

Routing Protocols simulation for Efficiency Applications in Vehicular Environments

Simulación de protocolos de enrutamiento para aplicaciones eficientes en ambientes vehiculares

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Fecha de recepción: Septiembre 3 de 2013

Fecha de aceptación: Noviembre 21 de 2013

Keywords

Intelligent Transport System,
VANET, Vehicular applications,
Ad hoc routing protocols.

Palabras clave

Sistemas inteligentes de
transporte; VANET; aplicaciones
vehiculares; protocolos de
enrutamiento Ad hoc.

Colciencias **1**
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Abstract

Recent research efforts of academia, automotive industry and transportation sector point to *Intelligent Transportation Systems* as a key technology for improving road safety, traffic efficiency and comfort driving. *Vehicular Ad Hoc Networks* (VANETs) have significant potential to enable applications for traffic safety, efficiency transportation and sustainable mobility. The dissemination methods and routing mechanisms play an essential role in the design and characterization of vehicular applications. This article provides an overview of vehicular ad hoc networks; we describe the fundamental concepts, communication standards and vehicular applications. This paper also presents a survey on routing protocols for VANETs and simulation results for Distributed Robust Geocast.

Resumen

Los recientes esfuerzos de investigación realizados desde la comunidad académica, la industria automovilística y el sector de transportes, apuntan a los sistemas inteligentes de transporte como una tecnología clave para mejorar la seguridad en las carreteras, la eficiencia en el tráfico y el confort de los conductores. Las redes vehiculares Ad Hoc [VANETs] tienen el potencial de habilitar aplicaciones para seguridad en el tráfico, eficiencia en el transporte y movilidad sostenible. Los métodos de diseminación y los mecanismos de enrutamiento desempeñan un papel esencial en el diseño y la caracterización de las aplicaciones vehiculares. Este artículo provee un marco de referencias de las redes vehiculares ad hoc, describe sus conceptos fundamentales, los estándares de comunicación y las aplicaciones vehiculares. Presenta además los protocolos de enrutamiento para VANETs y los resultados de la simulación para el protocolo Geocast Distributed Robust.

I. Introduction

Intelligent Transport System particularly *Inter-Vehicular Communications* [IVC] plays an essential role in traffic safety and efficiency transportation. The accelerated growth of urban centers around the world demands effective mechanisms for urban planning, traffic accidents avoidance and traffic flow monitoring in order to improve urban mobility based on real- time information. In this context, vehicular networks offer a technological platform for services and applications which contribute to energy saving, fuel consumption optimization and greenhouse gases [GHG] mitigation caused by transportation sector.

Since 1990, the concept of VANET took relevance in the scientific community due to advances in technology, standardization and the low costs of computational and electronic devices such as Global Positioning System [GPS] and programmable integrated circuits; in the same decade impressive results on cooperative driving provided milestones for future projects in vehicular networks in Europe, United States and Japan. At the same time, GHG emissions and energy consumption have increased due to the use of fossil fuels, which means a negative impact to global warming (Kelly & Adolph, 2008). This new trend is called Green- ITS, which contributes to mitigate the GHG emissions of the transport sector by collaborative communication systems and urban mobility planning.



Figure 1. Illustration of interactions within a vehicular environment

The rest of this paper is organized in the following sections: Section II describes the general characteristics of VANETs and reviews the communication standards IEEE 802.11p and IEEE 1609. In Section III we classify the applications for V2X networks and we also describe the simulation tools and techniques for VANETs. Section IV describes the design of VANET network layer. Section V shows results and finally Section V presents our conclusions.

II. Vehicular ad-hoc networks

A. Definition and components in VANETs

Vehicular Ad Hoc Networks are considered as an extension of *Mobile Ad Hoc Networks* [MANETs]; in a VANET each vehicle is a node of the wireless network, equipped with *On-Board Unit* [OBU]. The function of the OBU is to exchange information with other vehicles or access points in the road, called *Road Side Units* [RSU]; Figure 1 illustrates the unit's interactions. The data acquisition and the environment monitoring are collected by a sensor wireless network known as *Vehicular Sensor Network* [VSN]. The VSN senses real-time data, associated with traffic and environmental conditions (i.e. pollution, temperature, vibration, pressure, movement, etc.), the information is processed by vehicular applications in order to generate messages and send the data over the network (Karagiannis et al., 2011).

B. Characteristics

There are two (2) types of communication in the vehicular environment: vehicle-to-vehicle communication [V2V], where the nodes directly exchange messages; and vehicle-to- infrastructure communications [V2I], where the information exchanged takes place between a car and a device on the road such as tolls and Internet access points (Papadimitratos, La Fortelle, Evenssen, Brignolo, & Cosenza, 2009). VANETs characteristics are listed below:

Variant topology: Due to high speed and continuous movement of vehicles the network topology is highly dynamic.

Non-infrastructure network: V2V communications are based in the ad hoc network architecture; there is not a central authority node which manages the others. All the nodes must self-organize and self-manage the connections and transmissions.

Frequently disconnected network: The dynamic network topology causes frequent nodes disconnections; the link between the vehicles can be easily lost causing packet loss in transmissions.

Unlimited battery power and storage: The nodes have no restriction of power consumption, since the vehicles battery provides sufficient amount for the operation.

Radio-communication aspects: Radio-communication in VANETs is complex due to several factors: frequent interruptions of the radio-link, unfavorable conditions for signal propagation (diffraction, reflection, scattering, fading) and interference with other radiofrequency devices.

C. WAVE Family standards

The Intelligent Transportation Society of America [ITSA] recommended the adoption of a unique standard for the physical layer and MAC [Medium Access Control] layer for VANETs, known as WAVE, Wireless Access in the Vehicular Environment. This family of standards includes IEEE 802.11p and IEEE 1609 (Uzcategui & Acosta-Marum, 2009). Figure 2 shows the WAVE architecture.

The IEEE 802.11p defines the characteristics of the physical and MAC layer needed to operate in a vehicular environment. For the physical layer [PHY] IEEE 802.11p employs Orthogonal Frequency Division Multiplexing [OFDM] transmission. In the other hand, the purpose of the MAC layer is to establish mechanisms to access the communication channel, then a set of stations can efficiently share the wireless medium, the IEEE 802.11p standard defines the use of Carrier Sense Multiple Access/ Collision Avoidance [CSMA/CA] for V2X communication. The MAC layer also considers aspects of transmission and the probability of receiving packets, the channel access time, congestion control and prioritization of messages.

The IEEE 1609 standards family defines the operational and management aspects of the network, transport and application layer of WAVE architecture. The description of elements such as communication models, overall structure of the OBUs, RSUs and interfaces, channel switching, multichannel operation and security services for WAVE system are defined in the IEEE 1609.x standards.

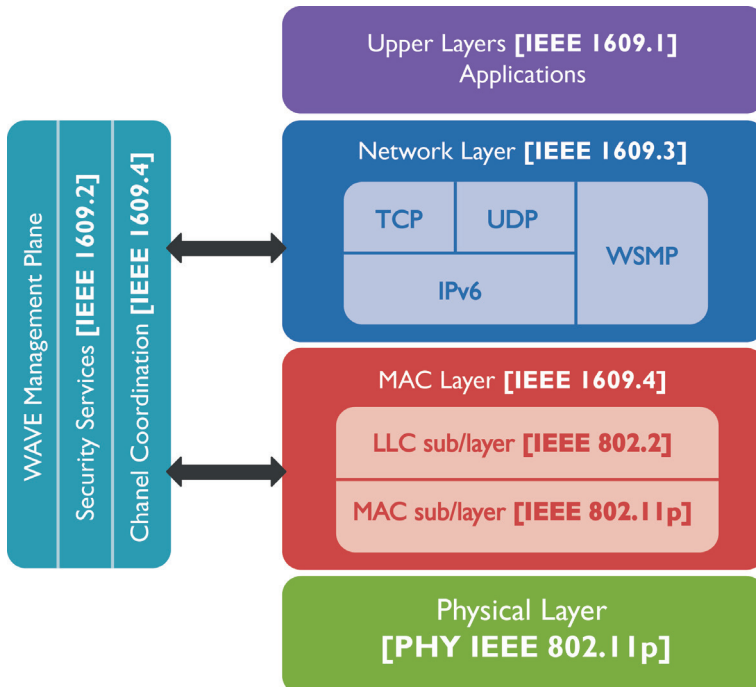


Figure 2. WAVE protocols architecture: IEEE 802.11p and IEEE 1609

III. Applications and simulations tools

A. Vehicular applications

VANETs represent an opportunity to develop applications to improve the transportation sector and the traffic conditions through collaborative systems based on V2X communications. The purpose of these Green Intelligent Transport Systems and its applications is the improvement of urban mobility through the management and monitoring of traffic flow and real time road information. Intelligent Transport Systems (ITS) are considered a valuable tool on the design of mobility models, which determine the traffic flow. The behavior of vehicles (positions, trajectory, density, etc.) provides critical data for the performance evaluation and functional urban planning, that leads to optimization of infrastructure (state of highways, intersections, tolling systems, dynamic traffic lights, etc.) and fuel consumption and GHG emissions reduce.

Efficiency applications are related with Green-ITS and these kind of systems aim to reduced GHG emissions and mitigate Global Warning. The benefits of G-ITS implementation are listed bellow (Tsugawa & Kato, 2010):

- » Reduce energy consumption and mitigate greenhouse gas emissions.
- » Optimize the use of road infrastructure.
- » Reduce the number of fatalities caused by traffic accidents.
- » Provide tools for sustainable transport and urban planning.
- » Estimate the transportation needs (highway constructions, public transportation systems, etc.).
- » Plan optimal routes in real time, reducing travel times.
- » Provide driving assistance. According to the functionality, the applications are classified in three (3) primary categories: traffic efficiency, traffic safety and commercial services and information (Dar, Bakhouya, Gaber, Wack, & Lorenz, 2010). Table 1 shows the applications classification and their environmental impact.

B. VANET simulation

VANET simulation is a valuable tool to analyze and evaluate the feasibility, benefits and requirements of ITS applications. The degree of realism and reliability of the simulation results mainly depend of two (2) aspects: the integration of a network simulator with a representative mobility model and the election of accurate metrics for results evaluation. The purpose of coupling a network simulator with a traffic simulator is to create a realistic scenario, where the mobile nodes in the topology network could be influenced by the mobility patterns in a real world map.

The network simulator software is used to model and evaluate the performance of the components in the vehicular communication systems such as protocols, standards, algorithms, configurations, channel conditions, among others. Moreover, the function of the traffic simulator is to generate a mobility model in a real topographic scenario,

Table 1. Vehicular applications classification

Impact of implementation	Category	Vehicular Application	Example of case of use
5*Fuel efficient driving	3*Traffic management	Intelligent traffic control	
		Roadways planning	Urban Mobility planning
		Toll-free traffic	
	2*Traffic monitoring	Road conditions sensing	Bottleneck elimination
53.5cmFuel consumption reduction by improving driving behavior	2*Cooperative driving	Vehicles and fleet tracking	
		Real-time notifications	
		Road signs notifications	Traffic jams notifications
	3*Assistance guidance	Updated routes and maps	
		Services announcement	Location-based information
		Parking assistances	
6*Safe driving	3*Collision avoidance	Pre-crash warning message	
		Hazardous location warning	Aware drivers of hazardous conditions
		Speed/Line change control	
	3*Incident management	Emergency vehicle alarm message	
		Healthcare center contact	Rapid and efficient response
		Post-crash warning	

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 using parameters such as vehicles speed, traffic density and road topology. Mobility patterns determine the behavior of traffic flow and provide the location, trajectory, etc., of the nodes in the topology map (Dressler, Sommer, Eckhoff, & Tonguz, 2011).

One of the key features of the simulators of VANETs is the coupling of network and mobility modules. We decided to choose Veins (*Vehicles in Network Simulation*) simulator among other simulation frameworks (TraNS, iTetris, VGSim, VSimRTI,

NCTUns and GrooveNet) (Martínez, Toh, Cano, Calafate, & Manzoni, 2011) in order to test our applications and protocols within geographic data scenarios because Veins is a V2X communication simulation framework composed of an event-based network simulator, OMNeT++, and a road traffic simulation software, SUMO (Simulation of Urban Mobility). Both models are bi-directionally coupled and the simulations run in parallel, connected by a *Traffic Control Interface* (TraCI). This allows the road traffic to have a direct impact on the network performance and vice versa.

IV. Design of vanets network layer

The VANET network layer is a very challenging field to investigate. VANETs characteristics make the normal design of the OSI 3 layer in the MANET framework not completely suitable for this special category. The routing protocols involved in the information dissemination mechanisms have to deal with these constraints. In this section, we will analyze the network attributes of applications focused on green solutions. Then we will explain what the different categories of VANET routing protocols are. Finally we will discuss in the conclusion the utility of these routing protocols for the other applications of the VANET framework.

A. Application characteristics and network attributes

Our main goal is to design and implement five (5) applications:

- » *Cooperative Collision Warning* (CCW): vehicles collect traffic information (speed, direction) to warn the driver of potential collision.
- » *Cooperative Violation Warning* (CVW): the RSU collects driving information to warn the vehicles of potential signal violation (speed, location, etc.).
- » *V2V Post Crash Notification* (PCN): Vehicles involved in a crash broadcast warning messages to approaching vehicles.
- » *Congested Road Notification* (CRN): A vehicle detects road congestion and broadcasts the information to other vehicles in the area.
- » *Traffic Probe* (TP): A probe vehicle monitors traffic information and transmits it to the next RSU. Then the RSU transmits it to a traffic management center.

In this section, we will describe for each of them the different characteristics and network assumptions. This process will help us to select the best suited routing algorithms.

Before diving into the description of the applications, it is important to have a quick look at the criteria of classification (Emmelmann, Bochow, & Kellum, 2010). For the application characteristics:

- » **Participants:** It basically specifies if it is a *V2V* or a *V2I* application.
- » **Region of interest:** it describes the geographical range of the application (long (> 1km), *medium* (~ 1km) and *short* (< 500m)).
- » **Trigger condition:** It states how the application is triggered (periodic, *event-driven*, or *user-initiated*).

- » Recipient pattern: This criteria is describing the message receiver's pattern. In other words, it says to whom the messages emitted have to be transmitted (one-to-many, *one-to-a-zone*, *one-to-one*, *many-to-one*).

For the Network attributes:

Channel frequency: describes the operational channel. We can choose between three (3) standards: *DSRC-Control Channel* (CCH), a single channel used for safety application, *DSRC-Service Channels* (SCHs), six (6) channels used for commercial applications and *Wi-Fi*. Infrastructure: specifies if we need a Road Side Unit (RSU) or not.

- » Message Time-to-Live (TTL): states the way we will forward messages. This criteria is highly correlated with the *region of interest* one. Here we have two categories: *single-hop* routing and *multi-hop* routing. We will later explain the difference between these two (2) modes of routing packets and what kind of impact they have on the design of the network layer.
- » Message packet format: specifies the network packets format used to encapsulate application messages. Here we can choose between two standards, the famous *IP protocol* or the *WAVE Short Message Protocol* (WSMP) designed within the WAVE standard framework. We will favor IP protocol when the application needs to be connected to outside of the VANET network.
- » Routing protocols: This network attribute is highly related to the *Recipient pattern* criteria. So we have basically four (4) different categories; *broadcast* (one-to-many) and *geocast* (one-to-a-zone) for safety applications and *unicast* (one-to-one) and *aggregation* (many-to-one) which are more suitable for commercial applications.
- » Network protocol initiation mode: it reflects the *Trigger condition* criteria but at the network level. There are three (3) different modes; *Beacon mode* (periodic), *event-triggered mode* (event driven) and *user-initiated- on-demand mode* (user-initiated).

On Table 2 we can see the application characteristics and on Table 3 the network attributes of the applications. CCW and CVW both share a lot of common features. But within the group of all applications, they are very specific and different from the others. There are the only safety applications that have single-hop TTL and broadcast routing protocols. The main difference between them is that CVW needs infrastructure (RSU) and CCW doesn't. This can also be seen in the application participant's criteria, CVW is V2I and CCW is V2V. The interesting characteristics for the design of the network layer are that they are single-hop and broadcast. This means that we don't need any ad hoc multi-hop routing protocol. We just forward the message to all the nodes that are in the range of transmission. Another property is that they are both triggered by beacon, so it means we are on a periodic message emission pattern. With the other applications, it becomes much more interesting in the routing protocols point of view. The main difference is that they are multi-hop, geocast / unicast and event triggered. This has huge repercussions on the network architecture. Now we need to implement routing algorithms that can handle the challenging nature of VANETs.

Table 2. Applications characteristics

Name	Acronym	Category	Participants	Region of interest	Trigger	Recipient pattern
Cooperative Collision Warning	CCW	Safety	V2V	Short	Periodic	One-to-many
Cooperative Violation Warning	CVW	Safety	V2I	Short	Periodic	One-to-many
Post Crash Notification	PCN	Safety	V2V	Medium	Event	One-to-a-zone
Congested Road Notification	CRN	Efficiency	V2V	Long	Event	One-to-a-zone
Traffic Probe	TP	Efficiency	V2I	Long	Event	One-to-one

Table 3. Network attributes

Acronym	Channel frequency	Infrastructure	TTL	Packet format	Routing protocol	Trigger
CCW	DSRC-CCH	No	Single-hop	WSMP	Broadcast	Beacon
CVW	DSRC-CCH	Yes	Single-hop	WSMP	Broadcast	Beacon
PCN	DSRC-CCH	No	Multi-hop	WSMP	Geocast	Event-triggered
CRN	DSR-SCH	No	Multi-hop	WSMP	Geocast	Event-triggered
TP	DSR-SCH	Yes	Multi-hop	WSMP	Unicast	Event-triggered

B. VANET Routing Protocols

Due to the diversity of applications in the VANET framework, we have to design specific protocols for the three main categories (Broadcast, Geocast and Unicast) (Lin, Chen, & Lee, 2010). Each category has its own challenges: Broadcast protocols are hard to design because we have to transmit the information to the whole network. Broadcasting usually generates a large amount of redundancy, contention and collision. These issues are known as the *Broadcast Storm* problem.

Geocast routing challenges are to forward the packets only to a selected region. The main goal is to solve the reliability issue due to the frequently variable topology.

Unicast routing protocols is a complex category, because we have to find a stable

route (that probably will change during the time of transmission) between the source and the receiver. The main challenge is to find a route and have recovery mechanisms when some path of the route is down.

In the following, we will analyze the two most used categories of protocols (because most of the applications use them): Geocast routing and Unicast routing protocols.

C. Unicast routing protocols

For the implementation of the TP application, we have to consider the unicast routing protocols. We can divide them in different categories (Watfa, 2010). This section is about explaining the main mechanisms of these groups of protocols. We will also walk through the pros and cons of each category.

First, we can classify all the unicast routing protocols in two (2) main classes: Topology-based routing and Geographic routing. The first one is considered as the traditional way of routing packets in MANETs. The second one is more specific to the VANET nature. We will now go through both of them. We can see on Figure 3 the anatomy of unicast routing protocols.

1) *Topology-based routing protocols*: The main characteristic of the Topology-based routing protocols is that they only use the links information. It means that we don't really care where the node is, but we just base the routing tables on which nodes are connected together. This is a very efficient method for MANETs, but let's see how it performs for VANETs. We can separate them in *proactive protocols* and *reactive protocols*. In the proactive protocols, the nodes are periodically sending route discovery packets in order to know the structure of the actual network. On the other hand, the reactive protocols are working "on demand". It is only when a node needs to transfer a packet that it will send the route discovery packet.

In the proactive routing, every node has a routing table that it updates on a periodic manner. It means at every moment t , each node knows the next hop to all the destinations. The strength of these protocols is that they provide low-latency for real-time applications. When node S (Source) needs to send a packet to node D (Destination), it just has to check in the table and send it. This is why it is very efficient. But on the flip side, it means that the network is periodically flooded with route discovery packets. Another issue with this kind of routing is that there are some paths that are almost never used but we still have to maintain the routes. It implies that we generate a lot of unnecessary traffic and therefore we lose a lot of efficiency, especially with the high mobility environment of vehicular networks.

Reactive routing presents a lot of interesting features. In opposition to proactive routing, the discovery mechanism is triggered only when a node wants to communicate and the route is maintained only during the transmission of packets. This permits to reduce flooding of the network and avoid the unused path problem. But as it is always a tradeoff, what we gain in network traffic, we lose in time of transmission. Let's get back to our example where node S wants to send a packet to node D. This time node

S has to start with the discovery phase to find a route from S to D. When it finds the route, it then can send the packet. So the time to transmit information is longer. This mechanism suits better the nature of VANETs: because we are in a highly mobile environment the route are changing very fast. So it is better to find a route at the time of transmitting, because we are sure that this route is still up. The most known reactive protocols are *Ad hoc On demand Distance Vector* (AODV) and *Dynamic Source Routing* (DSR).

Topology-based routing is definitely not the best solution for VANETs. These protocols were not designed to cope with nodes that are moving so fast. Lochert et al., (2003) performed some evaluation studies on these protocols and the results are that they all have the same problem: performance degrades as the network density increases. The main issue is the route discovery mechanism. Because it is based only on links information, the routes are always changing and the nodes have to perform several route discovery phases to succeed in transmitting packets to another node. This generates a surplus of traffic that congestions the network.

2) *Geographic routing protocols*: The position-based routing algorithms forwarding mechanism is based on the location of the destination node. This means that all nodes are aware of their proper location. This is why geographic routing requires a GPS (Geographic Positioning System). Every node is sending a beacon to figure out which other nodes are in the range of communication. They become the one-hop neighbor nodes. In order to prevent collision, the beacons are sent with a random *Packet Delay Variation* (PDV) to avoid collision of the beacon packets. The main strength of this category of protocols is that we don't need to establish a route to forward a packet. Let's revisit the example of node S wanting to transmit to node D. Node S will forward his packet to the one-hop neighbor node that is the closest of node D and so on until reaching it. This strategy has a flaw but we will discuss it and the way we solve it later. Geographic routing protocols contain three (3) main categories: *None Delay Tolerant Network* (None-DTN), *Delay Tolerant Network* (DTN) and *Hybrid*. The None-DTN is designed for highly dense network because if there is no route between two nodes (disconnectivity) the packet is lost. DTN permits to keep these packets in the node until they can deliver the packet to a closest node. This is why there are more designed for sparse network. Hybrid systems combine the two modes. They are designed to cope with partially connected network.

The first three (3) subdivision of None-DTN are *Beacon*, *None-Beacon* and *Hybrid*. We will only focus on the *Beacon* category because it contains the most diversified and mature protocols. Within this category we can classify the protocols in two (2) classes: *Non-Overlay* and *Overlay* routing protocols. These are the main interesting categories for our applications.

None-DTN principal mechanism is to forward the packets to the next hop closest to the destination node. This greedy approach has a flaw, it can happen that no other node is closer to the destination than the node itself but it cannot reach the destination. We

call this particular node the *local maximum*, because that's the furthest local node that the packet can travel to. If all the protocols in this category are based on this approach, each of them handles the local maximum issue in its proper way. The principle of Beacon protocols is that each node is periodically sending its location information to all of the nodes that are in the range of communication. Like this each node is aware of the position of its neighbors.

With the None-Overlay routing algorithms, every node has the same importance. However, with the Overlay routing algorithms, some nodes are more important for the routing protocol. They are called the overlaid nodes. It is very similar to the concept of peers and super peers in a Peer-to-Peer network. The overlaid nodes make the biggest part of the processing job. In the context of a vehicular network, we can easily see that the most important decisions are taken at the crossroads. Hence, the nodes that are located on these junctions are the chosen ones. The routing along the roads is easier because it is always in the same direction

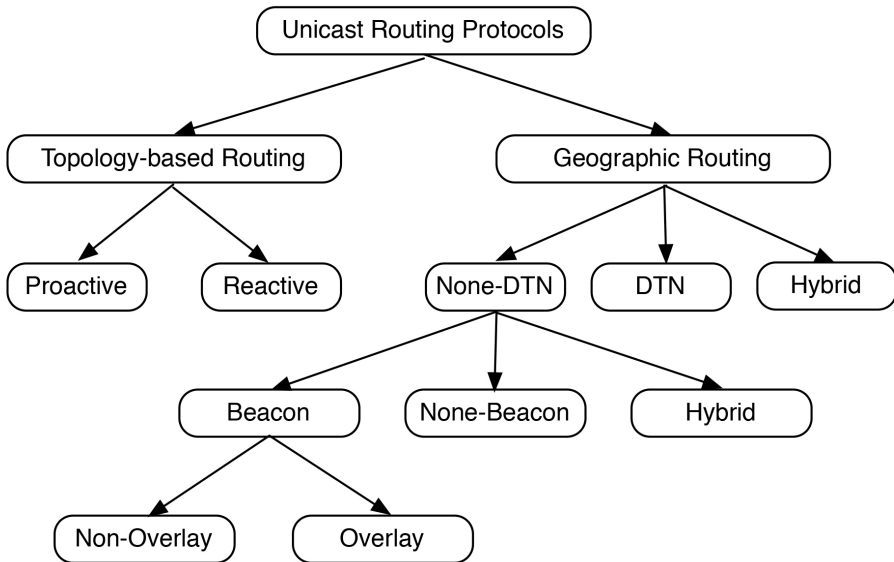


Figure 3. Unicast routing protocols anatomy

V. Results and discussion

We have performed simulations in a city scenario in order to evaluate the effectiveness and performance of the Distributed Robust Geocast protocol. For that purpose, we have used *SUMO* to model a local topographic scenario of the city of Cali (Colombia), and geodata has been obtained from the *OpenStreetMap* project.

We have used safety application parameters as reference for the evaluation of the performance of DRG. The critical latency for safety applications is up to 100 ms, Figure 4 shows the latency obtained for diverse coverage areas that vary from 500 m

to 4000 m; the impact on the end-to-end delay can be observed as the zone of relevance is larger. Larger distance to the intended receivers require more hops, therefore it takes longer to propagate the messages over the network. It is important to mention that even though the latency increments, the nodes up to 4000 m are receiving the geocast packets within the expected time. This reflects the effectiveness of this geocast protocol for safety and efficiency applications, we observe that for 1500 m - the zone of relevance for most safety applications - the efficiency is an 85% lower (14.85 ms) than the maximum delay accepted at the zone of relevance.

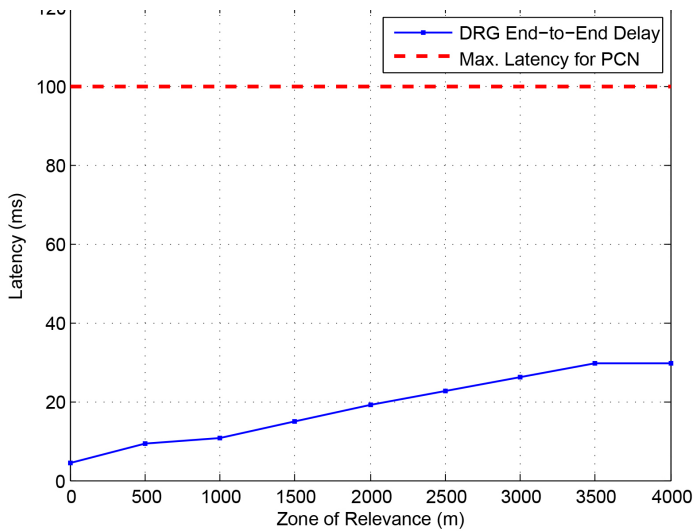


Figure 4. End-To-End Delay with variation of the Zone of Relevance.

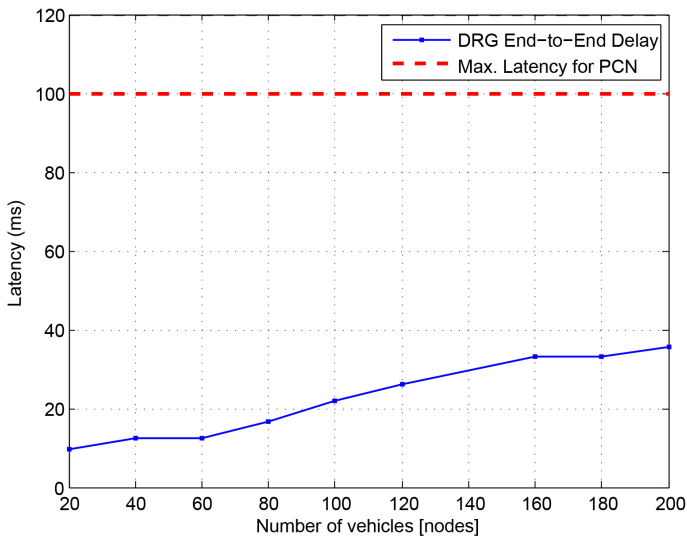


Figure 5. End-To-End Delay with variation of the number of nodes within the Zone of Relevance.

The effect of the vehicle density is depicted in Figure 5. It can be observed that the end-to-end delay gradually increases as the number of nodes increments, which is an expected behavior. When the traffic is denser, DRG meets the expected delay requirement - less than 100 ms - in the zone of relevance.

Conclusions and future work

Vehicular networks enable a technological platform in order to enhance safety driving and mobility of the transportation sector. The design and evaluation processes of vehicular applications may be simulated by bidirectionally coupled simulators, which integrate network and traffic behavior. The network layer has to be re-designed in order to comply with the VANET applications challenges. That is why several categories of protocols have to be tested before the final implementation. The unicast protocols are not suitable for safety oriented applications because we don't need to have a *one-to-one* communication, but rather a *one-to-many*. Geocast protocols are used with safety and efficiency oriented applications. However, the nature of the routing modules will be depending on the particular characteristics of each application and its requirements.

Our future work mainly concentrates on assess the network performance of the selected applications in order to infer the most suitable protocols for the vehicular environment; and then extend our results to all the set of VANET applications.SM

Acknowledgment

The authors would like to thanks Colciencias (Administrative Department of Science, Technology and Innovation) for supporting this project under the program "Young Researchers and Innovators".

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