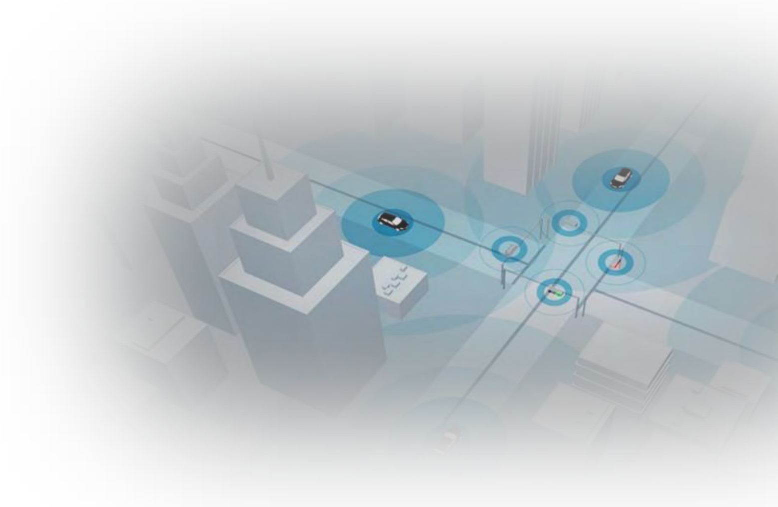

Intelligent social routing and information storage in vehicle networks

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Έξυπνη κοινωνική δρομολόγηση και αποθήκευση πληροφορίας σε περιβάλλοντα δικτύων οχημάτων

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Τμήμα Ηλεκτρολόγων Μηχανικών και Μηχανικών Η/Υ

Πανεπιστήμιο Θεσσαλίας

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To my family,

Dimos, Marianthi and Sofia

Abstract

Vehicular Ad-hoc Networks (VANETs) are a new technology which has taken enormous attention in the recent years. VANETs are a special case of mobile ad-hoc networks (MANETs). They enable the exchange of information between vehicles without any fixed infrastructure. VANETs can be formed either between vehicles providing vehicle to vehicle communication or between vehicles and an infrastructure units offering vehicle to infrastructure communication. These networks have several properties that distinguish them from MANETs. Nodes (vehicles) are highly mobile, the probability of network partitions is higher, end-to-end connectivity is not guaranteed and they have the potential to grow to a very large scale.

One of the most challenging fields in VANETs is routing. Due to rapid topology changing and frequent disconnections makes it difficult to design an efficient routing protocol for routing data among vehicles. However, due to intensive research in the field, many routing protocols were especially developed for MANETs and applied on VANETs.

In this thesis, we concentrate on the design of a routing protocol detecting influential nodes in a VANET that can be able to disseminate a message to as many vehicles as possible within the network. We propose a new approach of Range Probabilistic Control Centrality (RPCC) measure, the Probabilistic Control Centrality (pCoCe) which considers both the significance of a node estimating the influence region of it and the number of neighbors that are covered by this node. The new approach constitutes an on-demand routing protocol, which offers reliable and valid topology information. Yet, the only disadvantage is the charge of time delay due to exchange of messages concerning control centrality measures. The concept of stem significance will help us to identify such nodes. Range Probabilistic Control Centrality measure is based on control theory and designed and evaluated in dynamic complex networks.

Our protocol is compared to Optimized Link State Routing Protocol (OLSR), a IETF standard for Mobile Ad Hoc Networks. The basic mechanism of OLSR is the creation of Multipoint Relay Set, which consists of nodes satisfying the criterion of coverage’s number of two hop neighbors.

A comparison between two protocols is presented and is related to the coverage rate of the network, namely how many nodes receive a message within the network, the number of relays that each protocol choses to re-transmit a message and finally, the distance that a message can be disseminated from the initial sender, in terms of number of hops. The evaluation results illustrate the wider coverage rate that the proposed method achieves.

Περίληψη

Τα δίκτυα οχημάτων είναι μία καινούρια τεχνολογία, η οποία έλαβε τεράστιας προσοχής τα τελευταία χρόνια και είναι μία ειδική κατηγορία των κινητών δικτύων. Τα δίκτυα αυτά καθιστούν ικανή την ανταλλαγή πληροφορίας μεταξύ των οχημάτων χωρίς καμία δικτυακή υποδομή. Μπορούν να διαμορφωθούν είτε μεταξύ οχημάτων παρέχοντας απ’ ευθείας επικοινωνία ανάμεσα σε αυτά είτε μεταξύ οχημάτων και οδικών υποδομών. Υπάρχουν αρκετές ιδιότητες, οι οποίες κάνουν να δίκτυα οχημάτων να ξεχωρίζουν από τα κινητά δίκτυα. Οι κόμβοι, δηλαδή τα οχήματα, είναι υψηλής κινητικότητας, η πιθανότητα διαμελισμού του δικτύου είναι μεγάλη, δεν υπάρχει εγγυημένη επικοινωνία από άκρη σε άκρη και τέλος, υπάρχει η προοπτική αύξησης σε πολύ μεγάλης κλίμακας δίκτυα.

Ένα από τα πιο δύσκολα πεδία των δικτύων οχημάτων είναι η δρομολόγηση πληροφορίας. Εξ’ αιτίας της ραγδαίας αλλαγής στην τοπολογία και των συχνών αποσυνδέσεων είναι πραγματικά δύσκολο να σχεδιαστεί ένα αποτελεσματικό πρωτόκολλο για τη δρομολόγηση της πληροφορίας μεταξύ αυτών. Λόγω όμως του έντονου ερευνητικού ενδιαφέροντος σε αυτό το πεδίο, πολλά πρωτόκολλα δρομολόγησης αναπτύχθηκαν για περιβάλλοντα κινητών δικτύων και στη συνέχεια εφαρμόστηκαν σε δίκτυα οχημάτων.

Σε αυτήν τη διπλωματική εργασία, επικεντρωνόμαστε στο σχεδιασμό ενός πρωτοκόλλου δρομολόγησης της πληροφορίας ανιχνεύοντας ισχυρούς κόμβους, οι οποίοι είναι ικανοί να διαδώσουν ένα μήνυμα σε όσο το δυνατόν περισσότερα οχήματα μέσα στο δίκτυο. Προτείνουμε μία νέα προσέγγιση του μέτρου Πιθανοτικό Εύρος του Ελέγχου της Κεντρικότητας (RPCC), τον Πιθανοτιτκό Έλεγχο της Κεντρικότητας (pCoCe) η οποία λαμβάνει υπόψη και τη σημαντικότητα ενός κόμβου εκτιμώντας την περιοχή στην οποία ασκεί επιρροή αυτός, αλλά και τον αριθμό των γειτονικών κόμβων, οι οποίοι καλύπτονται μέσω αυτού του κόμβου. Η νέα προσέγγιση αποτελεί ένα κατ’ απαίτηση πρωτόκολλο δρομολόγησης, το οποίο προσφέρει αξιόπιστη κα έγκυρη τοπολογική πληροφορία. Ωστόσο, το μοναδικό μειονέκτημα είναι η επιβάρυνση της χρονικής καθυστέρησης λόγω της ανταλλαγής μηνυμάτων, που αφορούν τη μετρική του ελέγχου της κεντρικότητας. Η έννοια της σημαντικότητας του μονοπατιού θα μας βοηθήσει να αναγνωρίσουμε τους ζητούμενους κόμβους. Η μετρική του RPCC βασίζεται στη θεωρία ελέγχου και σχεδιάστηκε και αξιολογήθηκε σε δυναμικά σύνθετα δίκτυα.

Το παραπάνω πρωτόκολλο συγκρίνεται με το πρωτόκολλο δρομολόγησης της βελτιστοποιημένης κατάστασης σύνδεσης (OLSR), ένα προορατικό πρωτόκολλο δρομολόγησης. Ο βασικός του μηχανισμός είναι η δημιουργία ενός συνόλου πολλαπλών αναμεταδοτών (MPR set), το οποίο αποτελείται από κόμβους που ικανοποιούν το κριτήριο κάλυψης γειτόνων που βρίσκονται δύο γειτονιές μακριά.

Στη συνέχεια της εργασίας, παρουσιάζεται μία σύγκριση μεταξύ των δύο πρωτοκόλλων, η οποία σχετίζεται με το ποσοστό κάλυψης του δικτύου, δηλαδή πόσοι

κόμβοι μέσα στο δίκτυο έλαβαν ένα μήνυμα, τον αριθμό των αναμεταδοτών που επιλέγει το κάθε πρωτόκολλο και τέλος την απόσταση που μπορεί να καλύψει η διάδοση ενός μηνύματος από τον αρχικό αποστολέα, σε όρο «αριθμός των γειτονιών» (hops). Η εκτίμηση των αποτελεσμάτων δείχνει το ευρύτερο ποσοστό κάλυψης που πετυχαίνει η προτεινόμενη μέθοδος.

Contents

1. Introduction

Intelligent Transportation Systems (ITS) can be defined as the application of advanced information and communication technology to surface transportation in order to achieve enhanced safety and mobility while reducing the environmental impact of transportation. The addition of wireless communications offers a powerful and transformative opportunity to establish transportation connectivity that further enables cooperative systems and dynamic data exchange using a broad range of advanced systems and technologies.

Figure 1: Intelligent Transportation Systems
Source: http://www.etsi.org/images/files/membership/ETSI_ITS_09_2012.jpg

Vehicular Ad Hoc Networks are part of ITS. Due to rapid growth of the number of the cars on streets, the need for safe driving is required. To enhance the safety of drivers and provide comfortable driving environment, messages for different purposes need to be sent among vehicles through inter-vehicle communications.

Safety applications can decrease significantly the number of the accidents, since they can warn earlier the drivers and prevent an accident from happening in the first place. Also, they can be used to provide drivers information about the best route for their destination avoiding road congestions. Additionally, user applications can provide infotainment to passengers. This type of applications offers the possibility to road users to enjoy internet access, exchange information about restaurants and hotels or even more, share music or play interactive games with nearby cars. How delightful would be such a journey!

However, in order to achieve all these applications routing protocols should be designed. The term *routing protocol* specifies how nodes communicate each other, disseminate information and gain knowledge about network topology. A routing protocol defines the route that information follow in order to be sent. Nevertheless the design of a routing protocol in Mobile Ad Hoc Networks and concretely, in Vehicular

Ad Hoc Networks is more complex than in networks with static nodes, due to major problems they confront: high rate of topological changes and limited bandwidth. Thus, the goal of an efficient routing protocol is to be rapidly adapted to the new topology caused by nodes movement. Moreover, the dissemination of a message should not be unreasonably done by a node due to limited bandwidth. In order to avoid technical problems, suitable nodes should be defined as responsible re-transmitters of a message.

The aim of this work is to identify appropriate nodes to act like relays spreading a message within the network. In our routing protocol, these nodes either exert influence to a region closely to sender's neighborhood or provide access to nodes two hops away from sender. The proposed method is the Probabilistic Control Centrality (pCoCe) and it constitutes a new approach of Range Probabilistic Control Centrality method (RPCC).

The rest parts of this work are organized as follows: Chapter 2 firstly introduces Wireless Ad hoc Networks and Mobile Ad Hoc Networks which constitute the base of Vehicular Ad Hoc Networks providing their most important characteristics and it is followed by a detailed description about VANETs and their features. In chapter 3 are described the simulation tools that are used for the purposes of this work. Chapter 4 is related to an IETF standard routing protocol, OLSR. In chapter 5 we introduce our proposed control centrality-based VANET routing protocol, pCoCe. In chapter 6 the two methods of selecting relays in a Vehicular network are evaluated and finally, in chapter 7 we conclude our work while we propose future tasks.

2. Vehicular Ad Hoc Networks

Before we continue to a detailed description of VANETs, it is important to understand the wider concept of Ad Hoc Networks. The next two sections give a brief outline of Wireless Ad Hoc Networks and Mobile Ad Hoc Networks which are the foundations of Vehicular Networks.

2.1. Introduction to Wireless Ad Hoc Networks

In wireless networks the term *Ad Hoc* means the directly communication among the nodes of the network. It is allowed to all wireless devices within a range of each other to communicate in peer-to-peer way without involving any central access points.

A *wireless ad hoc network* is a decentralized type of wireless network, as shown in Figure 2, and does not rely on a pre-existing infrastructure [1]. The nodes communicate over wireless links and they have to contend with the effects of radio communication, such as noise, fading, and interference.

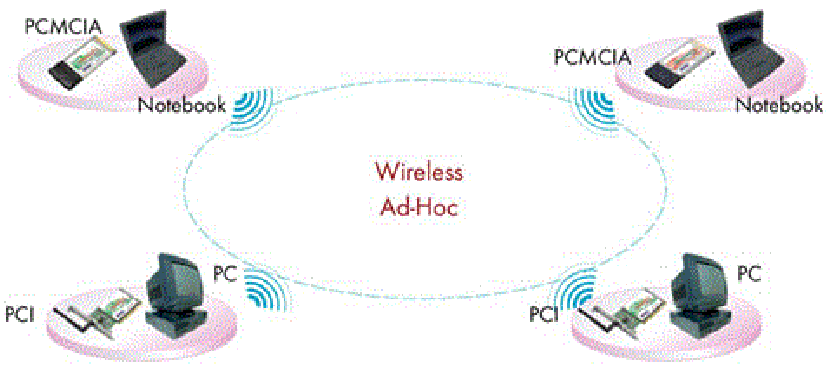

Figure 2: An example of ad-hoc network

The network topology is in general dynamic, because the connectivity among the nodes may vary with time due to node departures, new node arrivals, and the possibility of having mobile nodes. Each node in a wireless ad hoc network functions both as a host and a router, and the control of the network is distributed among the nodes. As a result, each node participates in routing by forwarding data for other nodes, so the determination of which nodes forward data is made dynamically on the basis of network connectivity. Ad hoc networks can use flooding technique for forwarding data, but this method floods the network with redundant messages and leads to contention and collision problems. Hence, there is a need for efficient routing protocols to allow the nodes to communicate over multi-hop paths consisting of possibly several links in a way that are not used additional resources of the network than necessary. The presence of dynamic and adaptive routing protocols enables ad hoc networks to be formed quickly including the identified theoretical and practical limits such as node's resources

(e.g. transmission power, memory) and link properties (e.g. signal loss, noise, interference).

The decentralized nature of wireless ad hoc networks, the minimal configuration and quick deployment make them suitable for a variety of applications, like applications for emergency situations. For example, natural disasters or military conflicts.

Finally, there are three major types of wireless ad hoc networks:

- **Mobile ad hoc networks (MANETs):**
  A MANET is a self-configuring infrastructure-less network of mobile wireless devices, which will be discussed in more details later.
- **Wireless sensor networks (WSNs):**
  A WSN consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. Modern networks provide bi-directional communication enabling control of sensor's activity. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance. Today WSNs are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring [2].

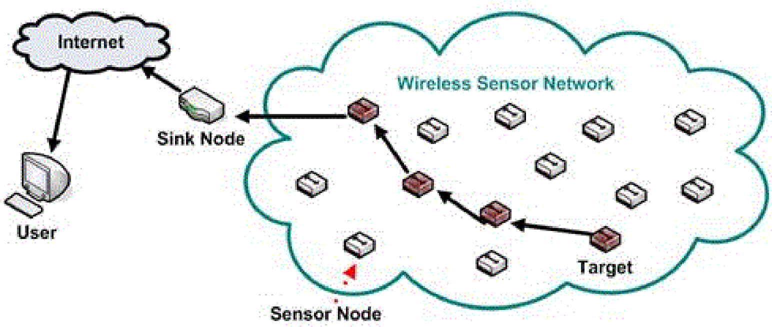

Figure 3: An example of WSN
Source: http://monet.postech.ac.kr/research.html

- **Wireless mesh networks (WMNs):**
  A WMN is a communication network made up of radio nodes organized in a mesh topology. Wireless mesh networks often consist of mesh clients, mesh routers and gateways. The mesh clients are mostly laptops, cell phones and other wireless devices while the mesh routers forward traffic to and from the gateways. The coverage area of the radio nodes working as a single network is called a mesh cloud. A mesh network is reliable and offers redundancy. When one node can no longer operate, the rest of the nodes can still communicate with each other, either directly or through one or more intermediate nodes [3].

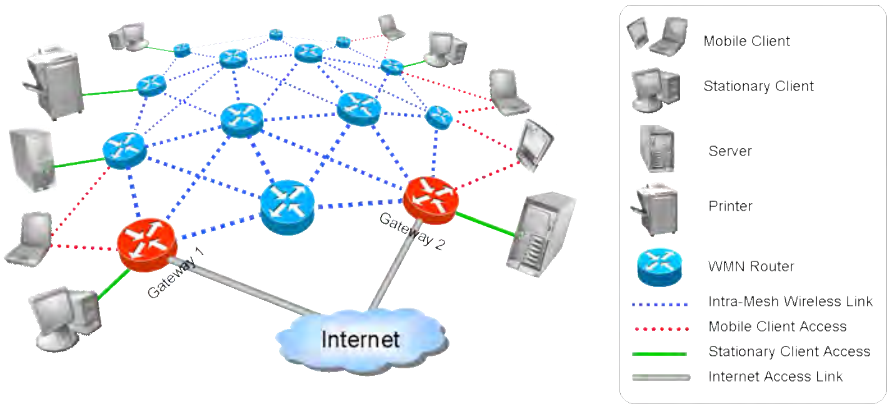

Figure 4: An example of WMN
Source: http://www.ece.ncsu.edu/wireless/WMN/intro.html

2.2. Introduction to Mobile Ad Hoc Networks (MANETs)

As it was mentioned above, a MANET is a kind of Wireless Ad Hoc Network and constitutes a set of mobile wireless devices without any existing infrastructure. It is a self-configured network and its basic characteristic is that devices can freely move in any direction [4]. As a result, there are frequent changes of links among them. Due to high mobility of the nodes, frequent disconnections and delay constraints should be addressed. Additionally, each device forwards data unrelated to its own use and acts like a router. For this purpose, each node is equipped with a mechanism to maintain the required information to properly route traffic. Many routing protocols designed for MANETs consider all the above limitations.

Mobile Ad Hoc Networks can be divided into the following types:

- **Vehicular Ad Hoc Networks (VANETs):**
  VANETs are used for communication among vehicles and between vehicles and roadside equipment. We will discuss VANETs in the next section with more details.
- **Internet based mobile ad hoc networks (iMANETs):**
  iMANETs are ad hoc networks that link mobile nodes and fixed Internet-gateway nodes. In such type of networks normal ad hoc routing algorithms do not apply directly.
- **Intelligent vehicular ad hoc networks (InVANETs):**
  InVANETs are a kind of artificial intelligence that helps vehicles to behave in intelligent manners during vehicle-to-vehicle collisions, accidents, drunken driving etc.

It is worth to mention that a MANET is an ad-hoc network but an ad-hoc network is not a MANET.

2.3. Introduction to Vehicular Ad Hoc Networks (VANETs)

A Vehicular Ad Hoc Network is a special case of a MANET network, where the nodes are represented by vehicles or Roadside Units (RSUs).

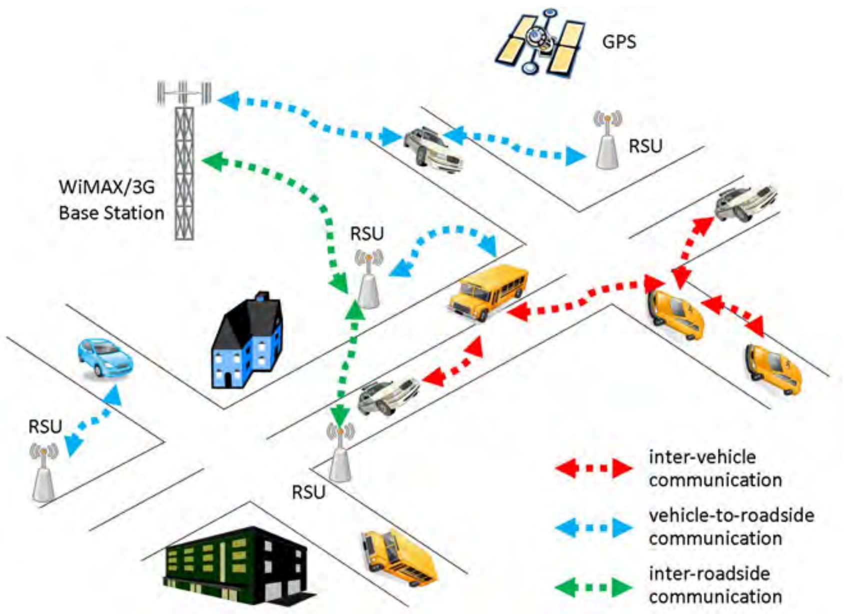

Figure 5: An example of VANET

Source: http://www.thebookmyproject.com/cars/optimal-content-downloading-vehicular-networks/

Starting with the idea of making driving safer by inter-vehicle communication, the concept of vehicular networks or vehicular ad hoc networks (VANETs) has been extended to a large collection of various applications that can profit from wireless communication among vehicles. Nowadays, vehicles are not only envisioned to communicate between each other, but also to get information from and send data to infrastructural units. The **communication mode** is divided into two major types:

- **Vehicle to Infrastructure communication (V2I)**
- **Vehicle to Vehicle communication (V2V)**

as shown in Figure 5.

The communication range is related to technology that is used and does not exceed 1km. Vehicles within the same communication range directly communicate and define the *one hop neighborhood*.

Network Characteristics

One of the most essential aspect of mobility in VANETs is the potential *node velocity*. Node velocity may range from zero when a node represents a RSU or the vehicle is stuck in the traffic jam to over 150km/h on the highways. The characteristic of high mobility leads to limited duration of communication, since the transmission range does not exceed several hundred meters. Consider two vehicles that are driving in opposite directions with 90km/h each. If we assume a theoretical wireless transmission range of 300m, the communication is only possible for 12s. Also, the transceivers have to cope with physical phenomena like Doppler effects ending to confront frequent link failures. These short encounters between vehicles render routing protocols essentially challenging.

Movement patterns in VANETs can be predictable or not. It depends on the type of road where the vehicles move. Highways are multi-lane roads, where the direction is usually one-way. On the other hand, the roads in a city are smaller than the roads in a highway and intersections can cut road segments into small pieces. The traffic in a city is basically unordered and the unpredictable behavior is occurred mostly at intersections.

The third key property of Vehicular Networks is *node density*. In a low density network the dissemination of an immediate message is almost impossible, especially when there are no other vehicles in transmission range. Information should be stored and be forwarded when vehicles encounter each other. In this case, a message may be repeated by the same vehicle multiple times, in order to be spread in the network. On the contrary, in high density networks only selected nodes should re-transmit the message in order to avoid collision problems and an overloaded channel. It is worth to mention, that the density of the network is not only correlated to the type of road but also to time. It is widely observed that traffic jams are created during daytime, while at night the traffic in a city is usually sparse.

Applications in VANETs

Applications in VANETs can be classified into three main categories:

- **Safety applications**
- **Efficiency applications**
- **Comfort applications**

The applications presented in Figure 6 are derived from work on [5] and constitute a classification of the existing ITS applications.

Safety applications are responsible to reduce the risk of an accident. They can be used for collision avoidance meaning the warning of a driver when there is a possible collision at an intersection. An example of collision avoidance is a safe distance application which is used to dynamically adjust distance from the vehicles ahead and

speed to a recommended value dependent on the actual traffic situation. Road Sign Notifications applications are used to provide drivers information related to traffic signs further down the road. An application of this type is the curve speed warning, which informs the driver about the curvature, the curve speed limitation and the road surface condition. Finally, in safety applications are incorporated incident management applications, which are responsible to inform drivers about an unfortunate incident, such as post-crash warning, which notifies approaching traffic about a vehicle having an accident.

Efficiency applications are utilized to manage traffic flow and monitor vehicle and road conditions. Traffic flow on the roads can be managed by an intelligent traffic flow control application, which is an infrastructure application and periodically broadcasts messages collecting information about the traffic in the nearby region. It is also helpful to the driver to know about the road condition using a road condition monitoring application which can be combined with safety applications.

Last but not least, *comfort applications* or *user applications* can provide road users with tourist information, advertisements and entertainment facilities during a long journey. The latest can offer the passengers the possibility to enjoy distributed games with passengers in surrounding vehicles, while restaurant information can be provided to those who are interested to finding out the nearest restaurant.

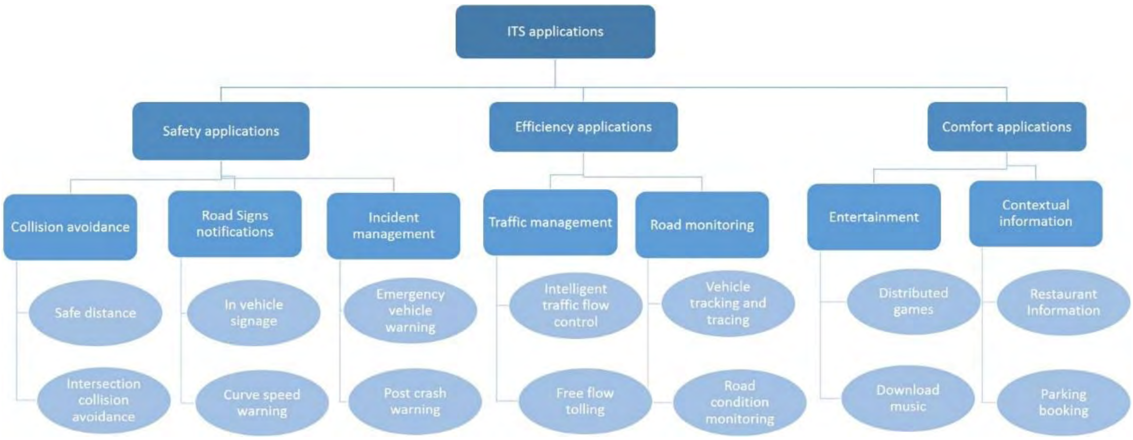

Figure 6: Existing ITS applications [5]

Wireless Communication Technologies in VANETs

The research community has been very proactive in the recent years with ongoing research regarding many aspects of VANETs. One of the major breakthroughs was the **IEEE 802.11p** wireless Standard, an approved amendment to the IEEE 802.11 standard, also known as WLAN, to offer **Wireless Access in Vehicular Environments** (**WAVE**). It was developed as the existing IEEE 802.11a/b/g standards presented shortcomings related to support of parallel medium access attempts of senders due to

utilization of Carrier Sense Multiple Access (CSMA)[1] [5]. On the other hand, WAVE is required to support ITS applications in short-range communication, ensure immediate, stable and high speed data transmission, and maintain information security. The ancestor of WAVE was Dedicated Short Range Communication (DSCR), a short range communication service, which was designed to support communication requirements for safety applications used in vehicular environments and based on IEEE 802.11a. IEEE 802.11p operates in the 5.9 GHz band (5.85-5.925 GHz), defines a transmission range between 300 m to 1 km, the signal bandwidth is at 10MHz and the date throughput ranges from 3 to 27 Mb/s [7].

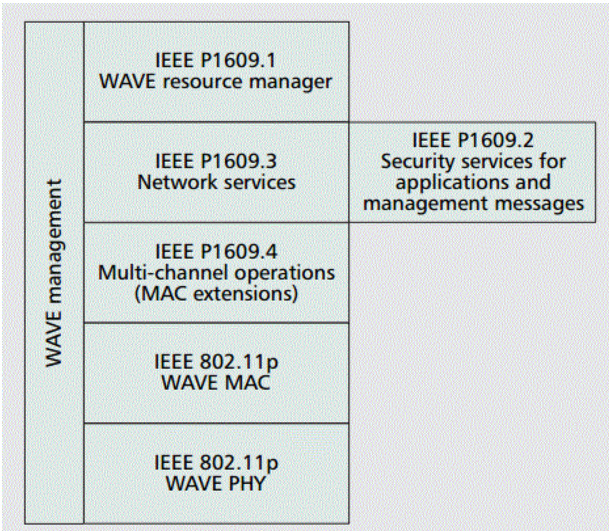

Figure 7: IEEE 802.11p in the IEEE P1609 standard family [7]

Besides the IEEE 802.11p, WAVE also contains the standard of IEEE P1609. The IEEE 1609 Family of Standards defines an architecture and a complementary, standardized set of services and interfaces that collectively enable secure vehicle-to-vehicle and vehicle-to-infrastructure wireless communications [8]. IEEE P1609 is the upper layer standard of IEEE 802.11p and offers several management protocols, such as resource manager, security, network services and channel selection. Figure 7 shows the complete structure of WAVE.

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[1] Carrier sense multiple access (CSMA) is a probabilistic media access control (MAC) protocol in which a node verifies the absence of other traffic before transmitting on a shared transmission medium [6].

3. Simulation tools

In order to design and implement routing protocols for Inter-Vehicle Communication, the working environment may be defined. This work is based on SUMO, a road traffic simulator, OMNET++, a network simulator and finally VEINS, a simulation framework composed of the above simulators and based on the work in [9].

3.1. Simulation of Urban Mobility – SUMO

SUMO is an open – source microscopic traffic simulator licensed under General Public License (GNU) and developed by Institute of Transportation Systems at the German Aerospace Center [10] using C++ standard. It is highly portable and it designed to handle large road networks. The aim of SUMO is to simulate the moving of a given traffic in a given road network. It is characterized as a microscopic simulator meaning that each vehicle is modelled explicitly, moves individually through the network and has its own route. Also, it updates the position of each vehicle every time step, which gives SUMO the feature of time-discrete vehicle movement. This traffic simulator also provides an OpenGL graphical user interface and all configuration and data input are accepted in the form of XML (eXtensible Markup Language) files.

SUMO allows users to create a road network containing buildings and streets. Streets are represented as a collection of lanes, including the position, the shape and the speed limit of every lane. The connections between lanes are named junctions and they include the right-way regulation. Also, traffic lights can be added to junctions to offer smooth traffic. The .nod.xml file contains the description of road network nodes, junctions, while the .edg.xml file describes the connections among lanes, named edges. However, it is also possible to import a road network from different format (e.g. OpenStreetMap, PTV VISUM, or OpenDrive) and convert it into a SUMO network. The creation of road networks is achieved using SUMO tool, NETCONVERT. The output is a .net.xml file, which constitutes the global description of the created network.

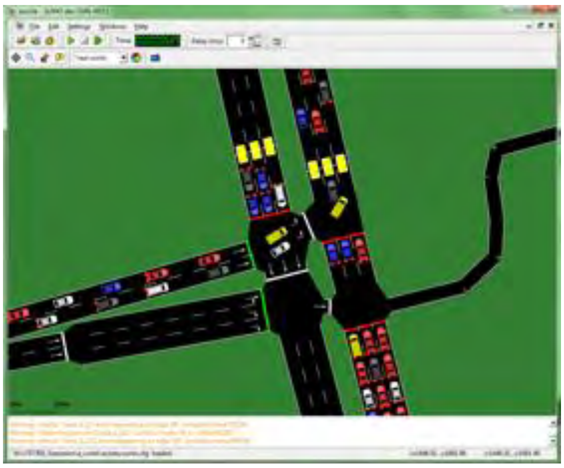


Figure 8: An example of road network simulation in SUMO

After having the generated network a traffic demand is needed to be defined, namely the description of vehicles and their routes. A route contains the start edge that a vehicle departs, the last edge a vehicle arrives and all the intermediary edges a vehicle will pass. There are SUMO tools to create routes and trips, such as DUAROUTER tool, but also the user can generate XML files (.rou.xml) by hand determining the type of vehicle and the routes. Vehicles in SUMO can be vary among busses, taxis, private cars, motorcycles and bicycles. Even more pedestrians can participate in

simulations. Features like vehicle's velocity, acceleration, type or driver's reaction and imperfection are described in these files to provide more realistic simulations.

3.2. OMNeT++

OMNeT++ is a C++ based object oriented discrete event simulator and focuses on simulations of communication networks like wired and wireless networks. Due to its generic and flexible architecture, it can also be used for modeling of multiprocessors and other distributed hardware systems. All these functionalities are provided by frameworks, developed as independent projects. OMNeT++ was developed at the Technical University of Budapest, Department of Telecommunications (BME-HIT) [11] and its use is for academic purposes. It offers:

- Simulation kernel library
- NED (NEtwork Description) topology description language
- OMNeT++ IDE based on the Eclipse platform
- GUI for simulation execution, links into simulation executable (Tkenv)
- Command-line user interface for simulation execution (Cmdenv)
- Utilities (makefile creation tool, etc.)
- Documentation, sample simulations, etc.

OMNET++ itself is not a simulator but provides infrastructure and tools for designing simulations. Its architecture consists of components, named *modules.* These reusable components communicate via gates exchanging messages and combined to form compound modules using high-level language (NED).

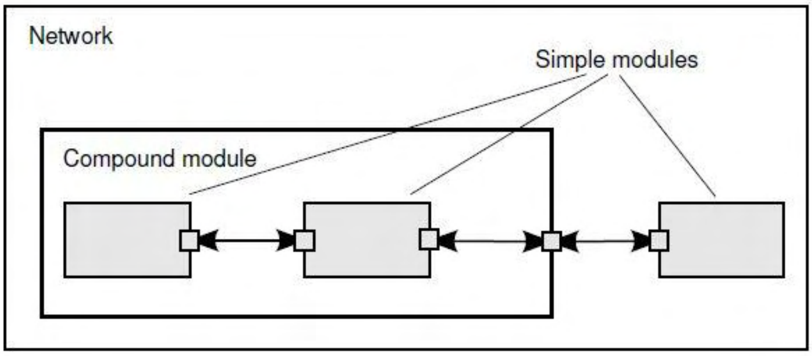


Figure 9: Simple and compound modules [11]

Modules can have parameters, which are assigned either in NED files or in the configuration file *omnetpp.ini.* The latest contains settings that control how the simulation is executed, values for model parameters or the number of simulation runs.

The main simulation frameworks of OMNeT++ are:

- **INET Framework,** which contains models for the Internet stack (e.g. TCP, UDP, IPv4 etc.), wired and wireless link layer protocols such as Ethernet and IEEE 802.11, support for mobility, MANET protocols and many other protocols and modules. INET framework is considered the standard protocol model library of OMNeT++.
- **INETMANET,** which is kept up to date with INET Framework in order to offer more experimental properties and protocols, especially for MANETs.
- **MiXiM,** which is created for mobile and fixed wireless networks like wireless sensor networks and vehicular ad hoc networks. It offered detailed models of radio wave propagation, interference estimation, radio transceiver power consumption and wireless MAC protocols [12].
- **Castalia,** a simulator for networks of low-power devices like Body Area Networks (BAN) providing realistic simulation parameters.

3.3. Vehicles In Network Simulations – Veins

Veins is an open source framework for vehicular network simulations consisting of SUMO and OMNeT++ simulators to tender a complete suite for Inter-Vehicle communication (IVC). It was designed by Transportation and Traffic Science community. Veins is part of MiXiM framework of OMNeT++ adding support for IEEE 802.11p and IEEE 1609 family - WAVE technology. Thus, this framework handles Wave Short Messages (WSM) and provides beaconing WAVE services, access categories for QoS and multi channels operations[2].

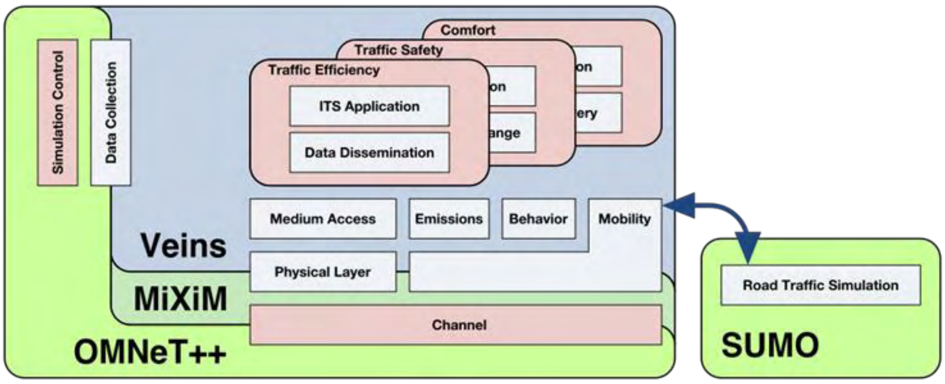


Figure 10: Bidirectional communication between OMNeT++ network simulator and SUMO road network simulator
Source: http://veins.car2x.org/documentation/

In order to perform IVC simulations, SUMO and OMNeT++ run in parallel and are connected via TCP socket. This communication offers bi-directionally coupled simulation of road traffic and network traffic [9]. Traffic Control Interface (TraCI) is

[2] QoS: Quality of Service
Vehicles periodically switch Control Channel (CCH) and Service Channel (SCH) [15]

the standardized protocol for the above communication. Figure 10 shows how the two simulators interact. As a result of bidirectional connection, movements of vehicles in road simulator SUMO are reflected in network simulator OMNeT++ as movement nodes and nodes in OMNeT++ can affect the movement of vehicles in SUMO. In Figure 11 is presented an example of this kind of communication between two simulators. It shows how messages (commands and responses) are exchanged in order for a vehicle's max speed to be changed.

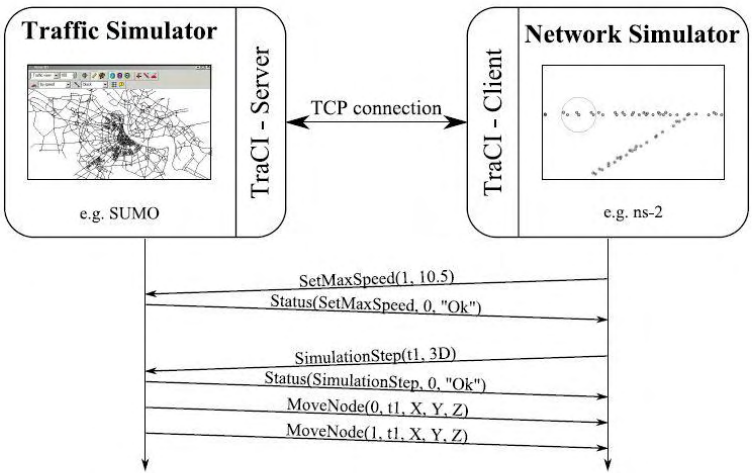


Figure 11: An example of interaction between traffic simulator and network simulator using TraCI [13]

Traffic Control Interface - TraCI

As already mentioned, **TraCI** is the provider for bidirectional communication between traffic simulator and network simulator. This communication is achieved via TCP based server/client architecture. Traffic simulator acts like a server, as is shown in Figure 11 while network simulator operates like a client. This connection is accomplished via a Python script which proxies TCP connections, starting a new copy of SUMO simulator for every network simulation connecting. The client is responsible for shutting down the connection. Figures 12 and 13 show how a connection is established with SUMO and how this closes, respectively. The client sends commands to server to retrieve information about traffic condition or to change a module's status. The server answers with a Status-response to each command. Moreover, the server informs client in each simulation step about vehicles positions in order to achieve the reflection as movement nodes in network simulator. The information that can be retrieved from SUMO is related to features of the road network environment such as traffic lights, routes, vehicles properties or information about the simulation, e.g. the number of loaded vehicles in a simulation time-step. Likewise, network simulator can change a state in SUMO through TraCI. For example, increase or decrease a vehicle's speed.

All the above functionalities are offered in Veins through TraCIMobility module controlled by TraCIScenario Manager.

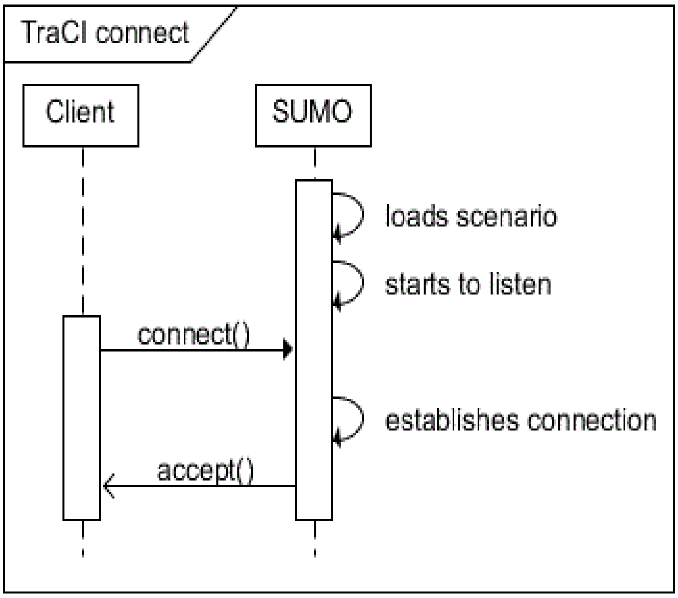


Figure 12: How a connection is established between client Network Simulator and server SUMO-traffic simulator using TraCI [14]

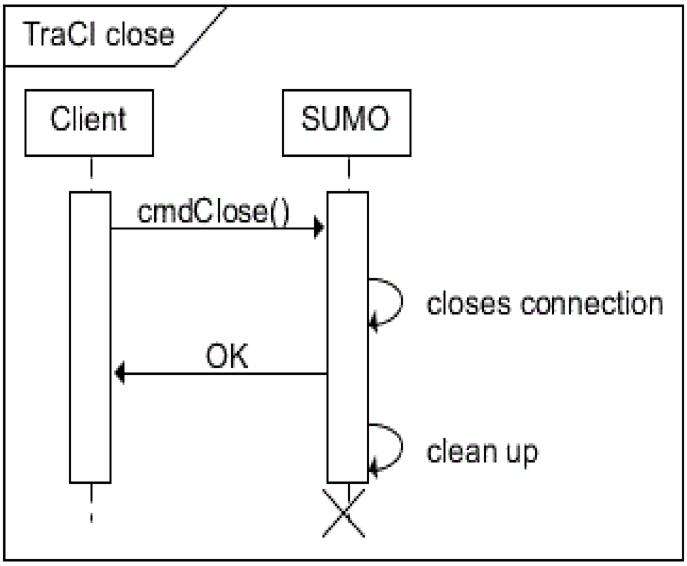


Figure 13: How a connection closes between client Network Simulator and server SUMO-traffic simulator using TraCI [14]

4. An IETF standard routing protocol

4.1. Introduction

Control traffic in vehicular networks is the topology information in which a node declares its position and its neighborhood. This information is usually exchanged among nodes that are in the same communication range and communicate directly (one-hop neighbors). Through this information a node obtains a better comprehension about the current topology of the network. Due to the mobility of nodes in a Vehicular ad hoc Network the connections among nodes have limited lifetime. Hence, the topology information should be frequently updated by each node in order for it to maintain valid topological consciousness.

Besides topology information, messages are also sent in the network. As aforementioned, many routing protocols have developed for VANETs derived from Mobile Ad Hoc Networks. These protocols can be divided into two basic types: proactive and reactive. Reactive protocols attempt to discover routes only when there is a data packet to be sent flooding their query in the network. This type of protocols reduces control traffic overhead at the cost of increased latency in finding the route to the destination. On the other hand, proactive protocols maintain a routing table by sending periodic control messages that contain topology information. The required nodes are immediately provided when needed, at the cost of bandwidth used in sending frequent updates of topology. A different type of developed routing protocols are geographic ones, which make forwarding decisions based on geographical position of the destination of a packet.

As is obvious, a message can be either destined for a specific node or is need to be spread among all the nodes. When a message is created for a specific destination, all the intermediate nodes namely the nodes which form a path from source-node to destination-node, agree upon a mechanism to re-transmit this message in order for the destination-node to successfully receive the message.

The problem is created when a message is not destined for a specific node, but it should be received by as much as possible more nodes within the network. In this case, it should be defined which nodes re-transmit the message. An example of such a case is the announcement of an accident. The easiest way to solve this problem is the pure flooding technique. By this way, every node that receives the message for the first time, re-transmits it. The drawbacks of this method are the redundant retransmissions charging the network with duplicate messages and consuming a large amount of bandwidth, which is limited. Furthermore, the possibility of collision problems is existed, since many nodes simultaneously re-transmit the message.

The need of having nodes acting as relays passing the message among nodes reducing the message overhead is now present. This requirement led to the consumption of the idea of *Multipoint Relays*, selected nodes that are responsible for the

retransmission of a message. The next section describes the OLSR protocol, an IETF standard for MANETs.

4.2. Optimized Link State Routing Protocol (OLSR)

Optimized Link State Routing protocol, OLSR, is n IETF standard [20] designed for Mobile Ad-Hoc Networks and applied to Vehicular Ad Hoc Networks. Due to its proactive nature, it has an advantage of having routes immediately available when needed. OLSR performs a periodic exchange of messages in order to maintain topology information related to both local neighborhood and topology among nodes in the entire network. This protocol is an optimization of pure link state protocol, which relies on employing selected nodes to retransmit a message among the nodes of the network instead of pure flooding. The selected nodes are called *multipoint relays* and constitute the basic feature of OLSR.

OLSR uses three different types of messages to gain knowledge about network topology: HELLO, TC and MID messages.

- HELLO messages are periodically exchanged between local neighboring nodes (1-hop distance) containing information about neighbor nodes. HELLO messages allow to a node to recognize the current one and two hop neighborhood. These messages are transmitted in the broadcast mode and received by all one-hop neighbors.
- TC (Topology Control) messages are generated periodically by each node in the network to announce its multipoint relays set.
- MID messages are generated by nodes running OLSR in more than one interface and flooded throughout the network by multipoint relays.

Multipoint Relays Selection

The idea of multipoint relays is based on the reduction of broadcast messages due to flooding technique by decreasing the number of duplicate re-transmissions in the network. Each node selects a set of neighbor nodes, which are the re-transmitters of a message. This set of nodes is called *Multipoint Relays*, MPR set. The rest of them, namely the neighbors of any node *x* in the network that are not belong to the MPR set, read and process the message packet but they do not re-transmit it. This technique works in a distributed manner, since each node can compute its MPR set independently of other's nodes selection of their set.

The concept of this method is a node to select a number of one-hop neighbors that cover all the two-hop neighbors. The required information for the creation of MPR set is the knowledge of one hop and two hop neighborhood. This information is known from HELLO messages that are periodically exchanged among nodes. The algorithm of the selection of relays is described below and based on work in [16].

Let x to denote a node of the network, N(x) the set of one-hop neighbors, N^2(x) the set of two-hop neighbors and MPR(x) the selected multipoint relay set.

1. *Start with an empty multipoint relays set, MPR(x)*
2. *First select those one-hop neighbor nodes in N(x) as the multipoint relays which are the only neighbor of some node in N^2(x), and add these one-hop neighbor nodes to the multipoint relay set MPR(x)*
3. *While there still exist some node in N^2(x) which is not covered by the multipoint relay set MPR(x) :*
    a. *For each node in N(x) which is not in MPR(x), compute the number of nodes that it covers among the uncovered nodes in the set N^2 (x)*
    b. *Add that node of N(x) in MPR(x) for which this number is maximum.*

Many studies have evaluated the performance of OLSR protocol either in MANETs or VANETs. In [16] is proved that finding a MPR set with the optimal size is NP-hard complete reducing the problem to Dominating Set Problem. In [17], the authors show that the protocol is able to flood messages efficiently without destroying the connectivity of the network. Finally, in [18] OLSR is evaluated in VANETs and it is indicated how the configuration parameters can affect the performance of an efficient routing strategy.

5. A control centrality-based VANET routing protocol: pCoCe protocol

5.1. Range Probabilistic Control Centrality (RPCC)

In the point of view that relays, nodes that act like re-transmitters for a message, can be the most influential nodes within a network**,** RPCC measure is proposed in [19]. Range Probabilistic Control Centrality (RPCC) is a method for identifying influential nodes in complex networks, such as VANETs, using probabilistic links. The identification of that nodes is accomplished using RPCC measure, which includes both the strength of links, meaning the quality of a connection and assesses the region that each node exerts influence. In a vehicular network the quality parameter of a communication link can range from value 0, noting the absent of a connection to 1 indicating a perfect communication. For the purposes of this work, we consider that this parameter takes only the values 0 and 1. RPCC method utilizes the term *stem significance, ssf* and it is defined as:

ssf = sizeOfStem * weightOfStem

where *stem* is a directed path starting from an initial node and all the intermediate nodes appear only once, *sizeOfStem* is the number of edges in a stem and *weightOfStem* is the product of its weights. The bigger the value of ssf the bigger the influential of a node in the network.

In [19] authors suggested two approaches to achieve their goal. The first one is called RPCC with Cycle Extraction ($RPCC_{CE}$) and concerns the adjustment of control centrality measure in probabilistic graphs that contain stems and cycles. The existence of a cycle impels the definition of *cycle significance, csf* as:

*csf = cyclePointer * weightOfCycle * (sizeOfCycle + 1)*

where *cyclePointer* is the weight of the edge through which the cycle is visited, *weightOfCycle* is the product of the weights of the edges that form the cycle and *sizeOfCycle* is the number of its edges. k-RPCC measure of a node is computed summing the stems and cycles significances within a k range after the extraction of all incoming links of the node and the cycle extraction procedure.

The second approach is named **RPCC without cycle extraction ($RPCC_C$)** and is the point of our interest in this work. This technique computes the importance of a node within a k range summing only the stem significances regardless of the existence of a cycle. The algorithm of this computation is given below:

1. *Remove all the incoming links of a node*
2. *Calculate and sum the stem significances*

Though this method it is estimated in how many ways a portion of a network can be controlled by a node, since a path can be accessed by more than one nodes. For example, assume the paths x → y → z and x → w → z. That shows that node x have access to node z by two different paths. The 2-RPCC value for node x is 4 considering that the weights of links are 1. As already mentioned, the bigger the value of a node's control centrality measure the more influent the node.

5.2. Probabilistic Control Centrality (pCoCe)

The aim of the routing protocol is the dissemination of a message within a broader region within the network beyond the close neighborhoods. To achieve this, a set of re-transmitters should be defined. We study how the above mentioned methods behave within a vehicular network. First of all, we have to mention that we are interested in information spread at intersections where the behavior of movement patterns is unpredictable. Moreover, the chosen relays are *outgoing* nodes. It is easy to understand the notion of an outgoing node in a directed graph. Let's take as example the directed graph in figure 14. Node 11 has outgoing neighbors the nodes 2, 9 and 10 while nodes 5 and 7 are incoming to it.

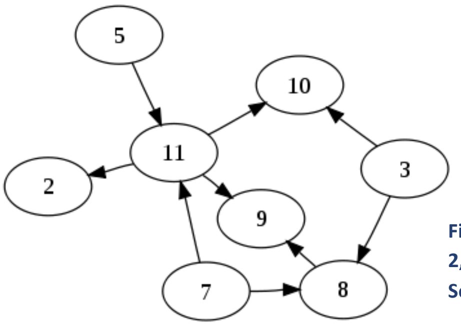


Figure 14 : An example of a directed graph showing that nodes 2, 9 and 10 are outgoing nodes to node 11.
Source: http://en.wikipedia.org/wiki/Directed_acyclic_graph

In a VANET, vehicle A is outgoing to vehicle B when A is moving either in front of B or away from B in an opposite direction. Figure 15 illustrates a snapshot of the road network explaining the notion of outgoing nodes in a VANET. Thus, each node has to separate the incoming and outgoing nodes either these are one hop neighbors or two hop creating outgoing stems. According to OLSR protocol, the multipoint relay set aims to cover all the nodes that belong in two-hop neighborhood, but since we are interested in finding the most influential nodes we target in coverage of all two hop outgoing neighbors. As is perceived, the interested range that we need to study is 2, two hops away from the starting point of a message, so the k-$RPCC_C$ method is applied to this value range.

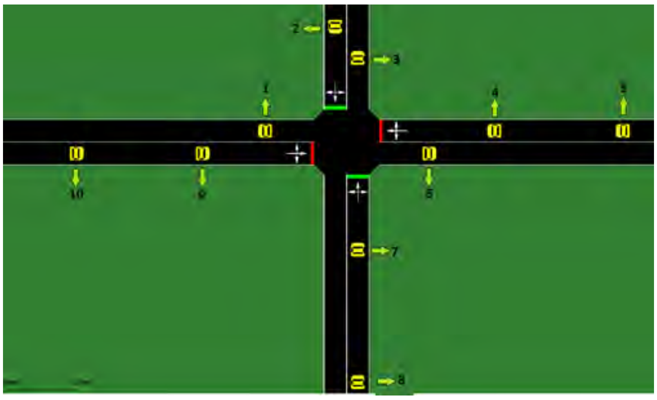


Figure 15: A snapshot from a simulation illustrating how outgoing nodes are defined in VANETs. In this example, vehicle 7 has outgoing neighbors the vehicles 1, 3 and 6 while vehicles 2, 4, 5, 8, 9 and 10 are incoming to it.

In this protocol, vehicles periodically exchange beacon messages (WAVE Short Messages) that act like HELLO messages in order to discover their neighbors. These messages are broadcasted within transmission range and indicate direct communication among nodes, one hop neighbors. Beacons include information related to the name of node, the coordinates of its position, the lane on which the vehicle travels and information about one hop neighborhood. The latter is required for identification of two hop neighborhood. When a node receives a beacon firstly evaluates if the sender is a new or an already existed neighbor node, in which case the receiver updates the timestamp of their communication noting that there is still communication between them and secondly determines if the sender is an outgoing neighbor. If the second is true, then the set of outgoing two hop neighbors that come from the sender will be defined. In order for a node to have a better and more valid percept of its neighborhood, it regularly has to update the sets of one and two hop neighbors and remove nodes from whom did not receive a beacon the last time period. It is known from the default parameters of network simulator OMNeT++ that beacons are sent every 1 sec. Hence, the time interval that an update is performed is set up in 2 seconds.

A node is arbitrarily defined as initial sender. Before the message is sent, the sender has to check if the set of outgoing two neighbors has been created. If this set has not created yet, the node has to wait till the creation of the respective neighborhood. On the other hand, if there are such neighbors at the decision time, the sender has to choose the relays using either the technique MPR set of OLSR protocol or the method of $RPCC_C$ measure. After the selection, the message is ready to be sent including the ids of nodes that are responsible for the retransmission of the message.

When a message arrives, each node reads the set of relays and determines if it belongs in it or not. If a node is not a relay then it continues its route without doing furthermore actions. If a receiver node is characterized as re-transmitter, then it repeats the above procedure trying to spread the message in more nodes.

At this point, it is important to describe the need of the proposed metric. According to the definition of $RPCC_C$, each node computes its own centrality measure

adding the stem significances values. In our first attempt to apply this metric, we consider that each node computes its centrality measure based on stems that are created from outgoing nodes. This value is exchanged among one hop neighbors via beacons. Thus, when a node, either the initial sender or a re-transmitter, has to decide about the relays, it sorts these values in ascending order and beginning from the first value chooses the suitable nodes that cover all the outgoing two hop neighborhood similarly with the MPR selection in OLSR protocol (steps 1, 3a, 3b). The problem in this approach is the inaccurate information about centralities and is created when a neighbor has outgoing neighbors, which are incoming to the node that takes the decision. As a result, the value of centrality can be increased affecting the decision of relays, since it includes information about uninteresting nodes. Also, the size of the set can be significantly grown because of nodes selection that have an appreciable value of control centrality but unfortunately they do not cover many two hop neighbors of the decider. Due to two-way roads, this scenario is specifically shown at intersections. The aim is the creation of a small relay set identifying the nodes that are both influential within the network and also they offer access to nodes two hop away.

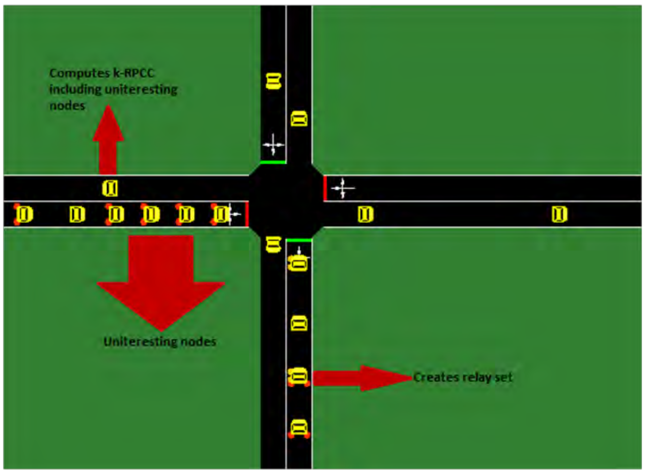


Figure 16: An example that shows that an outgoing neighbor has outgoing neighbors that are incoming to the node which creates the relay set.

A solution to this issue is an on-demand computation of control centrality values. **pCoCe** takes into account both the significance of a node and the number of two hop neighbors that are covered by a node. Before a node sends a message, it firstly broadcasts a request asking from one hop neighbors to compute their centralities. If a receiver is an outgoing neighbor, then it computes its control centrality measure, pCoCe, excluding all the nodes that are incoming to the sender. This is feasible, since the position information is already known. The sender waits until it receives the answers. When all the answers are received a new procedure begins. The sender comprises the number of two hop neighbors that are covered by each node to the respective centrality value. In order for these values to be comparable in a range from 0 to 1, a normalization is applied based on the maximum received control centrality value and the maximum noted size of a two hop neighborhood. The new values are sorted in ascending order and the selection procedure remains the same. This approach is fair, since a node is added in relays set either because it is influential or it provides

access to many two hop neighbors. The only disadvantage is the increased delay of relays election, due to on demand feature of the algorithm. A pseudo-code for this approach is as follows:

<u>Initial-Sender / Re-transmitter:</u>

1. *Send request asking neighbors to compute control centrality*
2. *Wait to receive the answers*
3. *Include to each answer the number of two hop neighbors and normalize the value:*

   Let denote pCoCe(x) the received value from one-hop neighbor x and n2(x) the two hop neighbors that are covered by x. Let max_pCoCe the maximum received control centrality value and max_n2 the maximum size of a two hop neighborhood.

   If (pCoCe(x) == 0) then pCoCe(x) = n2(x)

   *Else pCoCe(x) *= n2(x)*

   *pCoCe(x) / = (max_cc * max_n2)*
4. *Sort values in ascending order*
5. *Select nodes in order to cover all the outgoing two hop neighborhood*

<u>Received Request:</u>

1. *Check if node is an outgoing neighbor to the sender*
2. *If it is true*
   a. *Compute pCoCe*
   b. *Send the value*
3. *Else, ignore the request.*

Using this approach, it is not only provided information about topology three hops away from the dissemination point and the influence of each node in this region, but also a node knows in advance which nodes are moving out of communication range and they will not belong any more to one-hop neighborhood. This information is known, since the reception of control centrality values of these nodes is impossible to happen, because the distance between these vehicles is bigger than the defined distance by transmission range parameters. Based on recorded timestamps, which show the last communication link between vehicles, the sender-node cannot delete those nodes at decision time due to time threshold that determines the update of neighborhoods. On the other hand, OLSR selects relays based on recorded topology information. As a result, it may select nodes never receive the announcement that are re-transmitters because the transmission range cannot cover the distance. The dissemination of a message may be stopped and the remaining nodes within the network will never receive the message.

6. Performance Evaluation

Using the default parameters of our simulator OMNeT++ in the physical and mac layer of IEEE 802.11p, a theoretical transmission range is estimated about 500m. In our simulation model, the propagation model is the simple path loss. The PL equation in terms of dB is:

$$PL(dB) = 20*\log(d) + 20*\log(f) – 27,55$$

where **d** is the distance from the transmitter in meters and **f** is the signal frequency in MHz. A packet is received if:

$$\text{Transmission Power (dBm)} – PL(dB) > \text{Sensitivity (dBm)}.$$

Based on the defaults parameters of OMNeT++ : f = 5,8909e9 Hz, Transmission Power = 20 mW and Sensitivity = -89 dBm

The road network that is used in our experiments is a kind of grid 4x4. Each road is two-way and its length is 1km. Every 2km there are intersections with traffic lights proving a smooth a road traffic. The road network is shown in Figure 17:

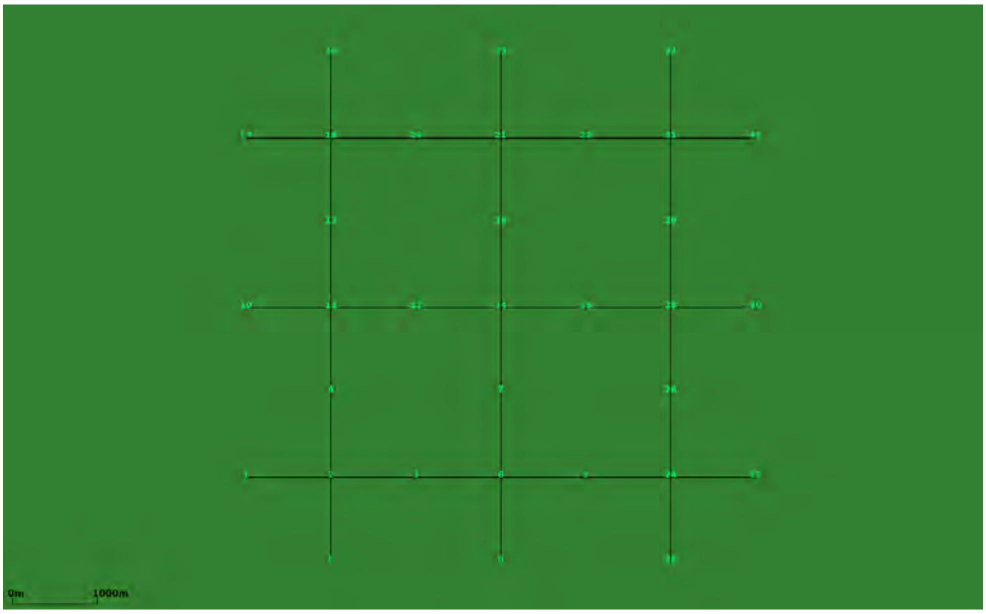


Figure 17: Road network used in simulations. The name of each road is appeared.

The metrics that concerned us in our experiments are:

- **Coverage:** how many nodes receive the message within the network
- **Dissemination distance:** how far a message is spread from sender-node, counting in hops

- **Number of re-transmitters:** how many nodes are selected to retransmit the message
- **Total time:** duration of a message dissemination

Last but not least, initial sender-nodes are located near intersections and there is only one message in the network.

6.1. First Scenario

The first scenario shows how a message is spread between two intersections.

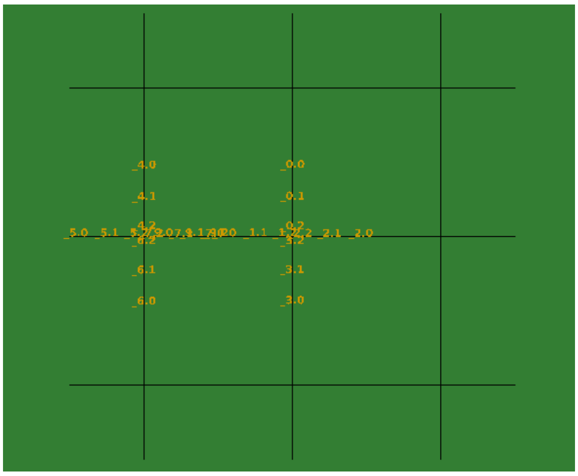
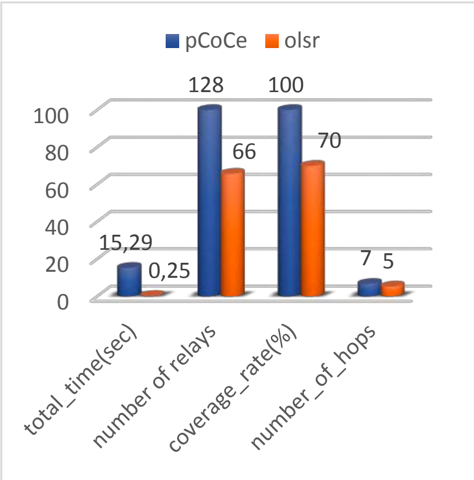
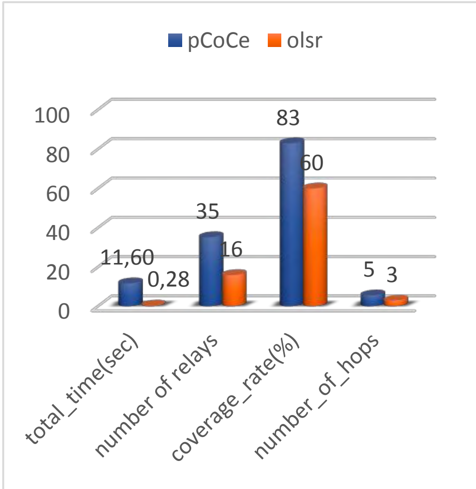


Figure 18: Scenario 1. Dissemination of a message between two intersections.

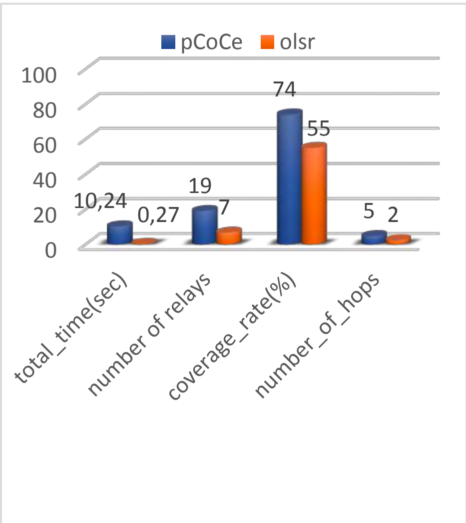
The vehicles travel at 50.4 km/h (14 m/s) and the distance among them varies depending on the frequency they enter the road network. Since the distance affects the total number of vehicles within communication range, the behavior of implemented routing protocols is evaluated with different frequency parameters. Indicatively, vehicles insert into the network every 1sec, 5sec, 10sec and 15sec. After the velocity stabilization, a distance between two vehicles approximately is 28m, 70m, 140m and 200m respectively. The total number of vehicles in the road network varies from 17 to 225.



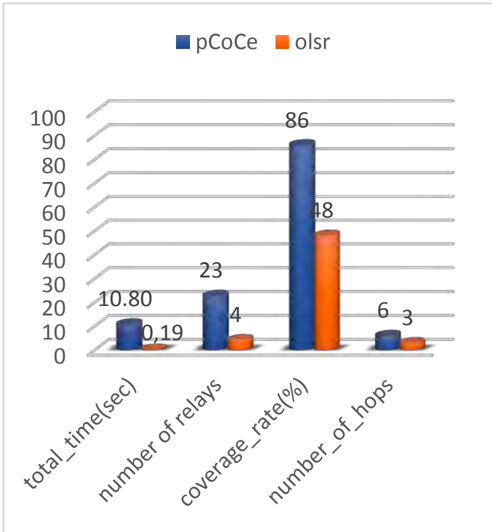
a. 28m



b. 70m



c. 140m



d. 200m

Figure 19: Scenario 1. Experimental results. Vehicles enter the road network every (a) 1sec, (b) 5sec, (c) 10sec and (d) 15sec. Total_time(sec) is the duration of a message dissemination according to two methods. Number of relays is the number of selected relays. Coverage_rate (%) of the network the trird comparison and it related to the current number of vehicles within the network during the message dissemination. Number_of_hops defines the maximum hop, where a message is spread from the initial point.

The overall behavior of routing protocols is illustrated below:

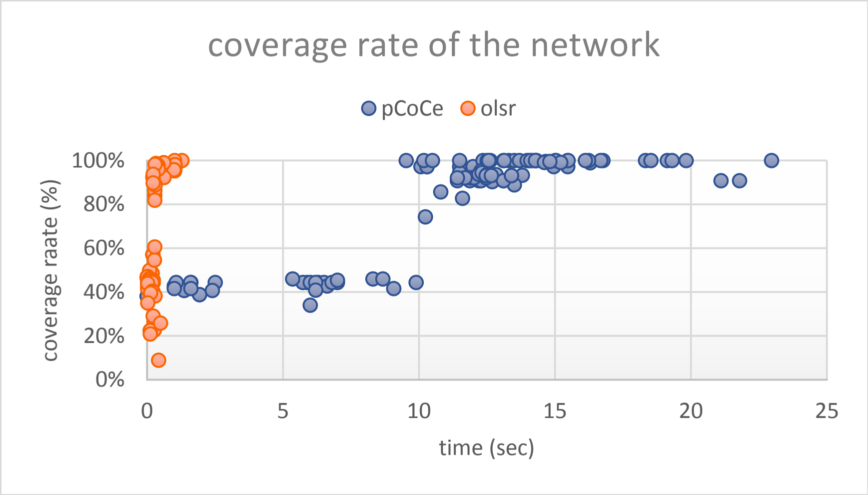


Figure 20: Scenario 1. The coverage rate of the network based on current number of vehicles during the message dissemination.

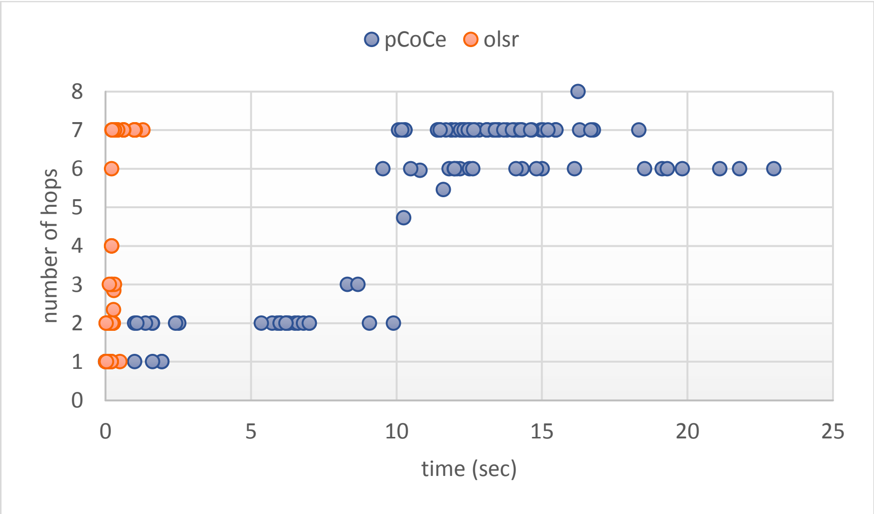


Figure 21: Scenario 1. Dissemination distance of a message in terms of hops.

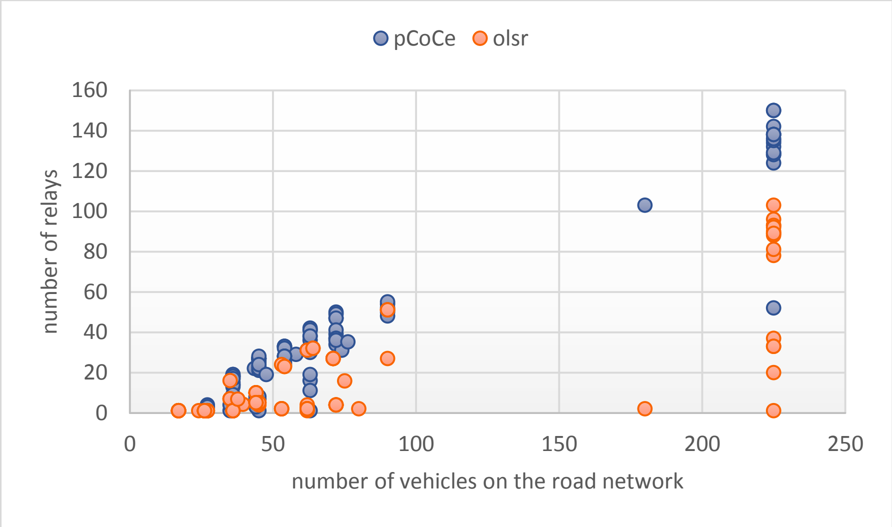


Figure 22: Scenario 1. Number of selected relays among the total number vehicles within the network.

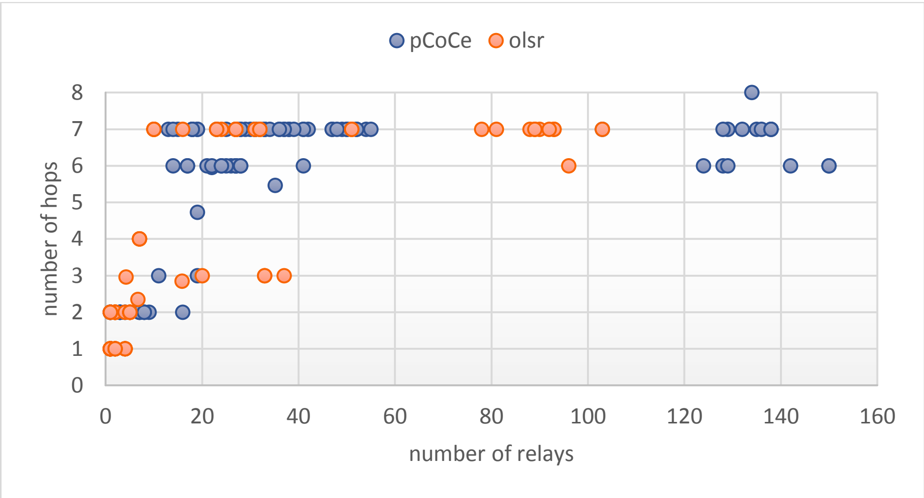


Figure 23: Scenario 1. Number of covered hops related to selected relays.

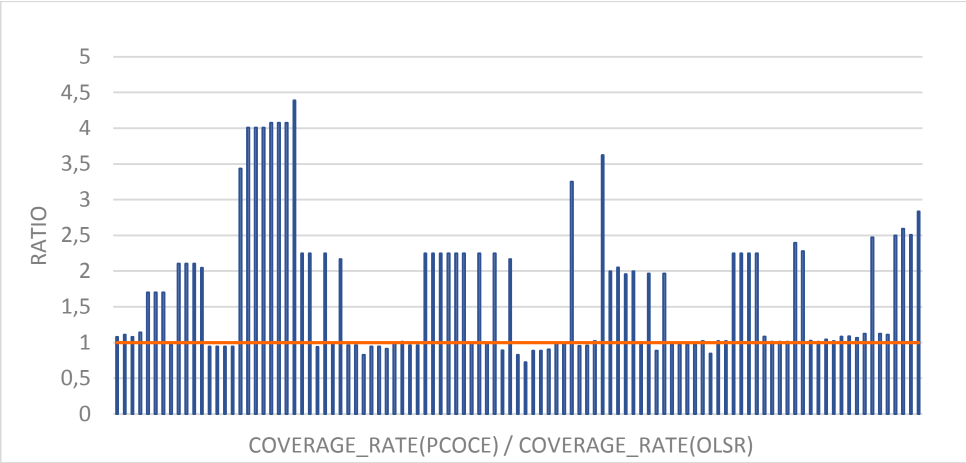


Figure 24: Scenario 1. The ratio of coverage rates based on current number of vehicles within the network between implemented protocols. pCoCe measure provides a wider coverage of the network.

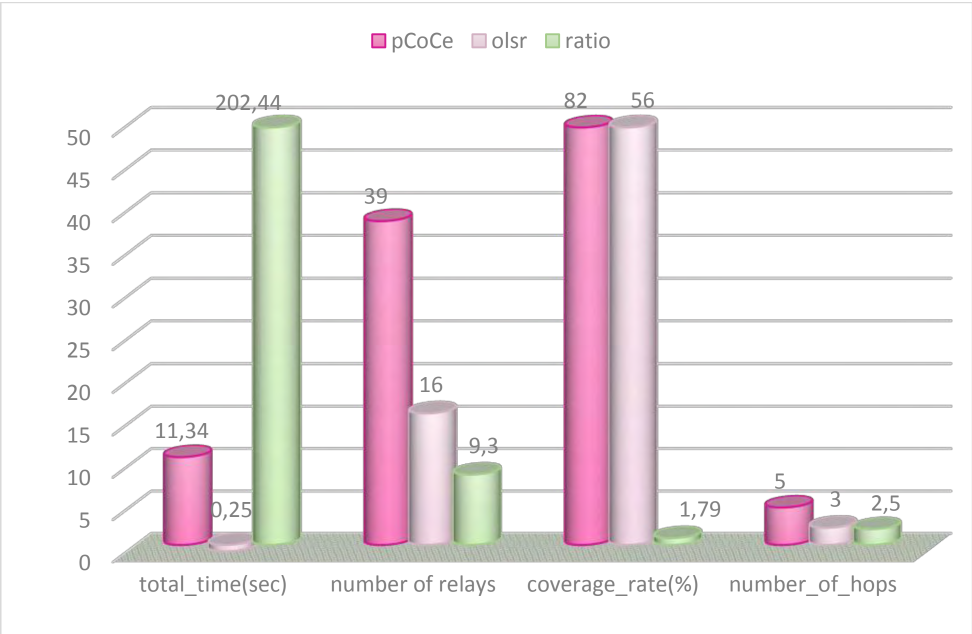


Figure 25: Scenario 1. Comparison among all metrics. The first pair shows the average time that each method needs to disseminate a message throughout the network. The second pair indicates the number of selected relays among the current number of vehicles during the message dissemination. The third pair shows the average coverage rate of the network. And finally the last pair illustrates the maximum number of hops, where a message is spread from the initial point. The third bar in all pairs is the respective ratio of the compared metrics.

Regarding the total time that a message needs to be disseminated among all the possible nodes in the network, OLSR is very efficient. Due to its proactive nature, it only needs some milliseconds to spread a message. Figure 20 shows that few seconds are sufficient to cover the 100% of the current network and reach the maximum distance from the initial sender. However, observing the average values in Figure 25 OLSR manages to cover only the 56% of the network disseminating a message only 3 hops away from the initial starting point. That is because the creation of MPR set is based on recorded neighbor sets and there is the possibility to select nodes which move out of communication range. These nodes lack to receive the message that defines the re-transmitters and as a result the dissemination stops.

On the other hand, the proposed approach of pCoCe measure is time consuming. Since this measure includes an on-demand feature, each node interested in creation of a relay set is charged with a time delay waiting to receive the values of control centrality measures. As a result, the average total time of dissemination using this approach concludes to be two hundred times bigger than the respective time using OLSR. Nevertheless, it manages to cover a wider portion of the network offering an average value of coverage rate at 82% unlike 56% of OLSR. In Figure 24 is illustrated the ratio between the coverage rates. As is shown, using pCoCe measure the coverage rate is fluctuating from two to four times greater than that of OLSR and fails only in few experiments.

Regarding to the number of selected relays routing protocol with control centrality metric selects more nodes than the second protocol. This is because this protocol succeeds to continue the dissemination of the message among more vehicles due to identification of influent nodes in contrast to OLSR, which selects inappropriate nodes to pass the message among the rest nodes.

Finally, the distance between two vehicles affects the total number of cars within communication range, since all the nodes move with the same velocity. The smaller the distance, the denser the road. In all cases, pCoCe provides a wider coverage of the network disseminating the message in more hops and holding a steady difference of 20%. The number of relays is twofold than the number of relays of OLSR, but the needed time is much bigger. A noticeable difference is presented at the distance of 200m. pCoCe measure succeeds to respond in a sparse road network covering almost the 90% of the nodes, while OLSR manages to spread a message only in the half of them.

Table 1 gathers all the average values of this scenario, where *frequency* is the input frequency of vehicles on the road network, *Routing Protocol* is the method of creation of relay set and the rest columns represent the four metrics we are interested in. The last column *Loaded vehicles* shows the total number of loaded vehicles in the network while a message is disseminated.

Frequency	Routing_Protocol	Total_time(s)	Relays	Coverage(%)	Hops	Loaded vehicles
1 sec	k-RPCC	15.29	128	100	7	222
	OLSR	0.25	66	70	5	222
5 sec	k-RPCC	11.60	35	83	5	76
	OLSR	0.28	16	61	3	75
10 sec	k-RPCC	10.24	19	74	5	47
	OLSR	0.27	7	55	2	37
15 sec	k-RPCC	10.80	23	86	6	43
	OLSR	0.19	4	48	3	39
AVERAGE	k-RPCC	11.37	39	82	5	77
	OLSR	0.25	16	56	3	72

Table 1: Scenario 1. The average values of experimental results

Observing the results, we conclude that the most interest metric of all is the coverage rate of the network, which is related to the current number of vehicles within the road network. Focused on that the below charts show the coverage rate in more details where:

- **numberOfCurrentNodes_OLSR**: is the current number of traveling vehicles within the road network during the dissemination based on OLSR
- **numberOfCoveredNodes_OLSR**: is the number of nodes that indicates how many of the current nodes receive the message using OLSR
- **selectedRelays_OLSR**: is the number of re-transmitters selected by OLSR
- **numberOfCurrentNodes_pCoCe**: is the current number of traveling vehicles within the road network during the dissemination based on pCoCe measure
- **numberOfCoveredNodes_pCoce**: is the number of nodes that indicates how many of the current nodes receive the message using pCoCe measure
- **numberOfRelays_pCoCe**: is the number of re-transmitters selected by pCoCe measure

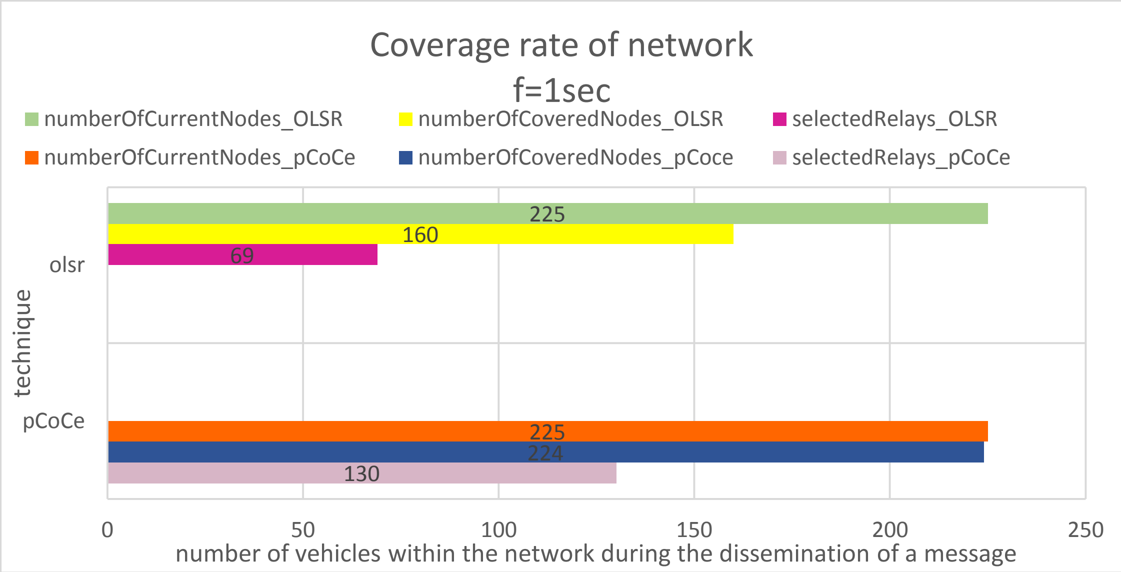


Figure 26: Scenario 1: Coverage rate of the network. Vehicles enter the road network every 1 sec. numberOfCurrentNodes_OLSR is the current number of traveling vehicles within the road network during the dissemination based on OLSR. numberOfCoveredNodes_OLSR is the number of nodes that indicates how many of the current nodes receive the message using OLSR, selectedRelays_OLSR is the number of re-transmitters selected by OLSR, numberOfCurrentNodes_pCoCe is the current number of traveling vehicles within the road network during the dissemination based on pCoCe measure, numberOfCoveredNodes_pCoce is the number of nodes that indicates how many of the current nodes receive the message using pCoCe measure and numberOfRelays_pCoCe: is the number of re-transmitters selected by pCoCe measure.

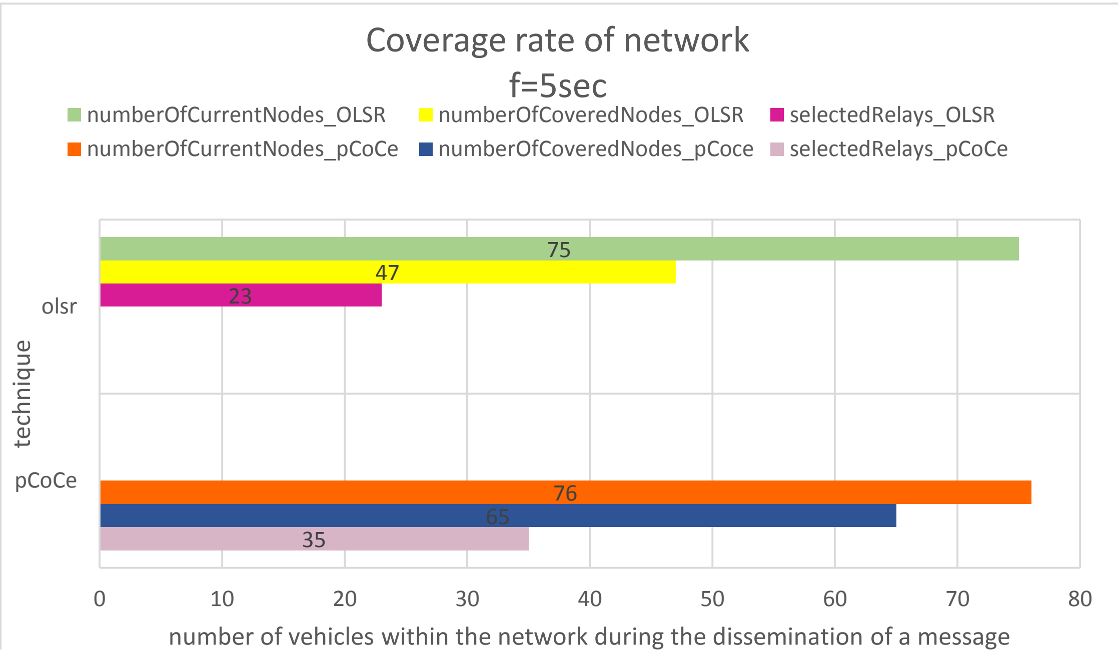


Figure 27: Scenario 1: Coverage rate of the network. Vehicles enter the road network every 5 sec. numberOfCurrentNodes_OLSR is the current number of traveling vehicles within the road network during the dissemination based on OLSR. numberOfCoveredNodes_OLSR is the number of nodes that indicates how many of the current nodes receive the message using OLSR, selectedRelays_OLSR is the number of re-transmitters selected by OLSR, numberOfCurrentNodes_pCoCe is the current number of traveling vehicles within the road network during the dissemination based on pCoCe measure, numberOfCoveredNodes_pCoce is the number of nodes that indicates how many of the current nodes receive the message using pCoCe measure and numberOfRelays_pCoCe: is the number of re-transmitters selected by pCoCe measure.

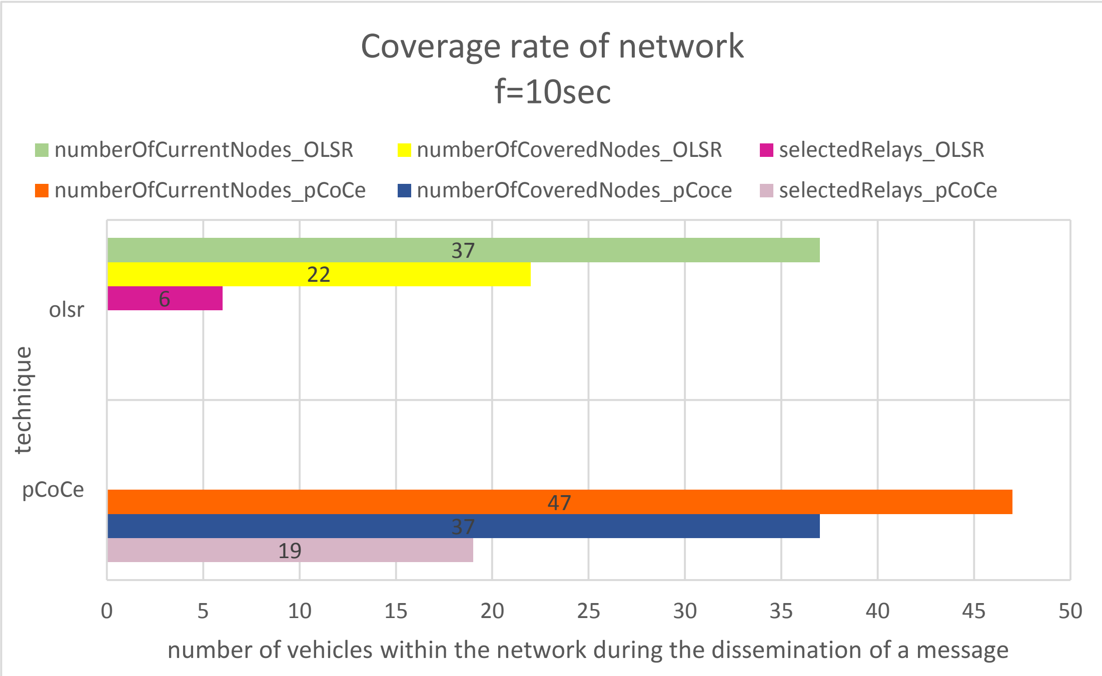


Figure 28: Scenario 1: Coverage rate of the network. Vehicles enter the road network every 10 sec. numberOfCurrentNodes_OLSR is the current number of traveling vehicles within the road network during the dissemination based on OLSR. numberOfCoveredNodes_OLSR is the number of nodes that indicates how many of the current nodes receive the message using OLSR, selectedRelays_OLSR is the number of re-transmitters selected by OLSR, numberOfCurrentNodes_pCoCe is the current number of traveling vehicles within the road network during the dissemination based on pCoCe measure, numberOfCoveredNodes_pCoce is the number of nodes that indicates how many of the current nodes receive the message using pCoCe measure and numberOfRelays_pCoCe: is the number of re-transmitters selected by pCoCe measure.

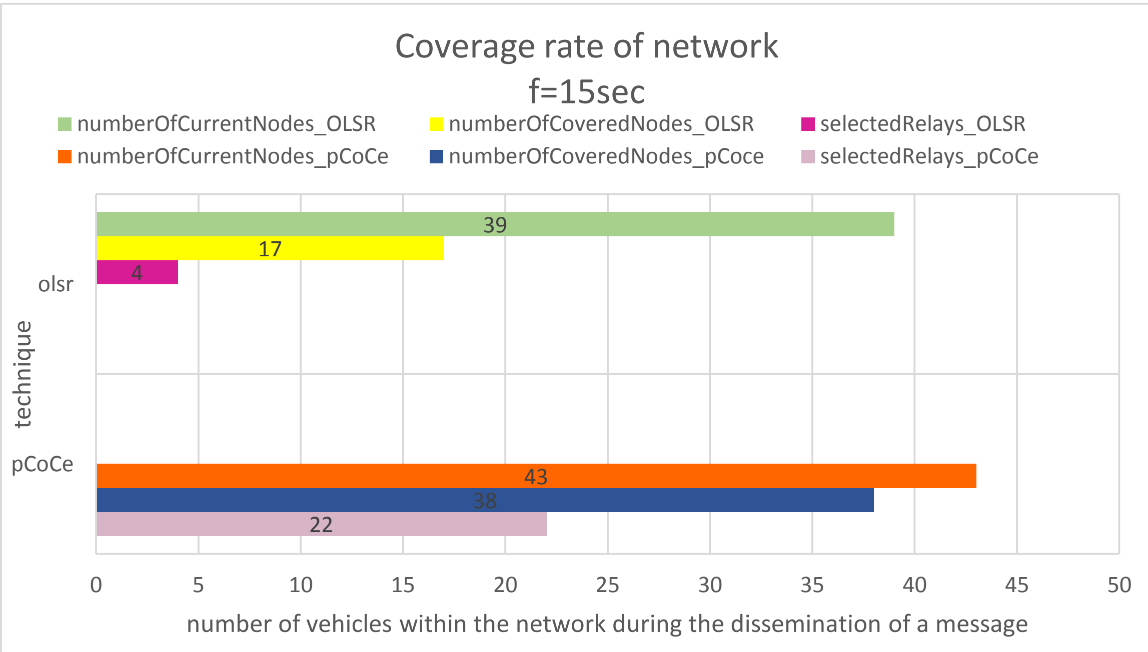


Figure 29: Scenario 1: Coverage rate of the network. Vehicles enter the road network every 10 sec. numberOfCurrentNodes_OLSR is the current number of traveling vehicles within the road network during the dissemination based on OLSR. numberOfCoveredNodes_OLSR is the number of nodes that indicates how many of the current nodes receive the message using OLSR, selectedRelays_OLSR is the number of re-transmitters selected by OLSR, numberOfCurrentNodes_pCoCe is the current number of traveling vehicles within the road network during the dissemination based on pCoCe measure, numberOfCoveredNodes_pCoce is the number of nodes that indicates how many of the current nodes receive the message using pCoCe measure and numberOfRelays_pCoCe: is the number of re-transmitters selected by pCoCe measure.

6.3. Second Scenario

The second experimental scenario concerns the dissemination of a message in the whole network. We evaluate the behavior of the routing protocols, when a message is sent from the lower left intersection and tries to be spread in all the rest intersections. A snapshot of the network is shown in Figure 30.

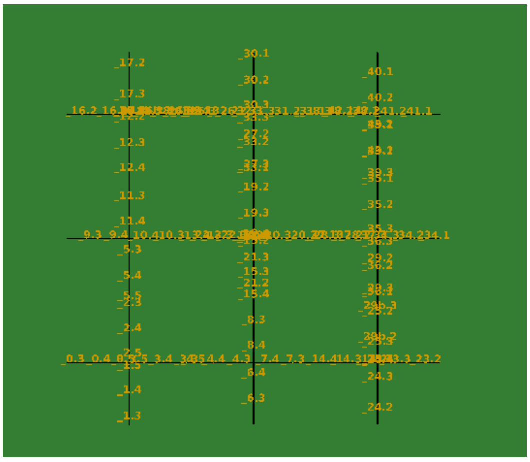


Figure 30: Scenario 2. The message is sent from the lower left intersection.

It is considered that vehicles enter the network every **(a)** 1sec, **(b)** 5sec, **(c)** 10sec and **(d)** 15sec. The maximum velocity of all vehicles is **(a)** 50.4 km/h (14 m/s), **(b)** 72 km/h (20 m/s) and **(c)** 100.8 km/h (28 m/s).

Ignoring the metric of total time, since it is not fair to compare a proactive routing protocol to an on demand routing protocol, it is shown that pCoCe measure clearly succeeds to spread a message in a wider portion of the network than OLSR's MPR method. Table 2 gathers all the average values for all the above cases concerning about the coverage rate of the network, which is the most interest metric of all.

It is observed that the current number of vehicles within the road network using pCoCe measure is higher than that of OLSR method. This happens because, pCoCe successfully continues the spread of a message selecting more appropriate relays. While the dissemination is continued more traffic appears on roads increasing the potential of new re-transmitters.

In all cases, independently of the velocity, our proposed method dominates against MPR method of OLSR.

Frequency	Velocity (m/s)	Mehod	Covered Nodes	Current nodes	Coverage rate	Selected Relays
1 sec	14	pCoCe	421	973	38.38%	243
		OLSR	43	460	9.29%	1
	20	pCoCe	63	645	47.64%	31
		OLSR	60	645	9.30%	2
	28	pCoCe	786	1175	66.89%	515
		OLSR	71	645	11.01%	39
5 sec	14	pCoCe	250	378	58.06%	144
		OLSR	50	250	19.59%	12
	20	pCoCe	443	466	95.17%	286
		OLSR	166	276	60.14%	43
	28	pCoCe	265	460	57.66%	186
		OLSR	109	276	39.76%	32
10 sec	14	pCoCe	209	250	78.59%	133
		OLSR	61	139	33.69%	22
	20	pCoCe	448	466	96.14%	103
		OLSR	166	276	60.14%	40
	28	pCoCe	167	297	61.01%	125
		OLSR	86	201	40.70%	52
15 sec	14	pCoCe	144	187	66.64%	94
		OLSR	27	86	31.03%	10
	20	pCoCe	158	233	67.68%	124
		OLSR	16	139	12.69%	4
	28	pCoCe	106	214	48.36%	65
		OLSR	81	149	56.54%	52

Table 2: A comparison among all cases. Column "Current Nodes" indicates the current number of vehicles moving in the network during the dissemination of a message, "Covered Nodes" shows how many of Current Nodes receive the message, "Coverage Rate" is the respective rate, "Selected Relays" illustrates how many of Covered Nodes selected as relays.

Finally, charts related to the coverage rate of the network of this scenario are presented below, where:

- **numberOfCurrentNodes_OLSR**: is the current number of traveling vehicles within the road network during the dissemination based on OLSR

- **numberOfCoveredNodes_OLSR**: is the number of nodes that indicates how many of the current nodes receive the message using OLSR

- **selectedRelays_OLSR**: is the number of re-transmitters selected by OLSR

- **numberOfCurrentNodes_pCoCe**: is the current number of traveling vehicles within the road network during the dissemination based on pCoCe measure

- **numberOfCoveredNodes_pCoce**: is the number of nodes that indicates how many of the current nodes receive the message using pCoCe measure

- **numberOfRelays_pCoCe**: is the number of re-transmitters selected by pCoCe measure

These charts illustrate the number of nodes that receive the message out of the total number of nodes that move within the network and are divided based on vehicles' velocity: 14m/s, 20 m/s, 28 m/s.

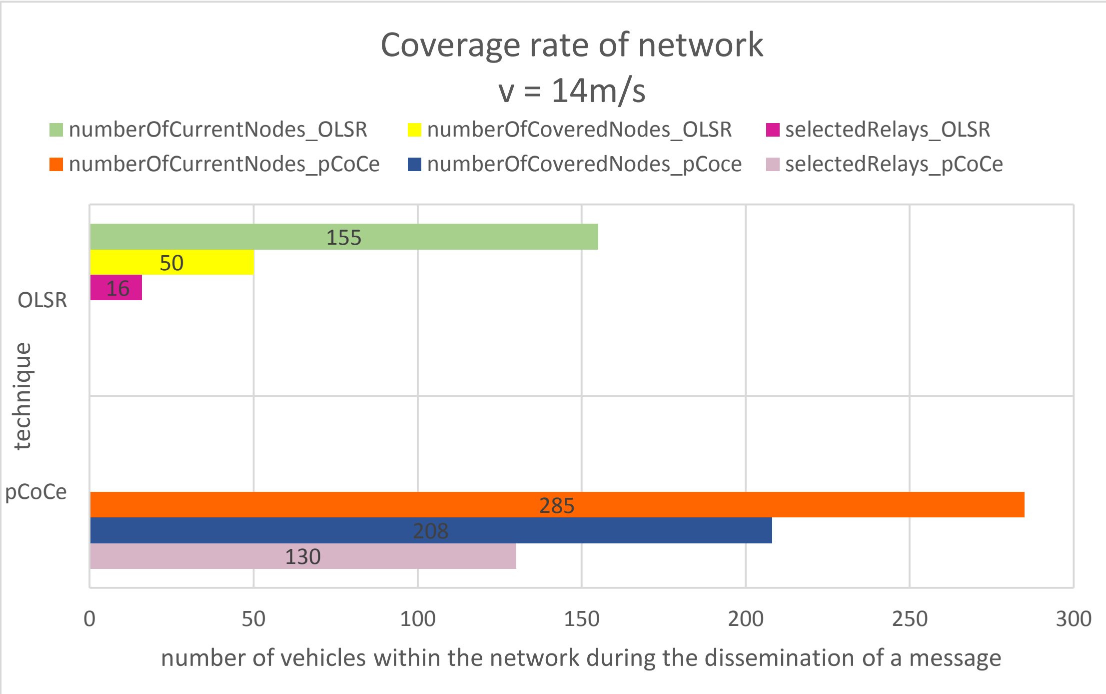


Figure 31: Scenario 2. Coverage rate of the network when vehicles travel at 14 m/s. numberOfCurrentNodes_OLSR is the current number of traveling vehicles within the road network during the dissemination based on OLSR. numberOfCoveredNodes_OLSR is the number of nodes that indicates how many of the current nodes receive the message using OLSR, selectedRelays_OLSR is the number of re-transmitters selected by OLSR, numberOfCurrentNodes_pCoCe is the current number of traveling vehicles within the road network during the dissemination based on pCoCe measure, numberOfCoveredNodes_pCoce is the number of nodes that indicates how many of the current nodes receive the message using pCoCe measure and numberOfRelays_pCoCe: is the number of re-transmitters selected by pCoCe measure.

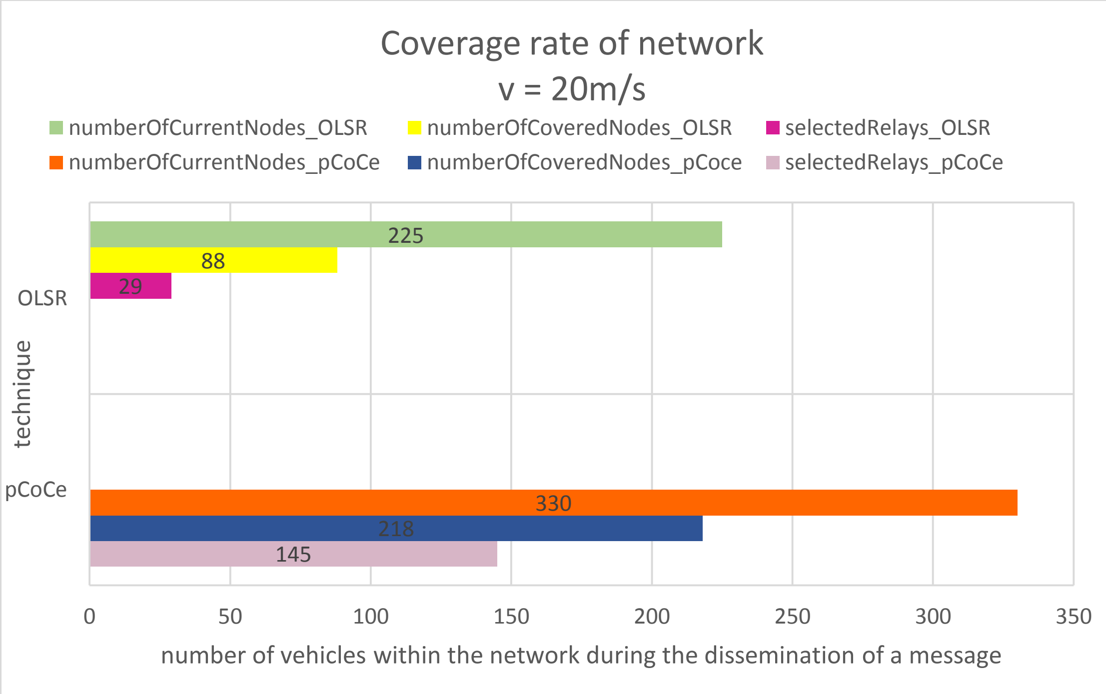


Figure 32: Scenario 2. Coverage rate of the network when vehicles travel at 20 m/s. numberOfCurrentNodes_OLSR is the current number of traveling vehicles within the road network during the dissemination based on OLSR. numberOfCoveredNodes_OLSR is the number of nodes that indicates how many of the current nodes receive the message using OLSR, selectedRelays_OLSR is the number of re-transmitters selected by OLSR, numberOfCurrentNodes_pCoCe is the current number of traveling vehicles within the road network during the dissemination based on pCoCe measure, numberOfCoveredNodes_pCoce is the number of nodes that indicates how many of the current nodes receive the message using pCoCe measure and numberOfRelays_pCoCe: is the number of re-transmitters selected by pCoCe measure.

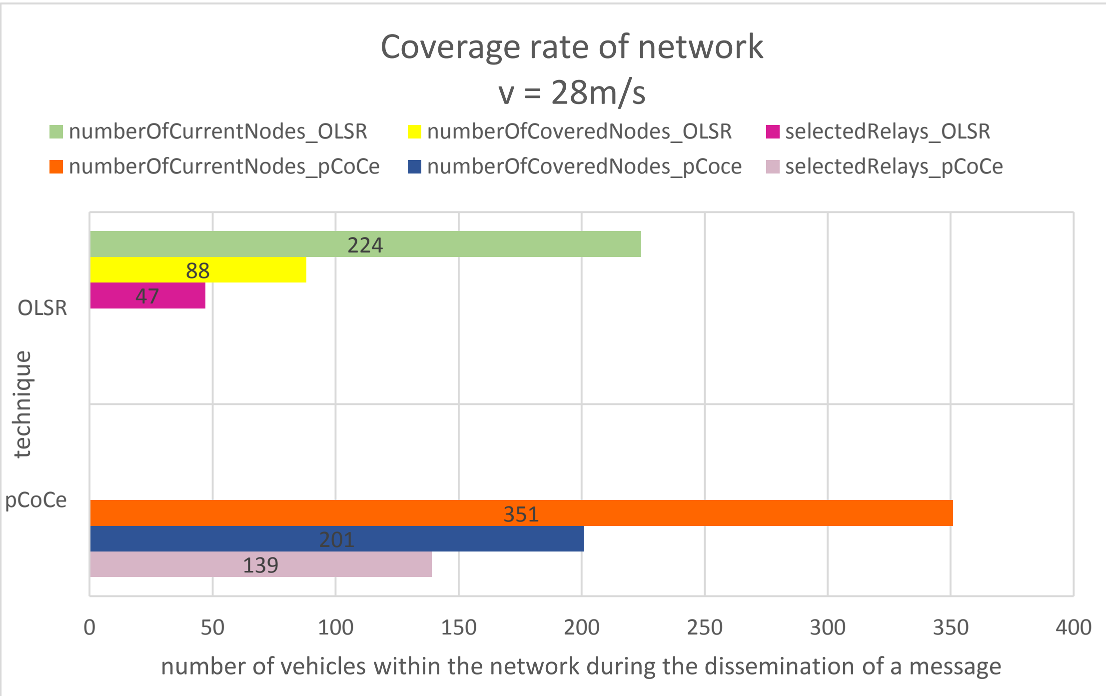


Figure 33: Scenario 2. Coverage rate of the network when vehicles travel at 20 m/s. numberOfCurrentNodes_OLSR is the current number of traveling vehicles within the road network during the dissemination based on OLSR. numberOfCoveredNodes_OLSR is the number of nodes that indicates how many of the current nodes receive the message using OLSR, selectedRelays_OLSR is the number of re-transmitters selected by OLSR, numberOfCurrentNodes_pCoCe is the current number of traveling vehicles within the road network during the dissemination based on pCoCe measure, numberOfCoveredNodes_pCoce is the number of nodes that indicates how many of the current nodes receive the message using pCoCe measure and numberOfRelays_pCoCe: is the number of re-transmitters selected by pCoCe measure.

Regarding the density of the network, the coverage rate is formed as follow:

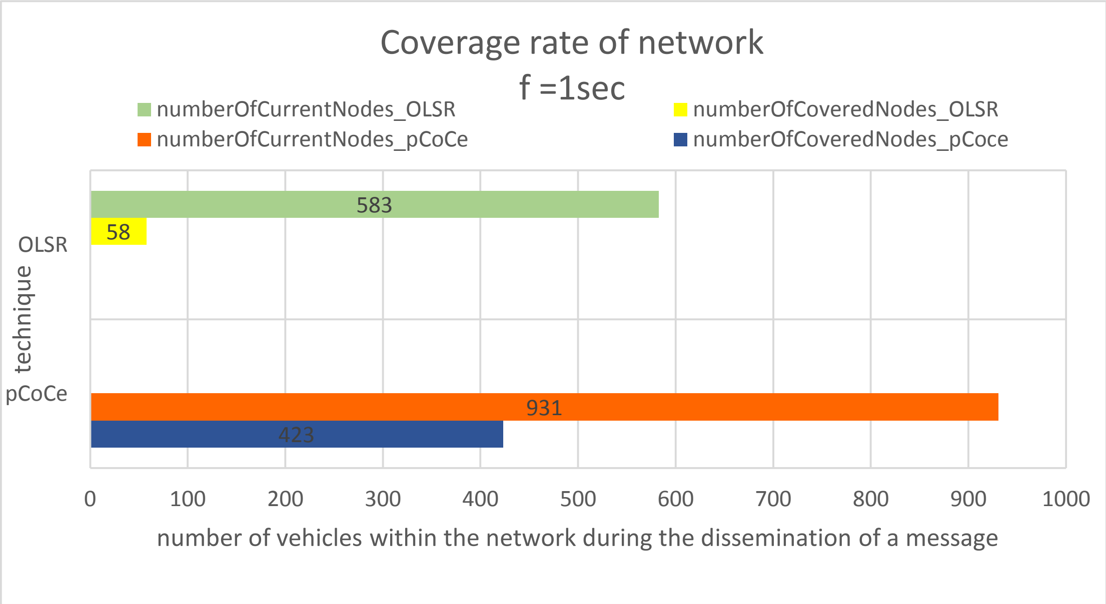


Figure 34: Scenario 2. Coverage rate of the network when vehicles enter every 1 sec. numberOfCurrentNodes_OLSR is the current number of traveling vehicles within the road network during the dissemination based on OLSR. numberOfCoveredNodes_OLSR is the number of nodes that indicates how many of the current nodes receive the message using OLSR, numberOfCurrentNodes_pCoCe is the current number of traveling vehicles within the road network during the dissemination based on pCoCe measure and numberOfCoveredNodes_pCoce is the number of nodes that indicates how many of the current nodes receive the message using pCoCe measure.

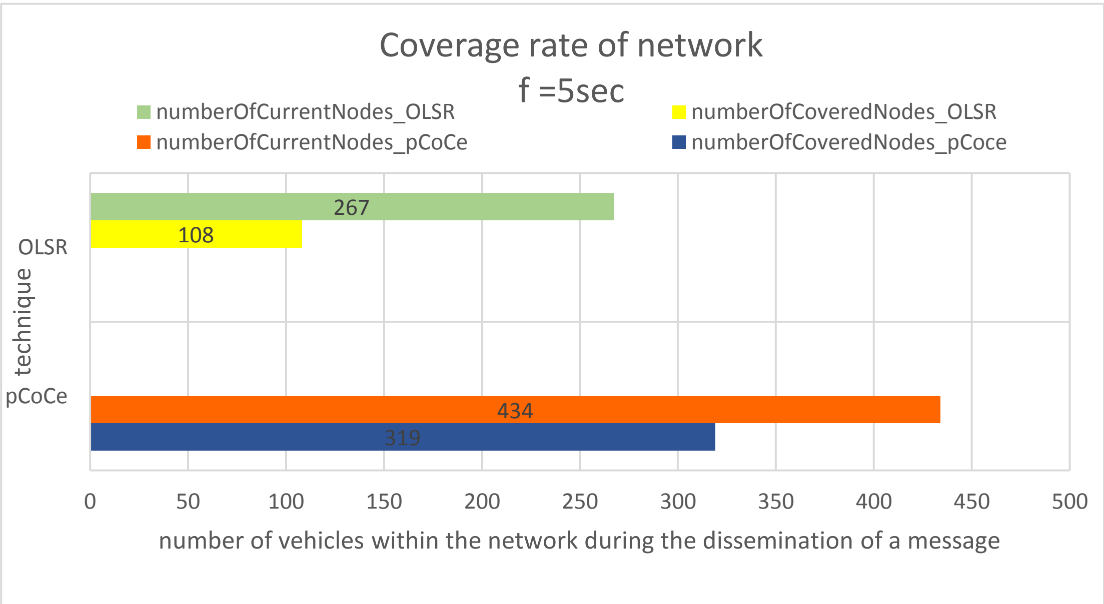


Figure 35: Scenario 2. Coverage rate of the network when vehicles enter every 5 sec. numberOfCurrentNodes_OLSR is the current number of traveling vehicles within the road network during the dissemination based on OLSR. numberOfCoveredNodes_OLSR is the number of nodes that indicates how many of the current nodes receive the message using OLSR, numberOfCurrentNodes_pCoCe is the current number of traveling vehicles within the road network during the dissemination based on pCoCe measure and numberOfCoveredNodes_pCoce is the number of nodes that indicates how many of the current nodes receive the message using pCoCe measure.

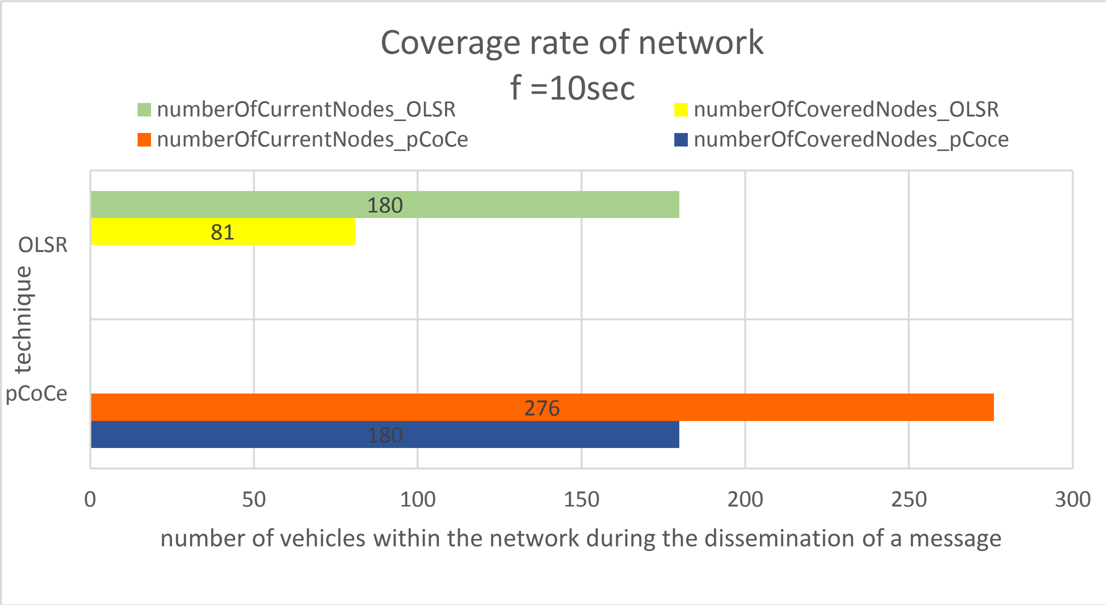


Figure 36: Scenario 2. Coverage rate of the network when vehicles enter every 10 sec. numberOfCurrentNodes_OLSR is the current number of traveling vehicles within the road network during the dissemination based on OLSR. numberOfCoveredNodes_OLSR is the number of nodes that indicates how many of the current nodes receive the message using OLSR, numberOfCurrentNodes_pCoCe is the current number of traveling vehicles within the road network during the dissemination based on pCoCe measure and numberOfCoveredNodes_pCoce is the number of nodes that indicates how many of the current nodes receive the message using pCoCe measure.

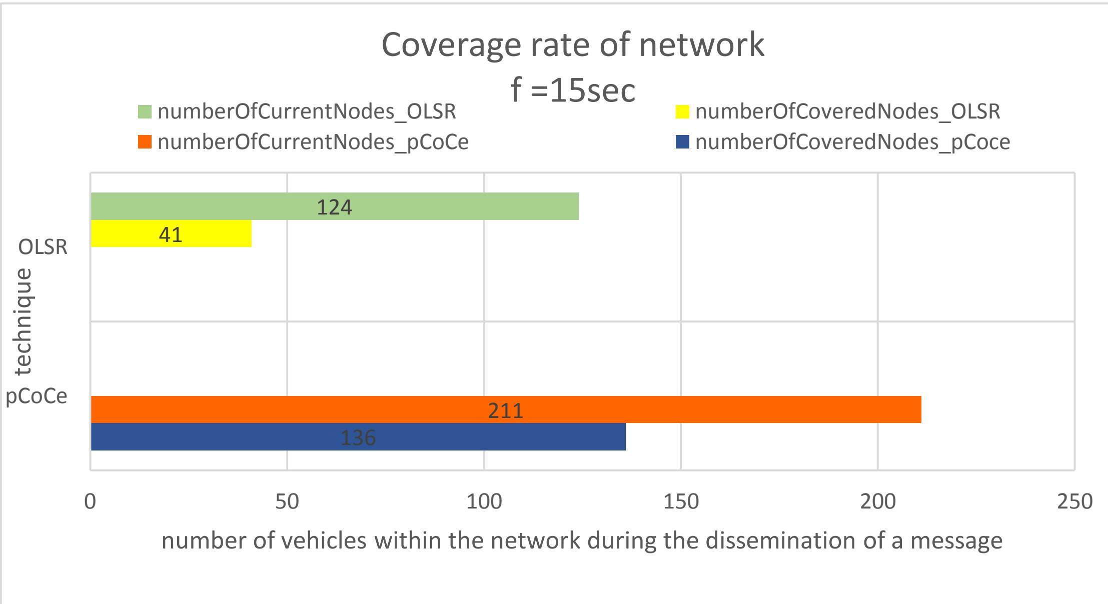


Figure 37: Scenario 2. Coverage rate of the network when vehicles enter every 15 sec. numberOfCurrentNodes_OLSR is the current number of traveling vehicles within the road network during the dissemination based on OLSR. numberOfCoveredNodes_OLSR is the number of nodes that indicates how many of the current nodes receive the message using OLSR, numberOfCurrentNodes_pCoCe is the current number of traveling vehicles within the road network during the dissemination based on pCoCe measure and numberOfCoveredNodes_pCoce is the number of nodes that indicates how many of the current nodes receive the message using pCoCe measure.

7. Conclusion

In this work we focus on identification of influent nodes within a VANET, which are able to disseminate a message to the rest of the road network. This recognition is based on our proposed metric, Probabilistic Control Centrality, pCoCe. According to this, a node is declared as re-transmitter either because it covers a part of two hop neighbors of initial sender or because it exerts influence in its two hop region. This method is compared to basic mechanism of OLSR routing protocol, Multipoint Relay set. Experimental results show that selecting nodes based on pCoCe measure leads to a wider coverage of the network, especially when the density within communication range is high. A controversial point is the on-demand nature of proposed approach. Requesting the control centrality measure is provided accurate information related to outgoing stems, but on the other hand, the drawback is the experience of delay resulting high aggregate dissemination time of a message.

As a matter of future work, it would be beneficial to evaluate the proposed approach on different road networks observing its performance in the presence of buildings and obstacles. More realistic scenarios, including speed distributions, different types of vehicles and a variety of drivers' behavior is currently under evaluation. Moreover, since the on-demand feature of the proposed method constitutes a drawback, it would be vital to improve this characteristic in order for the algorithm to be a strong competitor.

References

[1] http://en.wikipedia.org/wiki/Wireless_ad_hoc_network

[2] http://en.wikipedia.org/wiki/Wireless_sensor_network

[3] http://en.wikipedia.org/wiki/Wireless_mesh_network

[4] http://en.wikipedia.org/wiki/Mobile_ad_hoc_network

[5] Dar K.; Bakhouya M.; Gaber J.; Wack M.; Lorenz P.; "Wireless communication technologies for ITS applications", IEEE Communication Magazine, vol.48, no.5, pp. 156-162, 2010.

[6] http://en.wikipedia.org/wiki/Carrier_sense_multiple_access

[7] Toor, Y.; Muhlethaler, P. ; Laouiti, A.; "Vehicle Ad Hoc networks: applications and related technical issues", IEEE Communication Surveys & Tutorials, vol.10, no.8, pp. 74-88, 2008.

[8] https://standards.ieee.org/develop/wg/1609_WG.html

[9] Sommer C.; German R.; Dressler R.; "Bidirectionally Coupled Network and Road Traffic Simulation for Improved IVC Analysis", IEEE Transactions on Mobile Computing, vol. 10, no.1, pp. 3-15, 2011.

[10] Krajzewicz D.; Erdmann J.; Behrisch M.; Bieker L.; "Recent Development and Applications of SUMO – Simulation of Urban MObility", International Journal on Advances in Systems and measurements, vol.5, no.3&4, 2012. Available: http://sumo-sim.org/pdf/sysmea_v5_n34_2012_4.pdf

[11] http://www.omnetpp.org/

[12] http://mixim.sourceforge.net/

[13] Wegener A.; Pi´orkowski M.; Raya M.;,Hellbr¨uck H.; Fischer S.; Hubaux J.P.; "TraCI: An Interface for Coupling Road Traffic and Network Simulators", Proceedings of the 11th Communications and Networking Simulation Symposium, pp. 155-163,2008.

[14] http://sourceforge.net/apps/mediawiki/sumo/index.php?title=TraCI

[15] Eckhoff D.; Sommer C.; "A Multi-Channel IEEE 1609.4 and 802.11p EDCA Model for the Veins Framework", 5th ACM/ICST International Conference on Simulation Tools and Techniques for Communications, Networks and Systems (SIMUTools 2012): 5th ACM/ICST International Workshop on OMNeT++ (OMNeT++ 2012), Poster Session, 2012.

[16] Qayyum A.; Viennot L.; Laouti A.; "Multipoint Relaying for Flooding Broadcast Messages in Mobile Wireless Networks", System Sciences, 2002. HICSS. Proceedings of the 35th Annual Hawaii International Conference on, pp. 3866-3875, 2002.
Available: http://www.cs.jhu.edu/~dholmer/600.647/papers/OLSR.pdf

[17] Jacquet, P.; Muhlethaler, P.; Clausen, T.; Laouiti, A.; Qayyum, A.; Viennot, L.; "Optimized link state routing protocol for ad hoc networks", Multi Topic Conference, 2001. IEEE INMIC 2001. Technology for the 21st Century. Proceedings. IEEE International, pp. 62 – 68, 2001.

[18] Toutouh, J.; Garcia-Nieto, J.; Alba, E.; "Intelligent OLSR Routing Protocol Optimization for VANETs", IEEE Transactions on Vehicular Technology, vol. 61, no. 4, pp. 1884-1894, 2012.

[19] Basaras P.; Katsaros D.; Tassioulas L.; "Detecting influential nodes in complex networks with probabilistic links", Submitted, 2014.

[20] http://www.ietf.org/rfc/rfc3626.txt

[21] Cover photo: Source:
http://www.dailytech.com/Toyota+Concerned+WiFi+Will+Interfere+with+VehicletoVehicle+Communication+Systems/article33754.htm