature about network management;
- Study and detailed analysis of the SNMP protocol;
- Proposal and design of a network management solution for VDTNs based on SNMP protocol;
- Construction, demonstration, and performance evaluation of the proposed network management solution through the VDTN@Lab prototype.

This work of research and engineering expects to produce not only the desire network management solution for VDTNs, including the Network Management System (NMS) and management information bases (MIB) to control the network nodes, but also to provide the opportunity to disseminate the knowledge and software through a conference and a journal paper.

1.3 Main Contributions

This section is devoted to the scientific contributions of this dissertation to the state-of-the-art. The first contributions of this dissertation are described in a conference paper named An *SNMP-based solution for Vehicular Delay-Tolerant Network Management*.

More contributions are referenced in second paper named *Man4VDTN – A Network Management Solution for Vehicular Delay-Tolerant*. These contributions will be described in the two paragraphs below.

The first paper presents the design and demonstration of a network management solution in a laboratory-based testbed and some results showing the average delay and average number of hops between the creation of a request and the arrival of response between the NMS and a given node.

The second paper presents more performance results using the SNMP protocol through the developed solution. These tests focus on the network nodes performance when they are exchanging SNMP messages and in the number of hops until the NMS gets the response of a node.

This project was also presented at the 15th Meeting of the *Rede Temática de Comunicações Móveis* (RTCM), Guimarães, at June 15th, 2012.

1.4 Dissertation Structure

This dissertation is organized in four chapters. This chapter, the first, presents the focus of this work, defining the problem and objectives, the main contributions, and the dissertation structure.

Chapter 2 describes the proposed SNMP-based solution for VDTNs. It presents all configuration process of VDTNs in order to support SNMP protocol and its deployment in a laboratory testbed, called VDTN@Lab. This contribution will be presented at the IEEE GLOBECOM 2012, Anaheim, USA, December 3-7, 2012.

Chapter 3 also describes the configuration process to support SNMP. It presents the developed application and all application mechanisms and the results of this solution in a laboratory-based testbed. These contributions are included in a paper submitted for an international journal and it is under review.

Chapter 4 includes the main conclusions and suggests some directions for future works.

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2. An SNMP-based Solution for Vehicular Delay-Tolerant Network Management

This chapter consists of the following article:

An SNMP-based Solution for Vehicular Delay-Tolerant Network Management

Bruno F. Ferreira, João N. Isento, João A. Dias, Joel J.P.C. Rodrigues, and Liang Zhou

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An SNMP-based Solution for Vehicular Delay-Tolerant Network Management

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Abstract **- Vehicular delay-tolerant networks (VDTN) assumes the use of the delay-tolerant network (DTN) concept for vehicular communications in order to cope several issues, such as highly dynamic network topology, short contact durations, disruption, intermittent connectivity, variable node density, and frequent network fragmentation. These challenging characteristics of vehicular networks affect the design and construction of a network management solution for VDTNs. The standard simple network management protocol (SNMP) is widely used on conventional networks and it is not directly deployable on VDTNs. Then, this paper proposes an SNMP-based solution for VDTNs supporting load-related information collection from VDTN nodes using SNMP. It presents the design and the demonstration of this network management application in a laboratory-based testbed.**

Index Terms - Vehicular Delay-Tolerant Networks; VDTNs; Network Management; Performance Assessment; Testbed.

I. INTRODUCTION

Vehicular communications have been the focus of an in-creasing interest in the last few years. In part, this interest is due to the potential applications of these networks that include, but not limited to, road safety, driving assistance, road traffic optimization, monitoring, and a wide variety of commercial and entertainment applications. They can also be used to provide connectivity to remote/rural communities and regions, and support for communication between rescue teams in disaster situations.

Contrary to conventional networks, vehicular networks present some particular challenges that are receiving attention for the scientific community [1]. In particular, they have a highly dynamic network topology, variable node density, and are characterize by short contact durations. Limited trans-mission ranges, radio obstacles, and interferences, turn these networks prone to disruption, intermittent connectivity, and significant loss rates. Due to these particular issues, vehicular communications experience frequent partition (i.e., end-to-end connectivity may not exist). A variety of factors including node heterogeneity, node interactions, node cooperation, limited network resources, and energy constraints also add additional challenges.

Vehicular ad hoc networks (VANETs) [2] are a subset of mobile ad hoc networks (MANETs) where mobile nodes are vehicles. In VANETs, taking into account the type of node under communication with a mobile node, communication can be classified as a vehicle to vehicle (V2V) or vehicle to infrastructure (V2I). This kind of networks assumes that end-to-end connectivity is available. Therefore, they are not able to deal with network partitions, disconnection, or long time delays. These limitations were solved by the store-carry-and-forward paradigm proposed for delay-tolerant networks (DTNs). In a DTN-based network [3], the physical motion o vehicle and opportunistic contacts is harnessed to transport data between disconnected parts of the network. Data is stored and carried until a contact opportunity with other node is available. When a contact occurs, data are forwarded to that node, based on a routing protocol, trying to reach the destination as soon as possible and increase data delivery [4].

Vehicular delay-tolerant networks present a new approach for vehicular communications employing the store-carry-and-forward paradigm from DTNs [5]. VDTN architecture places the bundle layer under the network layer introducing an IP over VDTN approach. This architecture uses out-of-band signaling, with control and data planes separation. The data plane is responsible for the assembling, transferring, and processing data bundles while the control plane transmits and processes the setup messages and performs resources reservation hope by hope until the destination

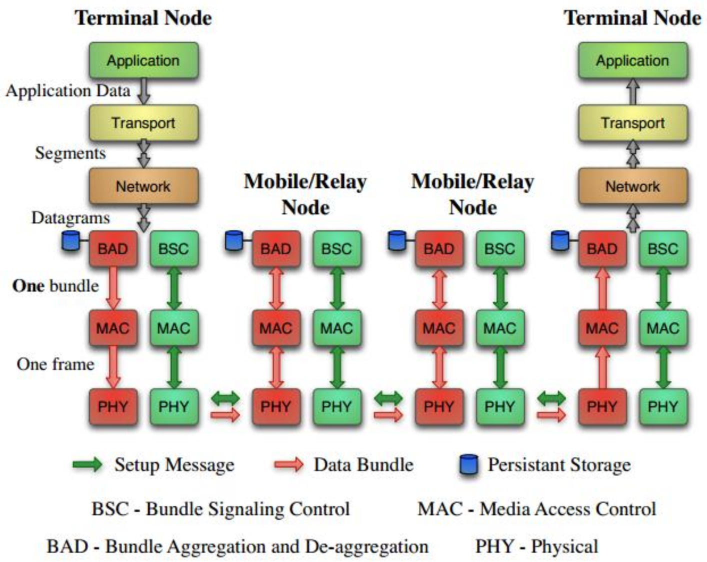

Fig 1 - Messages and Data Bundles transmissions between VDTN nodes, from a source to a destination.

The VDTN layered architecture may be seen in Figure 1. The bundle layer is split into two sub-layers: the bundle signaling control layer (BSC) and the bundle aggregation and de-aggregation layer (BAD). BSC executes control plane functions as setup message exchange, resource reservation, amzong others. BAD is responsible for data plane functions that deal with data bundles. At the source terminal node, the BAD layer assembles data units form network layer (IP packets) with similar properties in one unique data bundle. The bundle is then transmitted over a VDTN network, from source to destination, which may involve several intermediate nodes. When a bundle reaches its destination, the BAD layer does the reverse process, de-aggregating the bundle into individual IP packets.

Conventional network management systems use different solutions. Nevertheless, the standard simple network management protocol (SNMP) [6] is widely on used networks management and it allows the management information ex-change between a network manager and the agents. SNMP is a widely common used protocol for fixed network management (monitoring and configuration). The data are collected by the network management system (NMS) requests to the managed network devices. All objects that can be accessed are described in a management information base (MIB). NMS is responsible to keep the entire network operational, monitoring, and control the network devices. Due to the unique features provided by VDTNs, such as network intermittency, disconnection, and long delays, the SNMP cannot be directly applied. Then, this paper proposes a network management solution for VDTNs.

The proposed monitoring system can be considered as an SNMP-based system for VDTNs. This approach uses the SN-MPv3 protocol, compatible with other management solution. In VDTN architecture there was only one NMS responsible for all the network management. The communication between NMS and network devices was established by SNMP messages.

The proposed solution is evaluated through a VDTN laboratory testbed used for conducting experiments and evaluates the SNMP-based solution for VDTNs network monitoring. This testbed, called VDTN@Lab [7], provides a framework for demonstration and validation of the VDTN architecture, allowing the development, performance evaluation, and validation of new services, protocols, and applications [8].

The remainder of this paper is organized as follows. Section II reviews the related literature about other monitoring system approaches and applications used in vehicular communications. The design of the system and the software usability is presented in Section III. Section IV demonstrates the monitoring system on a laboratory testbed (VDTN@Lab). Finally, Section V summarizes the main conclusions of this work and suggests some topics for future work.

II. RELATED WORK

The proposal of a network monitoring system for VDTNs was based on other available solutions proposed for conventional and mobile networks. These approaches will be considered in this section.

An SNMP-based solution for monitoring a MANET net- work was proposed in [9]. It uses a smaller implementation of SNMP considering the limitations from this kind of networks. First, it describes the obstacles that hinder the direct implementation of the SNMP protocol in MANETs, in particular, the short time contacts and dependence of wireless communications. The MANET uses the optimized link state routing proto- col version 2 (OLSRv2) which offers three basic processes that helps the SNMP implementation: Neighborhood Discovery, MultiPoint Relay (MPR) Flooding, and Link State Advertisements. Neighborhood discovery (NHDP) allows network nodes to discover the routers that can establish bi-directional communication. MPR Flooding is the process whereby each router is able to conduct network-wide broadcasts. Link state advertisements let network nodes to determine the state of each link on the network. Consequently, it allows all routers to calculate shortest end-to-end paths. The OLSRv2 management system architecture considers three MIB modules: NHDP- MIB, OLSRv2-MIB, and REPORT-MIB. Both NHDP-MIB and OLSRv2-MIB are based on different groups, allowing changing protocol parameters and monitoring the router state.

In [10], the authors present an overview of the main avail- able management architecture approaches for MANETs and raise their theoretical and practical limitations.

They discuss issues related with building efficient management architecture adaptable for MANETs. This study is composed by three different models that can be applied to mobile ad hoc net- works. The first one is the SNMP-based model. Hierarchical model of management based on SNMP can perform, more accurately, complex tasks of management and management decisions. Although it presents several disadvantages, such as high message overhead or if some node has a failure in a fragmented network, all nodes are left without management functionalities. Because of the self-organized characteristic of MANETs, the management task should be distributed.

The second available model is the Policy-based approach. The policy-based system has the following components: a policy enforcement point (PEP), a policy decision point (PDP), a policy repository (PR), and a tool of political management. The PDP task retrieves and interprets political information, and passes it to the PEP. The policy repository is the place where all the policies are stored and made by PDPs. Policy-based management network offers this feature through the implemen- tation and enforcement of policies previously defined by the network manager. Otherwise, the complexity of establishing control makes its implementation very difficult.

The third model, called a self-managing based model, assumes that an autonomic network proposes the solution of self-management. This approach leads to network management architecture able to take into account the autonomous nature of MANETs. A disadvantage of this approach comes to the fact that it can be too much complex to compute nodes with limited resources and sensor nodes need to be dedicated to specific management functions.

The monitor for mobile ad hoc networks (MMAN) [11] was proposed for a network management solution used on MANETs. First, the authors present the major features showing how MMAN is better than previous monitoring approaches. MMAN uses multiple monitoring nodes collaborating to produce a snapshot of network conditions. MMAN relies on several monitoring stations that combine information to maintain an accurate up-to-time view of the current MANET topology. A number of monitoring units (MUs) are deployed throughout the MANET. These MUs are responsible for gathering information regarding network performance. After, the information gathered by the MUs is delivered to the management nodes, where they are analyzed and presented on a graphical user interface. To allow these monitoring capabilities of MUs, each one is equipped with two network interfaces. One wireless interface is responsible for packets transfer over MANET while the other (which can be wireless or wired) is used to change information between MUs. Thus, MMAN does not overload the MANET traffic with this additional monitor traffic. To validate and demonstrate this monitoring system, it was created a MANET with 10 nodes using IEEE 802.11b/g. The same MANET was monitored using two MUs with 80%- 90% total coverage. MMANs performance was evaluated from the following perspectives: ability to produce a dynamic and up-to-time picture of the MANET topology; ability to present traffic load information for covered nodes; ability to present as assessment of cooperation level for nodes under the coverage area of the MUs; and assessment of storage capability and CPU processing requirements for management nodes.

Diagnostic interplanetary network gateway (DING) protocol was developed to introduce monitoring capabilities in DTN technology [12]. DING uses a subscription-based model for information distribution to cope the connectivity of DTN. The goal of this work is to implement mechanisms for network monitoring on Bundle and lower layers that are not addressed by available mechanisms. The authors set up a DTN2 with 3 nodes, involving a several configurations steps. They evaluated this testbed switching DTN traffic between nodes using variable connectivity and bundle sizes. After this setup work, the next step is the implementation of network monitoring capabilities that would allow observer the status of the network and network traffic exchange at the DTN level. In original DTN2 implementation, no network monitoring functionality is built in. On this proposal, the nodes produce several log files created by shell scripts created over DTN2. Several parameters are considered because all of them are important for describing the status of the network. These parameters are the following: DTN nodes uptime, that shows whether a DTN node is running or not; Bundle Traffic, that shows a number of data related to Bundle traffic, such as how many Bundles may be received by a node and forward, how many are delivered, deleted or expired; and link statistics, that describes the status of each link between nodes, showing the speed of data transmission and the total of transferred data.

III. VDTN MONITORING SYSTEM

This section presents the proposed SNMP-based solution for VDTNs network management. It includes all the important aspects to deploy the SNMP protocol on VDTNs given their unique characteristics. This section considers three subsections. First, the system architecture and main operations will be described. After, the construction of a MIB file, which keeps information of network nodes and several metrics for performance assessment of VDTN networks, will be present. The last subsection presents the format of SNMP message used in this solution.

A. System Architecture

The SNMP deployment over a VDTN network has some similarities with conventional SNMP solutions. The NMS is embedded on a terminal node system and it will generate SNMP messages that will be aggregated in bundles to be transmitted over the

VDTN network.

The network management becomes an essential activity to guarantee its continuous operation and to ensure the high grade of quality services provided. So the VDTN network has a network management station (NMS) that allows messages exchange (sending and receiving) with the different network nodes. Through this application the manager can control and administrate the entire network once they can communicate with all nodes. VDTN NMS can perform a superficial management when data are analyzed, like the system information and the SNMP messages exchanged. It also can monitor a new group implemented in a MIB file, the VDTN group, described on the next subsection.

VDTNs may assume full cooperation among nodes. Following this approach, all of them are prepared to exchange SNMP messages in order to obtain not just a partial, but an entire control of the VDTN network. With this developed architecture, all the network nodes (terminals, relays, and mobiles) have a SNMP agent that contains a MIB file that allows communication between NMS and the respective network node in order to obtain a more efficient network management.

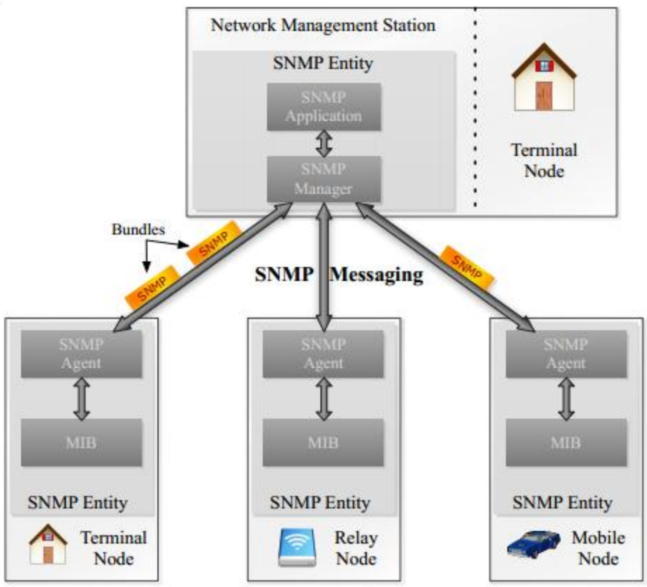

Fig 2 - Communication between VDTN nodes and the Network Management Station.

Figure 2 illustrates the interaction that occurs between the NMS and the network element (terminal, relay, or mobile node). NMS exchange SNMP messages with network elements that contains a MIB file and it is responsible for monitoring, reporting, and deciding if there was a problem and the network element (agent) is responsible to answer the requests of NMS, sending values back or making changes.

B. Management Information Base (MIB)

In this subsection, a description of management information base (MIB) files will be considered and all the process until the final step, the MIB creation, will be explained. MIB is a virtual database that keeps information about some management station in SNMP managed network. This file includes a set of variables displayed in a hierarchical structure (tree).

A MIB contains information about properties and definitions that an agent supports, which information is represented by objects or variables. To represent the MIB structure, the ASN.1 (abstract syntax notation one) is used. In a few words, MIB serves as a data dictionary or codebook to assemble and interpret SNMP messages. Before creating the MIB structure an approach that allowed creating the MIB file success fully was followed.

Figure 3 illustrates all the four steps that were followed to create a MIB module that corresponds to all the system requirements. The first step was carefully defined and what kind of objects should be analyzed in our network. After that, a document with the specifications of MIB object to quickly understand the purpose of any object was created.

Fig 3 - The MIB file creation process

Then, it was organized into groups and, finally, writes the MIB file. It is expected that additional MIB objects will be defined and implemented over the time to provide monitoring and control needs of new or changing components in network.

In order to make the NMS an application more robust and user-friendlier, a module that allow analyze the numeric data received by NMS on a graphic interface was developed. Through this implementation it is possible to detect and identify anomalies in the network or nodes performance degradation. It was been created a module aside this MIB. This module acts as an intermediary between SNMP application and VDTN nodes application, in order to get or set specific information in the nodes. This new module is the center of all monitoring because in there are allocated all the managed objects to the control of all nodes as vehicular network nodes. With this implementation is now possible monitor a set of important proprieties in vehicular network, Messages allocated in each node buffer (messages ids that are in a node buffer), Messages discarded by node (messages ids that are discarded by node),

Number of contacts that were established by managed node and other network node, Contact time between them, Messages delivered (messages ids delivered by managed node), Battery Status (reports the energy level of managed node), Buffer Space (the buffer space available to node receive messages).

C. SNMP Message

The SNMP protocol allows the exchange of multiple messages in a network, each one with a different purpose. SNMP uses four basic operations to establish the communication between NMS and an agent - GET, SET, GETNEXT, and TRAP. With these messages it is possible to NMS request or change object values from a management node. Traps are used to report a notification.

Figure 4 illustrates the overall SNMP message used in the proposed VDTN management system. The description, below, will explain the main fields of this message format. The Message Version Number describes the SNMP version number of this message; it is used for ensuring compatibility between versions. For SNMPv3, its value is 3. Message Identifier is a number used to identify an SNMPv3 message and to match response messages to request messages. Maximum Message Size sets the maximum size of message that its sender can receive. The Scoped PDU contains the PDU to be transmitted, along with parameters that identify an SNMP context, which describes a set of management information accessible by a particular entity. This PDU contains a Context Engine ID used to identify to which application the PDU will be sent for processing. In this solution only one application is considered.

It also includes a Message Body. It is composed by several fields that indicate the operation (GetRequest, SetRequest, Trap, ...) requested by NMS. This operation is defined in the PDU Type. Request Identifier is a number used to match requests with replies. Error Status uses an integer value that is used in a Response-PDU to tell the requesting SNMP entity the result of its request. A zero value indicates that no error occurred and the other values indicate what sort of error happened. Variable Bindings is a set of name-value pairs identifying the MIB objects in the PDU. In the case of messages, other than requests, they contain their values. The security fields of the SNMPv3 message were not considered on this work.

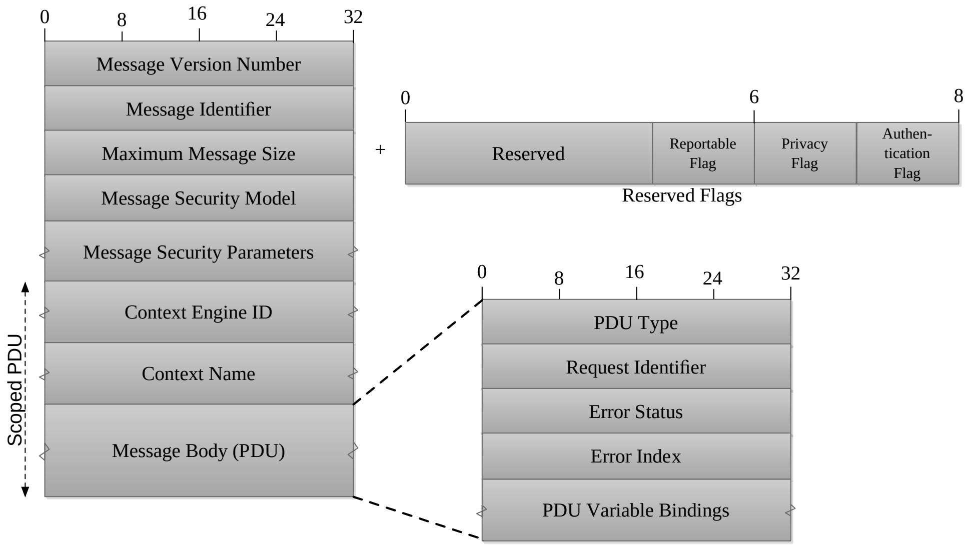

Fig 4 - SNMP General Message Format

IV. SYSTEM DEMONSTRATION

The management system was experimented and evaluated in a VDTN testbed, called VDTN@Lab. Three terminal nodes, two relay nodes, and four mobile nodes were considered on the testbed. The terminal nodes are located at different edges of the laboratory, while relay nodes are placed at crossroads. Mobile nodes have a random movement across roads. All nodes are equipped with Bluetooth and IEEE 802.11b/g devices to allow the use of different network technologies to demonstrate the out-of- band signaling with the separation of control and data planes. All nodes also have a set of software modules deployed to emulate the VDTN services. The management application was deployed on the terminal 2, without any special criteria. On relay and mobile nodes the SNMP Agent and the respective MIB file was deployed. All the SNMP solution directly interacts with the VDTN software modules. Figure 5 illustrates the VDTN testbed and all its interactions.

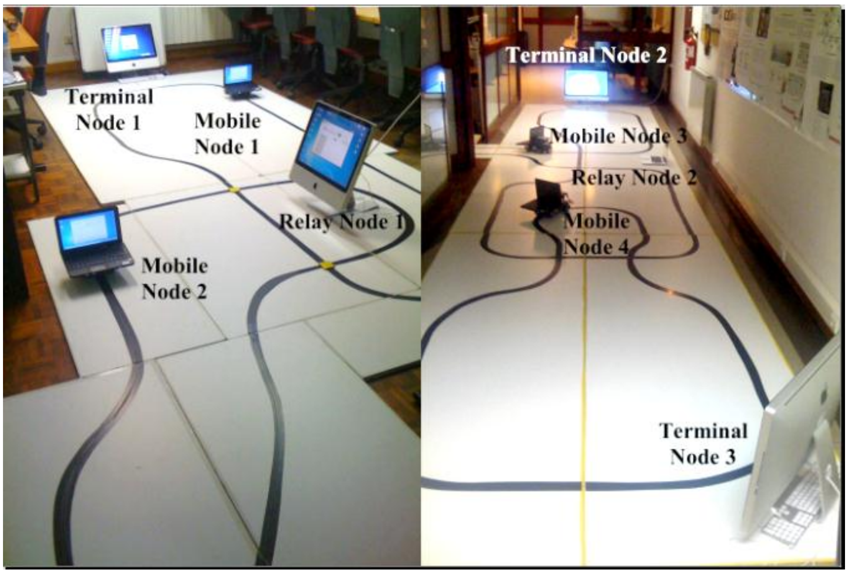

Fig 5 - Illustration of the VDTN@LAB testbed

Fig 6 - VDTN Management Application.

Figure 6 shows the manager application of this SNMP solution. This application was embedded on VDTN terminal node application and, in this demonstration, only one terminal node can be a SNMP manager. It is assumed that the manager is aware of all of the testbed nodes. The application shows important information about the network. As may be seen in the figure, in (a) the application shows a list of all the network nodes. When a node is selected, the application displays the node information (b), if it is available, and the management application can perform a SNMP operation (c) on that node to acquire the required information (such as battery status, dropped bundles, etc.). This application with the information of all the testbed nodes will create a line chart (d) that displays a metric to evaluate the network performance.

To demonstrate this SNMP management system at VDTN@Lab, several experiments whit the duration of one hour each one were performed. The main objective includes measuring the average delay and average number of hops between the creation of a request and the arrival of response to the manager node and a given node. The requests are performed along the testbed experiments and all of them are sent in broadcast to all the nodes. The Epidemic routing protocol is used on this study.

Figure 7 shows the SNMP message average delay between the creation of SNMP get message and the arrival of correspondent answer. The results show an acceptable delay time for getting the requested information from all the network nodes. As the considered mobile nodes movement is random, the found results suggest that the delay time is related to the relative position of nodes compared to terminal node 2.

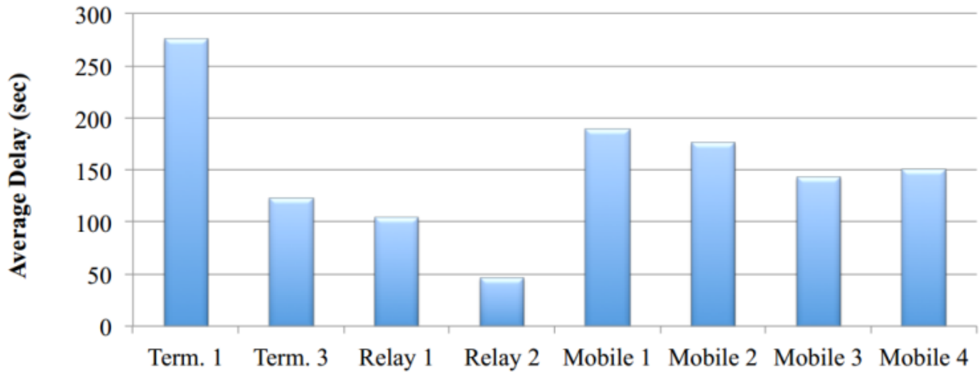

Fig 7 - SNMP message Average Delay between its creation and the corresponding answer for all the network nodes.

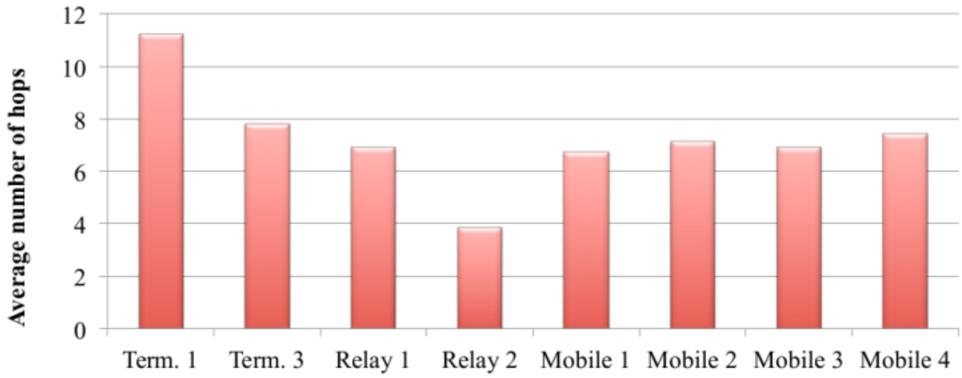

Fig 8 - Average number of hops of SNMP messages for all nodes of testbed.

For example, the Terminal node 1 has the worst average delay because it is positioned at the most distant point of the testbed scenario.

Figure 8 shows the average number of hops that the requests and corresponding answers perform until reaching the SNMP manager. Once again, these results emphasize the fact that the position of the nodes reflects the performance of the network. Both results show that performance of SNMP on mobile nodes is very similar. This is due to the fact of the random movement of the mobile nodes and when a request is sent the position of the mobile nodes is never the same.

V. CONCLUSION AND FUTURE WORKS

This paper presented a network management solution fo VDTNs using the standard SNMP protocol. A monitoring system is very useful to verify the proper network working, check possible network anomalies, and collect statistic data for the network administrator. Aiming to provide a robus mechanism for network monitoring, it was deployed in a laboratory testbed VDTN@Lab for validation and demon-stration. It was shown that solution works properly and it is ready for use. Nevertheless, the system may be improved in further works. In this demonstration case study, the SNMP application is embedded a VDTN terminal node application.

Then, the migration of this application for being independent and accessed outside VDTN network, such as in the Internet, can be considered for future work. The security mechanisms of the SNMPv3 Protocol should also be included in future works.

ACKNOWLEDGMENTS

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3. MAN4VDTN – A NETWORK MANAGEMENT SOLUTION FOR VEHICULAR DELAY-TOLERANT NETWORKS

This chapter consists of the following article:

Man4VDTN – A Network Management Solution for Vehicular Delay-Tolerant Networks

Bruno F. Ferreira, João N. Isento, João A. Dias, Joel J.P.C. Rodrigues

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Man4VDTN – A Network Management Solution for Vehicular Delay-Tolerant Networks

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***Abstract* — Vehicular delay-tolerant networks (VDTN) uses the delay-tolerant networking (DTN) paradigm for vehicular communications in order to manage several issues, such as short contact durations, disruption, variable node density, and fragmentation. All these issues represent a huge challenge for vehicular communications. The design and construction of a network management solution is also affected by these peculiar characteristics. The standard simple network management protocol (SNMP) is widely used on conventional networks and it is not directly deployable on VDTNs. Then, this paper proposes an SNMP-based solution for VDTNs supporting load-related information collection from VDTN nodes using SNMP. It presents the design, demonstration, performance evaluation and results of this network management approach through a laboratory-based VDTN testbed.**

***Index Terms* — Vehicular Delay-Tolerant Networks; VDTNs; Network Management; Simple Network Management Protocol; Wireless Communications; Performance Assessment; Testbed**

I. INTRODUCTION

Vehicular communications are emerging as a reliable and low-cost solution for Intelligent Transport Systems (ITS). This type of networks has a huge potential and may be applied to a massive number of applications, such as driving assistance, road safety, and traffic optimization. They can also be used to provide connectivity to remote/rural regions without Internet coverage and to support communications between rescue teams in catastrophic environments.

Although the wide range of application for vehicular networks, they still have to overcome several issues and constraints. Node density, short contact durations, and dynamic network topology are some examples of characteristics that receive special attention from scientific community [1]. In vehicular communications, an end-to-end connectivity may not exist due to node heterogeneity, node interactions, node cooperation, and limited network resources. These features lead vehicular networks to be prone to disruption, intermittent connectivity, and significant loss rates.

In order to overcome the above-presented issues, several architectures have been proposed, including Vehicular Ad-hoc Networks (VANETs) [2], Delay-Tolerant Networks (DTNs) applied to vehicular communications [3], and even Vehicular Delay-Tolerant Networks (VDTNs) [4]. In VANETs, vehicles are used as mobile nodes in order to enable communications. These communications can be classified into vehicle to vehicle (V2V) or vehicle to infrastructure (V2I). Both approaches assume an available end-to-end link among communication end points. However, they are not able to deal with network partition, disconnection, or long time delays. A possible solution to these limitations is the store-carry-and-forward paradigm proposed by the DTN architecture. In DTNs, vehicles are used to transport data between disconnected parts of the network. Data is stored until a contact opportunity is available. When this contact opportunity is available, data is forwarded based on a specific routing protocol, in order to reach its final destination.

This work focuses on VDTNs. This approach appears as a novel approach for vehicular communications and gathers several contributions from the above-presented architectures (e.g. the store-carry-and-forward from DTNs). In VDTNs, three types of nodes are considered: terminal nodes, relay nodes, and mobile nodes. Terminal nodes may be fixed or mobile nodes and are responsible for the origin or the destination of data. Relay nodes are stationary nodes, placed at crossroads, and are used to store-and-forward data. This type of nodes increases the number of contact opportunities and consequently increases the probability of data being delivery [5]. The VDTN architecture is also characterized for placing the bundle layer under the network layer introducing an IP over VDTN approach. It uses an out-of-band signaling, with the separation of control and data planes [4]. The control plane is used to exchange signaling messages, to reserve resources that will be used in the data plane, and to make routing decisions. On the other hand, the data plane is used for buffer management, traffic classification, data aggregation/de-aggregation, data exchange, among others.

A set of different solutions for management purposes is used for conventional networks. The standard Simple Network Management Protocol (SNMP) [6] is used to manage networks allowing the exchange of information between a network manager and a network agent. With SNMP, the Network Management System (NMS) requests and collects data to the managed network devices. The network operationally, monitoring, and network devices control is also a task for the NMS. A Management Information Base (MIB) describes all objects that can be access. The current version of SNMP cannot be directly applied into VDTNs. This is due to network disconnection and long delay that this type of network suffers.

In order to use the SNMPv3 protocol in VDTNs, a network management solution is presented in this work. In this solution, a NMS is responsible for all the network management, and the communication with network devices is established using SNMP messages. A performance study of the proposed solution is conducted using a laboratory testbed, called VDTN@Lab [7]. The main contributions of this paper are the following:

- Review the state of the art on network management for wireless, mobile, and vehicular networks;
- Proposal of a network management solution for VDTNs;
- A performance analysis of the proposed solution through a VDTN testbed;
- Demonstration and validation of a network management solution based on SNMP for VDTNs.

The rest of the paper is organized as follows. Section II overviews the main projects related to network management and monitoring systems, and enumerates several applications that may contributed to the development of a SNMP-based solution for VDTNs. The design and main features of the proposed solution is described in Section III. Section IV studies the performance of the SNMP-based solution in a laboratory testbed, called VDTN@Lab. Finally, Section V concludes the paper and points some topics for future work.

II. Related Work

VDTNs were proposed as a novel vehicular communication solution based on the DTN paradigm, designed to provide low-cost asynchronous communications in sparse and disconnected vehicular network scenarios, urban, and disaster scenarios. VDTN architecture was demonstrated and validated through a laboratory testbed, called VDTN@Lab [7]. Although work already developed so far [8-10], VDTNs still have several open issues that should be exploited. Network management and cooperation between nodes are important issues to be addressed. The proposal of an SNMP-based network management approach for VDTNs will gather contributions from other available solutions proposed for conventional and mobile networks.

After the maturity of ad hoc routing protocols, which dominated initial research interest, the need for managing ad hoc networks come out as an important issue and is receiving important interest. The specific issues that a Mobile Ad hoc Network (MANET) management solution must address are: node positioning, network mobility, communication intermittence, node connectivity, network traffic, communication fairness, security and misbehavior of communication and routing. Several management approaches that have been proposed or redefined for the Ad-hoc networks will be presented during this section.

In [11], the authors present an overview of the main available management approaches for MANETs and study three different models. The first one is the SNMP-based model. Hierarchical management model based on SNMP can perform, more accurately, complex tasks of management decisions. The second model is the Policy-based approach, which deploys and enforces policies based on the decisions of the network manager. The third model assumes an autonomic network solution of self-management.

Current network management systems use a set of solutions. The Simple Network Management Protocol (SNMP) [12] is one of these solutions, which allows the exchange of management information between a network manager and the agents. SNMP is a widely used protocol for fixed network management (monitoring and configuration). SNMP-Based approach focuses on developing a lightweight management protocol for MANETs that is compatible with SNMP protocol.

The Ad hoc Network Management Protocol (ANMP) [13] has been one of the first efforts and introduced an SNMP-based solution for MANETs. The compatibility with SNMP relies on using the same protocol data unit structure and the same management information base (MIB) structure. The major difference comes from the architectural model, which combines clusters and hierarchical levels. ANMP comes within the scope of management by delegation.

GUERRILLA Management Architecture (GMA) [14] proposes an alternative SNMP-based solution. Uses the cluster based management mechanism and mobile agents in order to implement an autonomic management environment. Nodes are clustered into groups with at least one nomadic manager in each group. The nomadic managers collaborate autonomously to manage the entire network.

An SNMP-based solution for monitoring an OLSRv2-routed MANET was proposed in [15]. It offers three basic processes that support the SNMP implementation: Neighborhood Discovery, MultiPoint Relay Flooding, and Link State Advertisements. The OLSRv2 management system architecture considers three MIB modules: NHDPMIB, OLSRv2-MIB, and REPORT-MIB. Both NHDP-MIB and OLSRv2-MIB are based on different groups, allowing changing protocol parameters and monitoring the router state.

The study proposed in [16] demonstrates a framework for incorporating Simple Network Management Protocol (SNMP) based reliable real-time control and performance-monitoring system for a hybrid automobile is proposed. This proposal is based on the usage of SNMP, Control Area Network, and access to the territorial GSM/CDMA networks by using mobile IP. The vehicles in this work are equipped with several sensors to monitoring speed, acceleration, steering angle, and air temperature. The data collected is used to provide remote management upon these vehicles.

Traditional approaches to network management focus on individual devices and often rely upon proven technologies, such as the SNMP protocol. However, it can be quite a time consuming resources if the number of managed nodes is great. Policy-based network management (PBNM) [17] simplifies the complex management tasks of large-scale systems, since policies monitor the network and automatically enforce appropriate actions in the system. However, policies specify the conditions that should be satisfied before executing management operations for any desired goals. Generally, policies are roles in the general form: ON <event> IF <condition> DO <action>.

DRAMA [18] is a PBNM system for MANETs, using intelligent agents. Policy agents are deployed and manage the network through a two tier hierarchical architecture (figure 4). Global policy agent (GPA) manages multiple Domain Policy Agents (DPAs). DPA can manage multiple DPAs or Local Policy Agents (LPAs). LPA manages a node. LPAs perform local policy-controlled configuration, monitoring, filtering, aggregation, and reporting. Thus reducing management bandwidth overhead.

MANNA [19] provides a architecture for Wireless Sensor Networks (WSNs) that use a policy based framework for network management actions. This architecture considers three types of management: functional areas, management levels, and WSN functionalities. These dimensions are specified to the management of a WSN and are the basis for a list of management functions.

The self-managing approach allows systems to manage them by given high-level objectives from administrators. This approach is based on autonomic computing paradigm that has been proposed by IBM in 2001 [20]. IBM has defined four general properties a system should have to constitute self- management: *self-configuring*: the ability of the system to configure and reconfigure automatically itself under varying conditions and changes in its environment; *self-optimizing*: the ability of the system to optimize efficiently its use of the resources by measuring and tuning them; *self-healing*: the ability of the system to detect instantly improper events and react to system disruptions; self-protecting: the ability of the system to detect, identify and protect against attacks.

A monitor called MMAN [21] was proposed for network management functions on MANETs. MMAN uses multiple monitoring nodes collaborating between them and a set of monitoring stations to produce an accurate up-to-time snapshot of network conditions.

Autonomic computing seems very useful in the case of MANETs, because these networks are self-creating and need to be self-managing. The application of the autonomic paradigms on MANETs is recent. In [22] Autonomous Decentralized Management Architecture (ADMA) has been proposed. This solution improves the self-configuring capabilities in MANETS by totally distributing policy-based management system. ADMA gives the system the ability to configure and reconfigure itself under varying conditions and changes in its environment without a human intervention.

Diagnostic Interplanetary Network Gateway (DING) protocol was developed to introduce monitoring capabilities in DTN technology [23]. DING uses a subscription-based model for information distribution in order to implement mechanisms for network monitoring on Bundle and lower layers that is not addressed by available mechanisms.

The study presented in [24] integrates the Open Gateway Service Initiative Vehicle Expert Group (OSGi/VEG) into an Android platform to generate a vehicular Android/OSGi platform that has the advantages of both original platforms. These features include remote management, rich class sharing, proprietary vehicular applications, security policies, easy management of Application Programming Interface (APIs), and an open environment. This study also integrates a cloud computing mechanism into the Android/OSGi platform, allowing service providers to upload their telematics bundles onto storage clouds using a provisioning server. A management agent in the Android/OSGi platform can simultaneously update its application service modules using remote storage clouds and use visual intelligence to continually change the distinguishing features of applications based on context-awareness without user intervention. To assess the feasibility of the proposed Android/OSGi platform, this study presents a vehicular testbed to determine the functionalities of different telematics applications. Android/OSGi platform applications require less memory and system resources than those on the original Android platform when performing complicated operations. Additionally, the Android/OSGi platform launches telematics services more quickly than the original Android platform. The proposed platform overcomes the problem of frequent non-responsive exceptions in the original Android platform.

In [25] an IEEE 802.11 network, the traffic load collectively given by wireless stations (WSs) is usually not fairly shared by all available access points (APs), as WSs independently select Aps to camp on. Prior approaches toward this problem either need to modify AP's behavior or require bandwidth negotiation and agreement enforcement between APs and WSs. These approaches are not practical due to their inability to apply to APs already in use. This paper proposes an application-layer approach, where a dedicated server is deployed to collects load- related information from APs utilizing SNMP (Simple Network Management Protocol). This approach applies to off-the-shelf APs and has been proven very effective through thoughtful experiments. Experimental results have clearly shown that this approach can distribute traffic load among available APs and thus significantly increase network throughput. The proposed scheme therefore resolves the unbalanced load problem that may arise in conventional IEEE 802.11 networks.

A lightweight management framework for wireless sensor networks is presented in [26]. This framework monitors the behavior of the protocol computation in each node, and recommends a set of actions to be taken in to correct some network anomaly. To do this recommendation this framework the management level computations are performed by a set of rules, instead of being computed by the object level of the protocols.

III. VDTN MANAGEMENT SYSTEM

The SNMP protocol could not be directly used in VDTNs due to the particular characteristics of these networks. In order to fill this gap, Man4VDTNs solution is proposed. This section presents the SNMP-based solution and all its features that will be deployed into a VDTN network. First, the system architecture and all it main features are presented and described. Afterwards, the construction of a MIB file, which will store all the nodes information and several metrics to be used for performance studies, will be presented. Finally, the third sub-section presents the SNMP message used by the Man4VDTN.

A. System Architecture

In a perfect world, networks would not require management, just should work properly. However, there a number of situations where it is impossible to foresee and control some anomalies that may occur. Currently, there is a continuous concern regarding to network management and ensure an efficient network performance. However, unexpected errors may occur that can jeopardize the behavior of the network. For example, if equipment breaks down, a network change occurs or a re-configuration is needed, or even if the performance of a network node is below than expected.

The SNMP protocol has become an excellent option to network administrators that intends a briefly network monitoring. This protocol allows network administrator visualize and evaluate the performance of some network equipment or links, and also allows finding and solving potential failures that can occur in the network. SNMP exposes the data configuration in MIB files placed on the managed systems in the form of variables. All the variables can be queried and sometimes set by the Network Management Station (NMS). Setting a NMS in VDTNs, it allows messages to be exchanged (sending or receiving) by different network nodes. Through the proposed solution the network manager may control and resolve anomalies that may occur in the network, once it can communicate with all the nodes. VDTN NMS performs several superficial management functions if data are analyzed to collect some specific information or the SNMP messages are exchanged. It also performs several monitoring functions, such as monitoring a new group implemented in a Management Information Base (MIB) file.

In VDTNs nodes may be fully cooperative. If all nodes follow this approach, they are able to communicate and exchange SNMP messages in order to give to the network manger the entire control of the VDTN. In order to follow this cooperative approach, an architecture where all the network nodes (terminal, relays, and mobiles) have a SNMP agent containing a MIB file is proposed. It allows the communication between the NMS and the respective node. Through implementation of this feature an optimized network management solution is assured.

Figure 1 illustrates the interaction that occurs between the NMS and the network element (terminal, relay, or mobile node). NMS exchange SNMP messages with network elements that contain a MIB file and it is responsible for monitoring, reporting, and deciding if there was a problem and the network element (agent) is responsible to answer the requests of NMS, sending values back or making changes. Firstly, all the nodes that will be managed must be manually configured in order to be able to support the SNMP messages. There are a number of proprieties that can be configured in managed nodes and define what kind of role nodes will have on network.

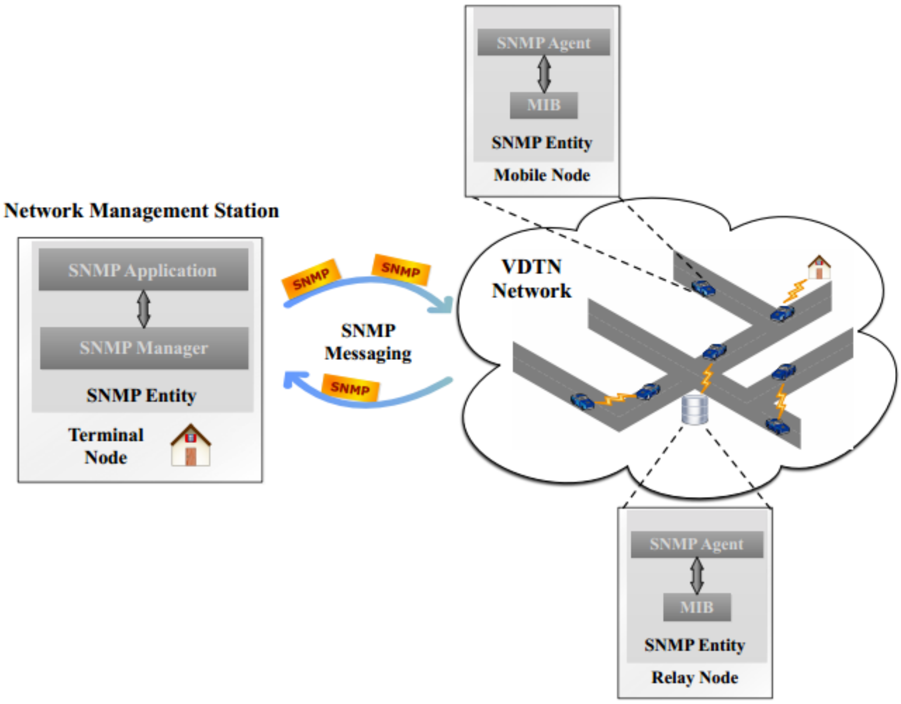

Figure 3 – Illustration of the communication between VDTN nodes and the Network Management Station.

B. Management Information Base (MIB)

To deploy the above-presented architecture, a MIB file has been created. In this sub-section the process of construction of this MIB file will be explained. First, it is important to define that a MIB is a virtual database used to store information about a certain management station in a SNMP managed network. This file is composed by several variables displayed in a tree structure.

A MIB stores information either in objects or in variables. These objects/variables contain information and definitions that the agent supports. In order to represent the MIB structure, the Abstract Syntax Notation One (ASN.1) is used. Summarizing, a MIB is a collection (dictionary) or codebook used to decipher SNMP messages. Before creating the

MIB structure correctly, an approach based on four steps was followed (Figure 2). The first step enumerates what kind of objects should be analyzed in the network. Afterwards, the specifications of the MIB object were documented. This step allows knowing the purpose of the creation of any kind of object. This document created in the previous step was organized into groups and, finally, the MIB file has been written.

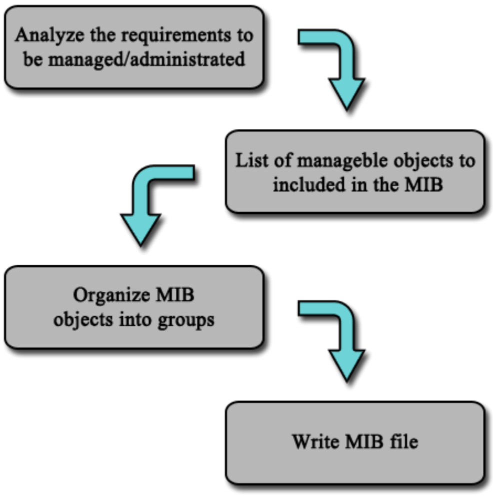

Figure 4 - The MIB file creation process.

A module to analyze the received data by the NMS was also created in order to transform the NMS in a robust and a user-friendly application. This module represents the information of the received data in a chart in order to allow the network manager to detect and identify network anomalies in a faster way to avoid the degradation of the network performance.

Aside the above-presented MIB file, a new module was created. This module is an intermediary between the SNMP application and the VDTN application that runs in each network node. It also allows Man4VDTN to collect several data that will be treated in order to get or set some information about the entire network or a specific network node. The monitoring functions were also part of this new module, once it contains all the managed objects to control all the network nodes. With this approach an important amount of properties could now be monitored using vehicular networks. Examples of these properties are the messages allocated in a node buffer, the dropped messages by that node, the delivered messages by a node, the number of established contacts by a node, the node battery status, or even the buffer space.

C. *SNMP* Message Format

To allow the exchange of multiple messages in a network the SNMP protocol may be used. This protocol makes use of four operations (GET, SET, GETNEXT, and TRAP) to establish the communication between the NMS and the agent. The GET, SET, and GETNEXT messages, the NMS is able to request, set or change an object from a managed node. The TRAP message is used to report a notification.

Figure 3 shows the structure of an SNMP message that is used in the proposed VDTN management system. The version number of the SNMP message is described in the Message Version Number, and it is used to ensure the compatibility between protocol versions. For the proposed system the considered SNMP version is the version 3. To identify the SNMP message and to match the response messages to the request messages, the Message Identifier is used. The Maximum Message Size gives information about the maximum size that its sender can receive. The Scoped PDU contains the PDU to be transmitted, along with the parameters that identify an SNMP context. This context describes a set of management information accessible by a particular entity. This PDU contains a Context Engine ID used to identify which application will receive the PDU for processing. In this solution only one application is considered. A Message Body is also considered and is composed by several fields that indicate the operation (GetRequest, SetRequest, Trap, etc.) requested by the NMS. This operation is defined in the PDU Type. Request Identifier is a number used to match requests with replies. Error Status uses an integer value that is used in a Response-PDU to tell the requesting SNMP entity the result of its request. A zero value indicates that no error occurred while other values indicate what sort of error happened. Variable Bindings is a set of name-value pairs identifying the MIB objects in the PDU. In the case of messages, other than requests, they contain their values. The security fields of the SNMPv3 message were not considered on this work but will be studied in further works.

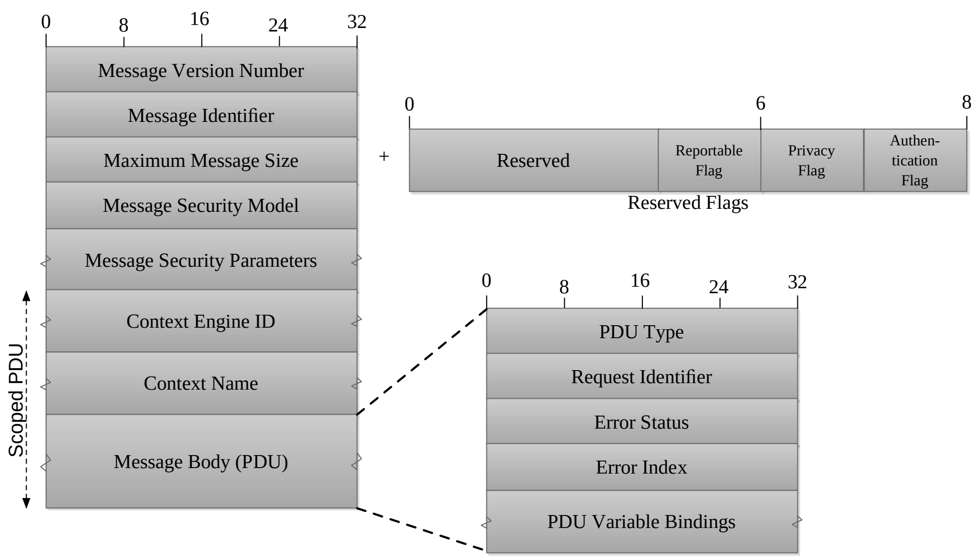

Figure 5 - SMNP general message format.

IV. System Demonstration

In order to turn VDTN@Lab more efficient, an SNMP-based solution that allows the network manager to evaluate and control all the network nodes was proposed. This solution has a number of options that allows the identification, control, and evaluation of different components of network equipment. It may be considered an innovative solution since the SNMP protocol is applied to vehicular network administration. It offers a friendly user's interface that easily allows interaction and understanding of all the application mechanisms. This section is split into two sub-sections. The first sub-section presents the application details as well as its functional requirements, while the second sub-section presents the non-functional requirements.

A. Application Details and Functional Requirements

This proposed application allows network administrator execute a number of operations that will help the network management tasks. There is a group of operations that occur before application begins. One of the first operations and, maybe, one of the most important is the MIB file loading. This process will define what kind of objects will be available for being administrated by network node. Any object that will be managed should be referenced in a MIB.

The application has an option that allows access to all the network nodes and chooses the node to analyze. Each application operation remains inactive until a node to administrate was chosen. After choosing a network node, an action that allows a graphical visualization with real time information about what happens with that node is triggered. After a node has been chosen it is possible to select the attribute that network administrator pretends to analyze.

The SNMP protocol has a particularity, beyond simple objects data access, it also allows the modification of particular objects. The network administrator can do two operations on objects, SET and GET. The GET operation, as name says, allows administrator getting the value from an object specified on .MIB file. The SET operation allows administrator change the value of an object since that has defined as a "Read-Write" object. There are properties where its access is made by default ("Read-Write") and, therefore, can be changed by the network administrator. Such properties are the node contact, name and location, and objects sysContact, sysName, sysLocation belonging to the MIB System group. Figure 4 illustrates de above-presented functionalities of the application.

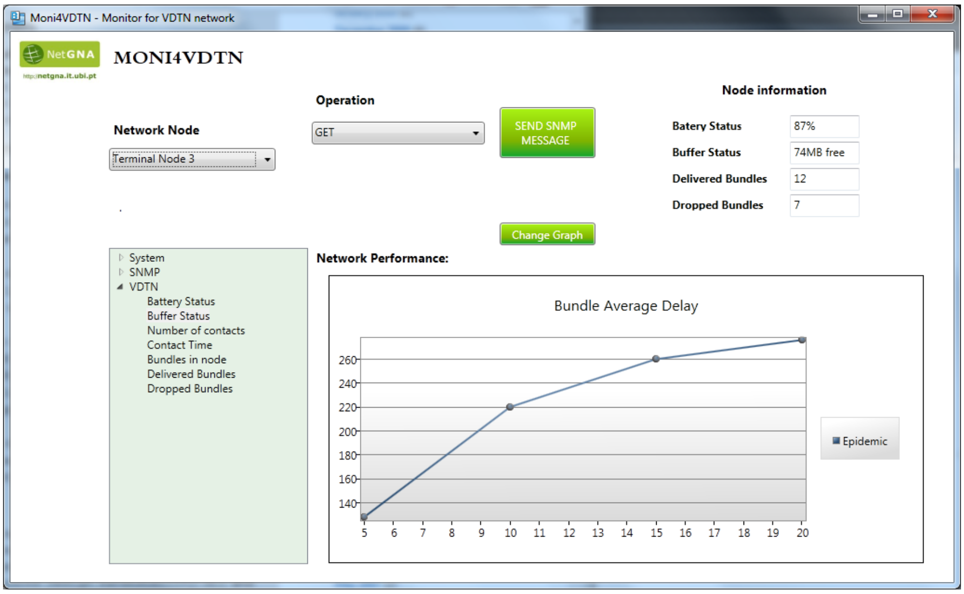

Figure 6 - VDTN Management Application.

After a rigorous requirement analyses, at an initial phase, two groups on MIB file were defined, the "*System*" and "*snmp*" groups. After, more groups may be added. Through the implementation of System group it is possible to get detailed information, such as, node description, time since last SNMP reboot (in hundredth of seconds), or the fully qualified name of the node. Through the SNMP group it is possible getting information, such as, messages that are delivered to SNMP or unsupported versions, total GetRequest PDUs that are accepted and processed, and total messages that are sent by SNMP.

As above-described, the application has a graphic component that is a very important element in network management systems (NMS). The graphic interface is activated since the moment that network administrator choose a network node and two kinds of information are presented, total messages that are delivered to SNMP, and the total messages that are sent by SNMP. Through this analyses, it is possible verify the performance of nodes, if they have or not a good behavior, and if a node is "healthy".

B. Non-Functional Requirements

This subsection presents all non-functional requirements of the developed application. The presented solution was developed using the programming language Visual C# and using the Microsoft Integrated Development Environment (IDE) Visual Studio 2010. To define the entire graphical user interface the Microsoft Expression Blend design tool was used. The solution was used and tested in Microsoft Windows 7 operative system. The application works in real time and has a user-friendly interface.

V. PERFORMANCE EVALUATION AND VALIDATION

The management system was experimented and evaluated in a laboratory VDTN testbed, called VDTN@Lab. Three terminal nodes, two relay nodes, and four mobile nodes were considered. The terminal nodes are located at different edges of the laboratory, while relay nodes are placed at crossroads. Mobile nodes have a random movement across roads. All nodes are equipped with Bluetooth and IEEE 802.11b/g devices to allow the use of different network technologies to demonstrate the out-of- band signaling with the separation of control and data planes. All nodes also have a set of software modules deployed to emulate the VDTN services. The management application was deployed on the terminal 2, without any special criteria. On relay and mobile nodes the SNMP Agent and the respective MIB file was deployed. All the SNMP solution directly interacts with the VDTN software modules. Figure 5 presents the VDTN testbed and all the interactions among nodes.

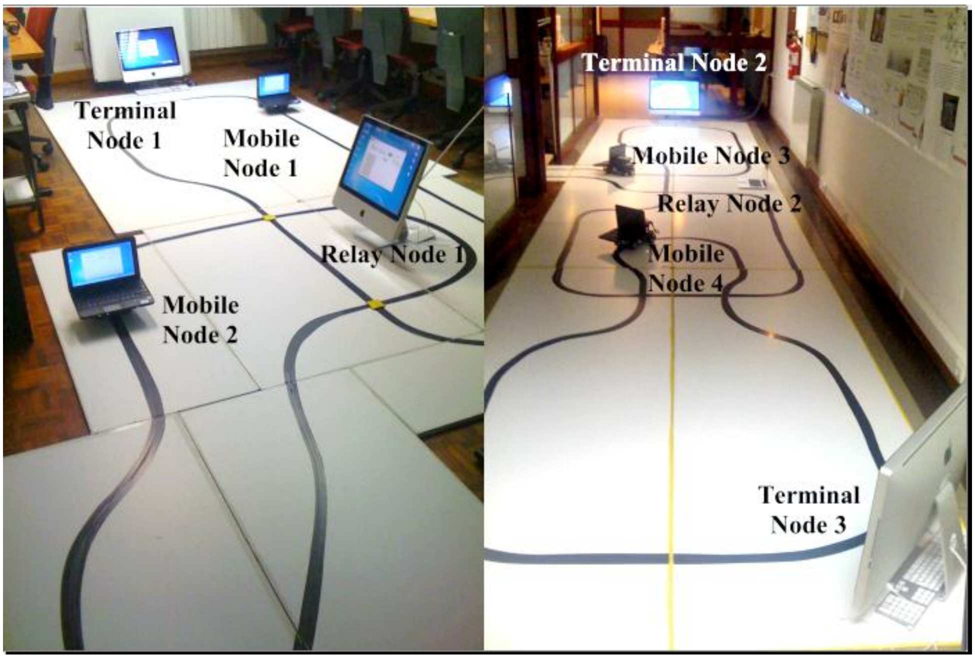

Figure 7 - Photos of the VDTN@Lab testbed.

To demonstrate this SNMP management system at VDTN@Lab, several experiments with the duration of one hour each one were performed. In terms of performance, the average delay and the average number of hops between the creation of a request in a given node and the arrival of correspondent response to the manager node were measured. The requests are performed along the testbed experiments and all of them are sent in broadcast to all the nodes. The Epidemic routing protocol is considered on this study.

During all the testbed experiments, the manager station produces several requests to all the network nodes. This requests include messages allocated in each node buffer, messages discarded by a node, number of contacts that were established between a managed node and another network node, the contact time between them, messages delivered, battery Status (reporting the energy level of a managed node), and available buffer space (the buffer space available to node receive messages). The requests about messages contain all the information, such as source and destination, time-to-live, and contained data. These SNMP responses origin large data packets. This allows demonstrating that this SNMP solution is viable under high traffic responses.

Figure 6 shows the SNMP message delay (in seconds) between the creation of an SNMP get message and the arrival of the correspondent answer for each network node, considering messages in the node buffer, messages discarded by the node, number of contacts of this node, contact time of this node with others, messages delivered by the node, battery status, and buffer space. In the figure, each bar shows the individual delay time for each request collected along the study. As an example, the bar relative to the messages in node buffer represents the time between a request by the SNMP manager to a specific node and the arrival of the corresponding response performed by the requested node. The delay for this collected information about messages in node buffer is about 300, 168, 159, 55, 276, 268, 264 and 253 for *terminal 1*, *terminal 3*, *relay node 1*, *relay node 2*, *mobile node 1*, *mobile node 2*, *mobile node 3*, and *mobile node 4*, respectively. These results show an acceptable time delay for getting the requested information from all the network nodes. Assuming the random movement of mobile nodes, the results suggest that delay time is related to the relative position of the nodes compared to the *terminal node* 2. For example, the *terminal node 1* presents the worst average delay because it is positioned at the most distant point of the testbed scenario.

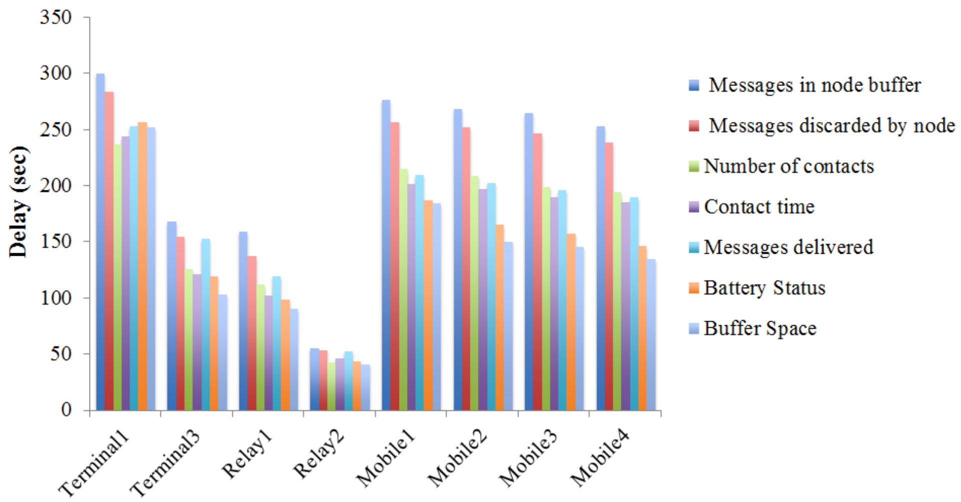

Figure 8 - SNMP message delay between its creation and the arrival of the corresponding response for all the testbed nodes.

Figure 7 shows the number of hops that requests and corresponding answers perform until reaching the SNMP manager. Like the previous example, the bar relative to the messages in node buffer represents the time between a request by the SNMP manager to a specific node and the arrival of the corresponding response performed by the requested node. The number of hops for the messages in node buffer is 12, 8, 8, 4, 7, 6, 7 and 7 for *terminal 1*, *terminal 3*, *relay node 1*, *relay node 2*, *mobile node 1*, *mobile node 2*, *mobile node 3*, and *mobile node 4*, respectively. Once again, these results emphasize the fact that position of the nodes reflects the performance of the network. Both results show that performance of SNMP on mobile nodes is very similar. This is due to the fact of the random movement of the mobile nodes and when a request is sent the position of the mobile nodes is never the same. Then, it may be concluded the strong influence of mobility models on the performance of the network.

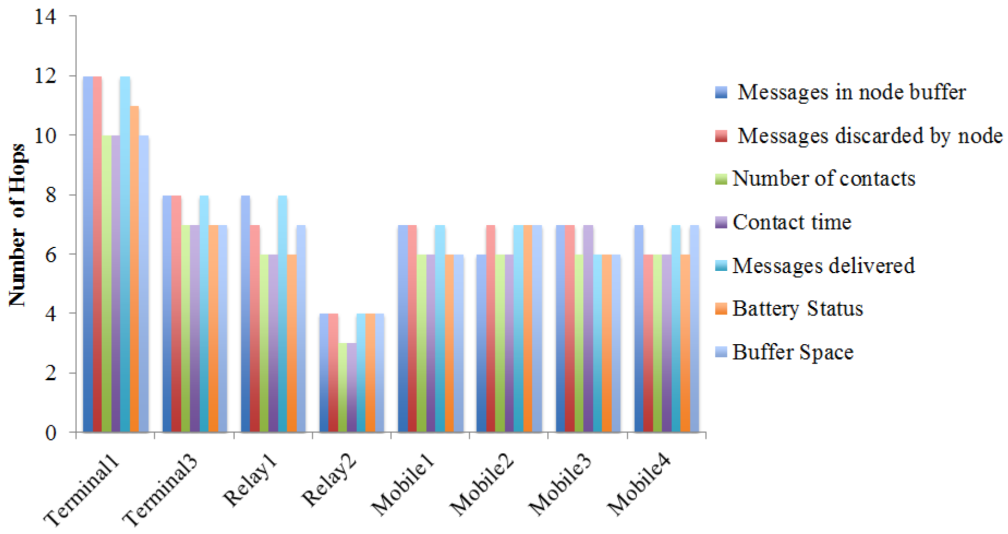

Figure 9 - Number of hops of SNMP messages for all the testbed nodes.

VI. Conclusion and Future Work

This paper proposed a network management solution based on the standard SNMP for VDTNs. It started with a review of the state of the art on network management for wireless, mobile, and vehicular networks. After, a network management solution for VDTNs based on the standard SNMP was proposed. The performance evaluation, demonstration, and validation was conducted through a VDTN testbed, called VDTN@Lab.

This approach represents an important contribution to the VDTN literature, since a monitoring system is considered a very useful tool to verify the proper network functioning. Among the functionalities of this system, network administrators could stand out the discovery of possible network anomalies and collecting important statistics for the network management.

In the proposed testbed deployment, the SNMP application is embedded in a VDTN terminal node. Then, the migration of this application to an independent solution and turn it available outside VDTNs, such as the Internet, can be considered for future work. The security mechanisms of the SNMPv3 Protocol should also be studied for future works.

Acknowledgments

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4. CONCLUSIONS AND FUTURE WORK

This chapter is organized in two sections. The first section summarizes the main conclusions of this dissertation, mainly focused on the proposal, deployment and performance analysis of a network management for VDTNs. The last section suggests further research directions that may result from this dissertation.

4.1 Main Conclusions

Throughout this dissertation the state-of-the-art of vehicular networks was presented and the Simple Network Management Protocol was studied.

The main objective of this dissertation was the implementation of a SNMP protocol in a vehicular network. With this protocol implemented we wanted to manage all network nodes in order to exchange SNMP messages to evaluate the performance and change some settings on network nodes. It was carried out with the construction of a C# application that allows a number of operations, based on SNMP protocol.

Therefore, all the objectives were successfully accomplished.

After introducing and delimiting the theme of the dissertation, describing a brief overview of vehicular networks and simple network management protocol, and showing its main contributions, chapter 2 presents the first article accomplished by this dissertation. This chapter presents a study of SNMP and the first steps for the implementation of this protocol in a VDTN laboratory testbed. Chapter 3 presents the second article accomplished and aims to demonstrate, with more results, a real implementation of a NMS using SNMP to administrate a VDTN. This article demonstrates, through images, the VDTN@Lab being monitored with the developed SNMP solution.

With the developed project, network administrator can act in network nodes and they can request and/or change nodes properties specified in MIB file. The application is constantly exchanging messages with nodes and presents them in a real-time graphic, so network administrator can see if a node has problems or not. All of these are the first big steps to create a stable solution in order to have a more efficient vehicular network.

Summarizing, the published results of this work contributed for the advance of the state of the art on network management for vehicular delay-tolerant networks.

4.2 Future Work

To conclude this work, it just remains to suggest future research directions based on current work, as follows:

- Increase the number of functionalities to the proposed NMS, such as traps;
- Increase the number of groups into each MIB in order to obtain a more precisely analyse of the network;
- Communications supported by the IEEE 802.11p protocol, protocol focused on WAVE (Wireless Access in Vehicular Environments);
- The enlargement of the VDTN@Lab testbed with more mobility models for vehicles.