Dynamic Time-stable Geocast Routing in Vehicular Ad Hoc Networks

by

Hamidreza Rahbar

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Abstract

Vehicular ad hoc networks (VANETs) have emerged as an area of interest for both industry and research scholars because they have become an essential part of intelligent transportation systems (ITSs). Many applications in VANET require sending a message to certain or all vehicles within a region, called geocast. Sometimes geocast requires that the message be kept alive within the region for a period of time. This time-stable geocast has a vital role in some ITS applications, particularly commercial applications. This study presents a novel time-stable geocast protocol that works well even in too sparse networks. Moreover, since commercial applications sometimes make it necessary to change the duration of the stable message within the region, the dynamic nature of a geocast protocol should allow this time to be extended, reduced, or canceled without any additional cost. Therefore, we call it a dynamic time-stable geocast, DTSG, protocol. It works in two phases (the pre-stable period and the stable period), and the simulation results show that it works well in its performance metrics (delivery ratio and network cost). In addition, these results validate the protocol prediction of its performance metrics. Moreover, with the informed time of zero, all the intended vehicles will be informed as soon as they enter the region. The fact that the protocol is independent of the networks' density, the vehicles' speed, and the vehicles' broadcasting range, makes it more robust than others that fail in sparse networks or in high-speed nodes.

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Dedication

I would like to dedicate this work to my wife for her constant and beyond measure support during the entire period of my study, and my kids Ali and Raha for their cheering and charming inspirations.

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List of Abbreviations

DCF	. . . .	Distributed Coordinated Function
DTN	. . . .	Delay Tolerant Network
DTSG	. . . .	Dynamic Time Stable Protocol
GEOCAST	. . . .	Geographical Broadcast
GPS	. . . .	Global Positioning System
IP	. . . .	Internet Protocol
ITS	. . . .	Intelligent Transportation System
LAN	. . . .	Local Area Network
MAC	. . . .	Media Access Control
MANET	. . . .	Mobile Ad Hoc Network
NS	. . . .	Network Simulator
OBU	. . . .	Onboard Unit
PDR	. . . .	Packet Delivery Ratio
RSU	. . . .	Road Side Unit
TCP	. . . .	Transmission Control Protocol
V2I	. . . .	Vehicle To Infrastructure
V2R	. . . .	Vehicle To Roadside
V2V	. . . .	Vehicle To Vehicle

Chapter 1: Introduction

1.1. Background

With the rapid development of microelectronics and wireless communication technologies and equipping the vehicles with intelligent electronics devices, called wireless on board units (OBUs), vehicles are becoming "computers on wheels [1]." With the integration of computing processers, global positioning systems (GPSs), sensors, and storage devices, OBUs provide ad hoc network connectivity for vehicles. With the OBUs, vehicles can communicate with each other as well as with fixed roadside infrastructure when moving on roads. These fixed roadside infrastructures, described as roadside units (RSUs), are usually connected to backbone Internet through wired or wireless connection. Thus, vehicle-to-vehicle (V2V) communications and vehicle-to-roadside infrastructure (V2I or V2R) communications basically form the vehicular ad hoc networks (VANETs) which are attracting considerable attention from the automotive industry, insurance companies, and research community. However, interest in vehicular ad hoc networks has only recently gained momentum, as such capabilities were in the past either not technically feasible or too costly to implement and operate.

The wireless ad hoc networks are completely distributed and do not depend on any infrastructures. Contrary to cellular networks, they are organized without infrastructures that prevent networks from being blocked and unavailable. Thus, the absence of infrastructure and central equipment allows faster and cheaper deployment. Although the applications of VANET make it fascinating, its greater sophistication poses considerable challenges.

A. Applications

Continuing development of VANET has made it possible for the intelligent transportation system (ITS) to achieve its goal of providing driving safety and comfort. Therefore, the applications of VANETs applications are organized into two basic categories: first, safety applications; and, second, commercial or non-safety applications (also called comfort application).

The safety applications basically involve issues related to the safety of the vehicles on the road. Their main goal is to inform drivers of accidents or other events that they are facing while driving, thus definitely reducing the number of fatalities on the roads. The collision warning and other safety warnings are included within the safety applications.

The goal of non-safety applications is to make drivers more comfortable and contented with the use of real-time notification of traffic congestion, high-speed tolling, mobile infotainment, local advertisement, and many others.

B. Challenges

Creating high-performance, highly scalable, and secure VANET technologies presents an extraordinary challenge to the wireless research community. The high mobility of the nodes causes considerable fragmentation and topology variability in VANET. Although many of the previous works on mobile ad hoc networks (MANETs) can be applied to VANETs, the high variability of the topology creates new challenges in this area. Mobility patterns are constrained by road paths and driving speed restrictions. The physical [1, 2, 3], link [4, 5, 6], and network layers [7, 8, 9, 10] must address the limited bandwidth as well as the unstable and fragmented network topology. Moreover, security mechanisms in VANETs must also work within the constraints of the limited bandwidth and cannot rely on the redundancy normally present in MANETs.

Especially in safety applications, as the topology of the network is typically unknown and highly variable in time, broadcasting mechanisms should then operate by ignoring the vehicles' location. Moreover, the density of vehicles and, hence, the connectivity of the network, can be quite variable depending on traffic conditions, the considered environment and so on. Finally, the warning delivery service requires guarantees in terms of delay and reliability, which are typically difficult to achieve through multi-hop transmission over a network with variable and unknown topology and connectivity. For example, for a vehicle moving at very high speed, say 140 km/h, the space covered during the transmission and propagation of a 1500Byte message at 1Mbps is less than half of a meter.

1.2. Motivation and Objective

Emerging inter vehicles communication based on mobile networks has sparked considerable curiosity about the intelligent transportation systems (ITSs). Wireless communication plays a vital role in ITS. By using a global positioning system (GPS), VANETs overcome the limitation of traditional systems, like radar and video cameras, and make possible more advanced services in ITS.

Among these services, non-safety applications require sending messages to a certain number of vehicles in a certain geographical area, called geocasting, a sub class of multicasting. Unlike multicast, which sends a packet to arbitrary nodes, geocast enables transmission of a packet to all nodes within a pre-defined geographical region. The goal of geocasting is to guarantee delivery while maintaining a low cost.

Moreover, since the geocasted message should be stable for a certain period of time, say T hours, it is called time-stable geocast. Its purpose is to maintain the availability of the message for a certain period of time within the region. In other words, all the vehicles should be informed of the message for a specific time as soon as they enter the region. Some of the time-stable geocast applications are accident warnings, information on bad road conditions (e.g. black ice), emergency vehicle preemption, and generic information services (e.g. facts on tourism or free parking). For example, when an accident on the road causes a traffic jam, all the oncoming vehicles will be involved in it until it is removed. There should be a mechanism to inform all the coming vehicles of the incident so they can change their route and avoid the delay.

There have been some studies on geocasting. However, the time-stable geocast is a novel concept for scholars. The next chapter comprehensively reviews both geocast protocols and time-stable geocast protocols. The limitations of these protocols encouraged us to define and develop a new routing protocol with unique capabilities. These limitations are described below.

In most of the protocols, the source is out of the geocast region. Thus, two stages for protocol are introduced: how the message reaches the region and how it is disseminated within the region. Their primary focus is on the first stage, and most of them are good at it. However, within the region, they simply use a simple flooding approach that is not efficient.

In addition, as the node's broadcasting range is limited, all of the previous protocols have a problem in sparse networks within the region. Flooding works well while the nodes move within each other's broadcasting range. In networks with low density, however all of them, even simple flooding, fail to stabilize a message for a period of time within a region.

Moreover, even in a dense network, when vehicles are informed that there is a problem on the road, drivers try to exit the region and avoid the problem, causing the previously dense network to become sparse within the region. As a result, the proposed protocols fail and their performance metrics are unreasonable. Therefore, although these protocols work well immediately after the event, their performance decreases significantly later on.

In addition, many of these proposed protocols have problems when the node's speed increases. Having a protocol that is independent of the speed of the nodes is also desirable. Moreover, none of the mentioned protocols presents a strategy to extend, reduce, or cancel the stable protocol lifetime.

1.3. Research Contribution

The main objective of this research is to define a new time-stable geocast protocol that works well even in sparse networks. This protocol defines a novel routing to help vehicles to disseminate a message within a specific region, say D km, for a specific duration of time, say T hours. The routing platform is a vehicular ad hoc network that uses vehicles for routing. No roadside units are available to help in dissemination, but onboard localization devices, like GPS, can be used.

For example, a vehicle that encountered an incident on the road while moving originally produced the non-safety message. This incident caused severe traffic congestion. Therefore, the other vehicles coming toward the event must be made aware of it before they are caught in traffic. Therefore, the region is D km before the incident and the time is the period required for moving the problem off the road. Furthermore, advertisers can use a time-stable geocast to inform drivers of their products or services at a specific time and in a specific region that depend on the commercial policy of the advertising companies.

The following features make our proposed protocol unique:

- It works even with sparse network densities.
- It guarantees delivery of the message to the vehicles when they enter the region with the informed time of zero; they have been informed as soon as they enter the region.
- It dynamically depends on network's density and the vehicles' speed to adjust the parameters of the protocol for better performance.
- The time of geocasting is changeable (i.e. it can be expanded or cancelled). This, what we call the dynamic nature of the protocol, is simply a new idea in time stable geocast protocols for stopping or extending the time in the geocasted message. For an event that happened and its message is in the time-stable geocast phase; all the oncoming vehicles will be informed of the event as soon as they enter the region, after a specific time the message will expire and not be relayed anymore. However, since the problem may last longer than the expected time, there should be a mechanism to expand the time of dissemination within the region. In addition, if the incident is solved sooner than the

time expiration of the message, there should also be a mechanism to ensure that it will not be relayed anymore. In other words, there should be some strategy to stop disseminating the original message.

The accuracy of a protocol is important. One of the goals of this protocol is to deliver the message to all the vehicles that enter the region during the desired time. Therefore, the first performance metric is the packet delivery ratio (PDR), defined as the percentage of informed vehicles within the total number of vehicles that enter the region during the specified time.

On the other hand, beside accuracy, the protocol should be scalable as well. The resources on the network are limited, for example, the channel in which the nodes communicate with each other. This limitation increases when the nodes move with higher speed. In fact, the cost of the protocol to the network also should be low. The network cost is defined as the average number of broadcasts and the average number of duplicate messages received by the vehicles. As the nodes intend to keep the message alive in the area, they need to rebroadcast it more than once. Moreover, too much rebroadcasting, like simple flooding, seriously affects resources. In sparse networks, too much rebroadcasting may not cause too much cost on nodes, as the number of the nodes is too low. Therefore, the number of messages received by nodes is low. However, in dense networks, one rebroadcasting causes many messages to be received by the nodes. This is also another unique characteristic of this protocol. It tries to adjust the costs, a tradeoff between broadcasting and receiving cost, according to the density of the road. In addition, it is worth mentioning that the size of the message that is disseminated in this protocol is the same as the hello packet size. As a result, it will not affect resources a lot.

1.4. Thesis Organization

This thesis consists of six chapters. Chapter 1 presents an introduction to this work and the other chapters' outlines are as follows:

- Chapter 2: In this chapter, a number of geocast and time-stable geocast protocols are surveyed. This chapter overviews these protocols' future, advantages and disadvantages. Although a considerable number of geocast protocols exist in literature, the time-stable geocast is relatively new to the VANET environment.
- Chapter 3: This chapter explains the novel dynamic time-stable geocast protocol by presenting the system model, the dynamic parameters of the protocols, assumptions, and a flow chart of the protocol along with the protocol details. In addition, it defines the stable period that is also novel to these protocols.
- Chapter 4: This chapter describes the results of the proposed protocol by doing an intensive simulation, including both road traffic simulation and the protocol simulation. Then, it shows how much better this protocol works in sparse networks than simple flooding, which fails in these densities. In addition, the protocol's advantages and its drawback are also covered.
- Chapter 5: This chapter briefly summarizes the significance of the protocol and offers suggestions for a future extension of this work.

Chapter 2: Literature Review

This chapter reviews some important protocols related to the current research objective. The first part reviews 14 papers that offer geocast protocols, and the second part presents two papers that explain time-stable geocasting. Each part is followed by a table that compares the specifications of these protocols.

2.1. Geocast Protocols

A. *A Highly Adaptive Distributed Routing Algorithm for Mobile Wireless Networks [11]*

This paper introduces a temporally ordered routing algorithm, TORA, is a kind of link reversal algorithm used for mobile, multi hop, wireless network. It provides loop free, multi route path from a source to a destination. This protocol has three separate stages (creating routes, maintaining routes and erasing routes) and uses three control packets of query (QRY), update (UPD) and clear (CLR), respectively. After creating the routes, upon changing of the topology, the protocol rapidly re-establishes the routes. On segmentation, the protocol detects the fragments and erases the invalid routes.

System Model: There is a network such as graph G= (N, L), with N sets of nodes. L_i is the number of undirected routes in the set N_i. Each node has a node identifier and each of L_is is changed with time due to the mobility of the nodes. Having an undirected route means that the two nodes are not in one hop distance of each other. On the other hand, in each of the two neighbor nodes, i and j, if i is connected to j, node i is said to be upstream of node j and node j is said to be downstream of node i. There is an assumption that, by the existence of the link layer protocol, every node is aware of its neighbors.

Protocol Description: At any given time, a height will be associated to each node with the protocol rules. Initially, each node's height is set as NULL and the destination node's height is zero. If node i is higher than node j, the link between them is named Upstream; otherwise it is named Downstream. The NULL height is considered as the highest.

i. Creating route: as a node requires creating a route, it sends a QRY packet. The route is created as all the links are downstream of the destination as determined by each node's height.
ii. Maintaining the route: route maintenance is done only for nodes whose their heights are not NULL. While detecting a disconnection to the destination for any reason, a node reverses its entire links, causing the other nodes to use the same algorithm. The reversal algorithm will be propagated only to the nodes that have no undirected link to the destination. When this node is reached, all the other nodes again maintain an undirected route to the destination.
iii. Erasing route: maintaining the new route means that the previous route is no longer used. So propagating a CLR packet allows the previous routes to be deleted in related nodes routing tables.

Performance Metrics: Time complexity, the number of steps for a protocol to be executed, communication complexity, and the number of packets that should be propagated for execution are its performance metrics.

Simulation: There is no specific simulation software and no numerical initiation mentioned in the paper. However, the variables used in the simulation environment are the network diameter and the number of nodes.

Pros and Cons: It is only useful in large, dense mobile networks. It creates and maintains the routes quickly but minimizes the communication overhead. It also adopts rapidly with topology changes in the network and its ability to detect fragmentation in networks and erase all unnecessary routes is unique. Nevertheless, it fails in sparse networks.

B. Geocast – Geographic Addressing and Routing [12]

This protocol uses Geocast routers to help the geocast message to reach the geocast areas. In other word, it tries to link geographical coordinates to IP addressing over the internet.

System Model: Geocast region is defined as a closed polygon with its vertex points. Also, some geo-routers, specifically satellite routers, are in charge of moving the message from the sender to its receivers. The Geo-Nodes are also those located in the geocast area and interested to receive the packet. The source is willing to send a message to the groups of nodes residing in a specified geographical area.

Protocol Description: Sending a message involves three steps (sending, shuttling between routers and receiving).

Sending a message is done by the source. The source prepares the packet that contains the specifications of the geographical area as well. The source delivers the packet to the local Geo-Router.

Now the local Geo-Router starts to find an appropriate router or routers that cover the region polygon. At this time, the Geo-Router also gets help from its parent Geo-Routers as well specially for routing the packet. By this time, the message has been sent to the region's Geo-Router.

While the message has been sent to one of the Geo-Nodes in the region by the Geo-Router, the Geo-node assigns a multicast group to the packet and starts to multicast it periodically to the assigned destinations.

Performance Metrics: These involve how long it takes for routing, and delivering a message to its destination.

Simulation: The simulation was written in C++ code in a Linux environment. Three computers with the simulation software were connected through a LAN. Each of these computers was considered as a Geo-node and Geo-router as well. The simulation software controlled the process. The three computers were connected to each other using IP tunnel. The simulation ran by sending 100 packets on different geocast areas, like a polygon, a circle, and a point. Routing to a circle was 9 times more expensive than routing to a point, and routing to a polygon was 25 percent more expensive than routing to a point. The simulation revealed that the earlier packet routing time is much longer than the rest of the packets as the routers cashed all the information they required by the initiating packets. Therefore, it is recommended that, by sending some of the preliminary packets and waiting for some time, the performance of the system will increase significantly.

Pros and Cons: One of the drawbacks of this protocol is the assumed use of satellite routers, which are expensive devices. Moreover, all the nodes should have satellite receivers that are compatible by these routers. On the other hand, this protocol should have more development to support mobile nodes within the region. Registering and unregistering the entered and leaving modes also should be considerd.

C. Geocasting in Mobile Ad Hoc Networks: Location-Based Multicast Algorithms [13]

This paper proposes two location based multicast to reduce the network overhead compared to the regular multicast flooding.

System Model: In this scheme, all nodes are considered as knowing their own location using one of the localization aid tools. The host S wants to send a message to a group of nodes called multicast region. The multicast region can be a circle or a closed polygon. Therefore, the node S is intended to inform the nodes that reside in the region at time t_0. The node S also defines a forwarding zone like [14] defines that helps the message reach the multicast region. To increase the probability that the packets reach all the members, the forwarding zone should include the multicast region.

Protocol Description: There are two schemes for this protocol. In scheme 1, the forwarding zone is defined as the smallest rectangle from source to the destination, that includes the multicast region as well. The source identifies the coordination of the rectangle and includes it in the header of the packet. The receiving nodes simply discard the packet if it is not in the forwarding zone. On the other hand, if a node receives a packet that resides in the rectangle, it simply broadcasts it to its neighbors.

In scheme 2, the source, instead of adding the forwarding zone coordinates explicitly in the packet, adds three other pieces of information in the packet: the geocast region specification, the geometrical centre of the geocast region, and the coordinates of the source *S*. When a node receives a packet, it calculates its distance from the center of the zone. If its distance is more than the sender of the packet, the receiving node discards the packet. Otherwise, the receiving node sends the packet to its neighbors. It is worth mentioning that each sender assumes itself as a source and modifies the packet header.

Performance Metrics: Accuracy of multicast and network overhead are the two performance metrics of this protocol. Accuracy of multicast delivery is calculated as a ratio of the number of multicast group members that actually receive the multicast packets and the number of group members that were supposed to receive the packets (i.e., the number of nodes that were in the multicast region when the multicast was initiated). The network overhead is defined as the total number of multicast packets received by nodes per multicast.

Simulation: The simulation took place in MaRS (Maryland Routing simulator) [15]. These two schemes were compared with the simple multicast flooding in this simulator. There are 30 nodes within a rectangular area of 1000×1000 units square, moving with an average speed of v units/second. The transmission range of each node is equal in each simulation but varies from one simulation to another among 200, 250, 300 and 400 units. A randomly selected node multicasts a packet per second. The multicast region is a 300×300 units square region, where its both X and Y coordinates vary from 500 to 800 unit.

Pros and Cons: As the forwarding zone increases, the accuracy of the protocol increases, but the network overhead also increases. In general, scheme 2 has a better performance then the simple flooding and scheme 1. Nevertheless, in both of the schemes, the network overhead increases when the transmission range of the nodes increases. Therefore, the paper mentions some optimization for the protocol, like an alternative forwarding zone definition, adaptive forwarding zone, and the use of directed antenna.

D. (ODMRP) On Demand Multicast Routing Protocol [16]

This is a mesh based multicast scheme that runs an on demand procedure to dynamically build and maintain routes. It uses the concept of forwarding group [17] to build a forwarding mesh for each multicast group.

System Model: There are some sources on the network with some interested receivers. The receivers like to receive the messages from sources.

Protocol Description: The protocol is split into two parts. The first part builds the route on demand. This happens when a source wants to send messages to some destinations. First the source sends a member advertising packet to the network, called Join Request. This periodic transmission refreshes the membership information and updates the routes. The intermediate nodes always store the upstream node ID, so they are backward learning. This condition will continue until it reaches the multicast receivers. Thus constructing a route from sources to receivers and building a mesh of nodes, the forwarding group. The second part forwards the packets via selected routes and forwarding groups.

Performance Metrics: The packet delivery ratio (scalability), the number of control bytes transmitted per number of bytes delivered, and number of data and control packet transmitted per number of bytes delivered (constitute the performance metrics).

Simulation: The simulation takes place in Global Mobile Simulation (GloMoSim) [18]. There are 50 mobile hosts placed randomly in a 1000m×1000m area. The radio propagation for each node is 250 meters and the channel capacity is 2Mb/s. The IEEE 802.11 Distributed Coordinated Function (DCF) [19] has been used with CSMA/CS. Multicast members are randomly chosen with uniform probability, and nodes are moved randomly.

Pros and Cons: The mesh provides richer connectivity among multicast members than forwarding trees. Flooding redundancy among forwarding groups helps overcome node displacements and channel fading; however, unlike trees, periodic reconfiguration is not required. The ODMRP does not require running over a unicast routing like other protocols, however, it can support a unicast as well. The simulation results indicate that the delivery ratio is high except when the mobility is too high because the mesh has not been created. An increase in the number of nodes will reduce the effect of mobility.

E. Role-Based multicast in highly mobile but sparsely connected ad hoc networks [20]

At a glance, the nodes in this protocol will not forward the message until they sense a new node in their broadcast range. This protocol assumes that it works on the top of a data link layer that keeps tracking of the neighboring nodes. So the system is notified of the entry of the new vehicles or of the exit of the current nodes in the region.

System Model: In this scenario, a crashed vehicle on the road wants to inform other approaching vehicles of the event. All vehicles should be aware of their location through a specific tool like onboard GPS. Each node has two sets of identity that are kept updated by the data link layer : *N*, the identity of the neighboring nodes; *S*, the identity of the senders.

Protocol Description: The source/crashed vehicle starts to send message when it senses a neighboring vehicle. After that, say in the initiation stage, all the vehicles do the following.

If {N}-{S} ≠ 0, the node has neighbor(s) other than the source(s); then the node enters the "WaitToResend" mode. In this mode, the node waits for some time, say WT, before resending the packet. Each packet's header contains its sender position. The system calculates WT which is related to d, the distance between the node and the event, by the following formula

$$WT(d) = -\frac{MaxWT}{Range}.\hat{d} + MaxWT \text{ , where } \hat{d} = \min\{d, range\} \ and$$

$MaxWT{:}\, maximum\ waiting\ time, Range{:}\, transmission\ range.$

During the waiting time the system updates the sets N and S and, upon satisfying the condition {N}-{S} = 0, the system goes to next mode that is "WaitForNeighbor".

If {N}-{S} = 0, the system finds no more new vehicles and waits until new vehicle has been sensed.

Performance Metrics: The accuracy of the multicast delivery (i.e. the number of vehicles informed per the total number of vehicles) constitutes the performance metrics.

Simulation: The simulation consists of a road of 10 km length where an accident happened in the middle. Two roadways are considered: a highway with and without divider. The velocity of the vehicles is around 130 km/h and the density of the vehicles in the highway is 5 vehicles per km per lane. The number of vehicles equipped with wireless devices is changed during simulation to these amounts: 1, 10, 15, 20, 25, 50, and 100%. The transmission range of vehicles is 600 m and the maximum waiting time for a vehicle to forward a packet is 40ms. The simulation is started by an accident and proceeds until all the vehicles have passed the accident. The results of both divided and undivided highways are somewhat similar. A result when the number of equipped vehicles is more than 50% is good, but the protocol acts poorly in with amounts less than 50%.

Pros and Cons: Some flaws can be seen in this algorithm. First, it does not mention when the packet should be discarded in a node. Second, if $d > Range$ then $WT(d) = 0$, thus, when the vehicle is located farther from the source of the packet than its multicast range, it starts to broadcast it repeatedly without any waiting time and can never be stopped by any algorithm.

F. GPS-Based Message Broadcast for Adaptive Inter-Vehicle Communication [21]

This protocol proposes a broadcasting approach that uses the GPS benefit to improve the performance of broadcasting in Inter Vehicle Communication.

System Model: All the vehicles use GPS. To categorize the neighbors' GPS, information is assumed to be available for each node through beaconing.

Protocol Description: The first protocol is TRADE, which uses vehicle movement and the position vector to classify the positions of neighboring vehicles into different group and then chooses fewer vehicles for rebroadcasting. The nodes are classified as "opposite road nodes", "same road ahead nodes", and "same road back nodes". Therefore, the source determines the last vehicle in front and behind itself on the same road. Then the source broadcasts the message with the ID of the farthest vehicle in its front, the farthest one in its back, and all the opposite road vehicles. The receiving vehicles determine whether their ID is included in the message. If yes, they become another source and use the same method for rebroadcasting.

The second protocol, DDT, intentionally takes defer time into account for each rebroadcasting cycle. After the defer time expiry, each vehicle determines whether to drop the message or rebroadcast it. In this protocol, the bordering vehicles should rebroadcast earlier than the middle vehicles, so the middle vehicles can drop the message. For this purpose, the defer time should be inversely proportional to the distance of the vehicle from the source.

Performance Metrics: Bandwidth utilization (the number of accepted messages versus the number of received message) and reach ability (the number of informed vehicles over the total number of vehicles in the region) are the two performance metrics of the protocol.

Simulation: ***T***he simulation considers both the urban (high-density network) and rural (low-density network) traffic pattern separately. Collisions and congestion can be avoided. There are two road structures, which is the intersection of two 20 km roads with some differences. The transmission range is a variable in this simulation.

Pros and Cons: This porotocol effectively reduces the number of rebroadcasting messages but does not affect the number of nodes that receive the message. The simulation result shows an improvement of several hundred percentage in bandwidth utilization. However, one of the drawbacks of TRADE is that it requires a GPS information exchange between its members. Nonetheless, the TRADE shows better bandwidth utilization improvement than DDT in both scenarios. On a winding road, the DDT will show a better performance. In regard to reach ability, the DDT shows better performance in both scenarios than TRADE.

G. Flooding-based geocasting protocol for mobile ad hoc networks [22]

System Model: A node S intends to send a packet to the nodes located in a rectangular geocast region at a specific time, say t_0. The nodes inside the geocast region are called the geocast group. A node automatically becomes a member of geocast group when it moves into the region, and it leaves the group when moving out of the region.

Protocol Description: To send the packet to the geocast group, a forwarding zone that includes the geocast region as well is created. A forwarding zone is the smallest rectangle between the source and the Geocast region. The source includes the coordinates of the forwarding zone in the packet. If a node receives the packet outside the forwarding zone, it discards it. This protocol uses simple flooding [23] by a minor modification. The only nodes inside the forwarding zone flood the packet instead of all networks. Three methods of creating the forwarding zone are introduced.

Static Zone Scheme: In static forwarding, the forwarding zone is defined by the source and will not be changed by other nodes.

Adaptive Zone Scheme with One-hop Flooding: In this scheme, the receiving node, if it is located in the forwarding zone, before rebroadcasting, changes the forwarding zone by applying itself as a source and replaces the previous forwarding zone coordinates with a new one in the original packet. It is obvious that in this scheme the forwarding zone will be smaller than the first scheme.

Adaptive Distance Scheme: In this scheme, the source, instead of adding the forwarding zone coordinates explicitly in the packet, it adds three other pieces of information in the packet: the geocast region specification, the geometrical centre of the geocast region, and the coordinates of the source *S*. When a node receives a packet, it calculates its distance from the center of the zone. If its distance is greater than the sender of the packet, the receiving node discards the packet. Otherwise, the receiving node sends the packet to its neighbors. It is worth mentioning that each sender assumes itself as a source and modifies the packet header.

Performance Metrics: Two performance metrics, accuracy and network overhead, are considered. Accuracy means the percentage of informed nodes within the geocast region. Overhead means the number of packets that all nodes receive during the scenario. Increasing the forwarding zone will increase the probability of delivering the message to the nodes while it also increases the network overhead. Therefore, there should be a tradeoff between these two performance metrics.

Simulation: The NS2 simulator is used for simulation of this protocol. The nodes are moving randomly and are uniformly distributed with different speeds of 5, 10, and 20 unit/s in a region of 1000×1000 unit square. The geocast region is a 300×300 unit square rectangle whose coordinates, X and Y, are changed between 700 and 1000. The numbers of node used are 10, 30, and 50. The wireless bandwidth is 2 Mbps with a transmission range of 250 units for each node. The accuracy of the two adaptive schemes is the same as simple flooding and does not varying while the speed is changed. The static scheme is also at an acceptable level but is lower than the others are. The overhead of all three proposed protocols is significantly lower than simple flooding but the adaptive scheme zone is the lowest at all. Therefore, overall, the adaptive scheme zone offers a good tradeoff between the metrics.

Pros and Cons: In a sparse network, the results of all three schemes are poor. But in dense networks, the adaptive scheme can be used without much network overhead and with a good level of accuracy, compared to simple flooding, without depending on the nodes' speed.

H. IVG: Inter Vehicular Geocast [24]

This article's focus is on multicasting in wireless ad hoc networks which are relevant to ITS. IVG is a protocol to inform all the vehicles on a highway about a danger (e.g. an accident or any other obstacles).

System Model: A message is relevant to the node when it delivers relevant information to a node (i.e. an accident in front of this node and in the same direction of this node). The risk area is defined according to the driving direction and the positioning of the vehicles. The nodes moving toward the event include the source vehicle, and the vehicles behind it and in the lane toward the event are all located in the risk area. All the vehicles in the risk area define a multicast group that is defined temporarily by the location, speed and the driving direction of the vehicles.

Protocol Description: IVG is not based on the maintenance of the neighbors' list on each vehicle. The source broadcasts the event. The receiving nodes do not rebroadcast the receiving message immediately; they wait for a specific time, called the differ time, to make a decision to rebroadcast. After the expiration of the differ time, if the node has not received the same message from the nodes behind, it deduces that there are no relaying nodes behind it and it should be act as a relaying node. Therefore, it starts to rebroadcast the message. This differ time algorithm is described in [25] and is improving in this paper. The differ time of node x while receiving a message from node s is inversely proportional to the distance between them. By this time, the farthest nodes wait less and rebroadcast faster.

$$defertime(x) = MaxDeferTime.\frac{(R^{\epsilon} - D_{sx}^{\epsilon})}{R^{\epsilon}}$$

In the above formula, R is the transmission range and D_{sx} is the distance between node x and source s. Assuming uniform distribution for the nodes in the area and assigning the $\varepsilon = 2$, the nodes' differ time is uniformly distributed over *[0, MaxDeferTime]*.

Performance Metrics: The two performance metrics of this protocol are reliability and scalability. Reliability guarantees coping with all defragmentation of the network so that all the vehicles in the risk area are informed about the event. Scalability means that it is a lightweight protocol in order to reduce the network overhead.

Simulation: The simulation runs through Glomosim [26]. A highway with the length of 10km and the breadth of 40m is considered for the two scenarios, one with 200 vehicles and the other with 100 vehicles. The message length is 64 bytes and the MaxDeferTime is 4ms. The broadcast range of vehicles is between 150m and 400m with the average speed of 125Km/h (110Km±15Km). The simulation starts by broadcasting the event and lasts until all the broadcasting area is covered. The result shows that IVG reliability is 100% in reducing the overhead of the network compared to other protocols like DDT [27]. In addition, IVG reduces the number of unnecessary messages by maintaining dynamically one relay node at a time.

Pros and Cons: This protocol reduces the background traffic caused by hello messages that the other protocols use and offers more bandwidth for message dissemination. In addition, the reliability of this protocol is 100%.

I. GAMER: Geocast Adaptive Mesh Environment for Routing [28]

GAMER uses source routing, the routing that is used in the dynamic source routing (DSR) protocol [29, 30]. Also, GAMER can be easily modified to use a local routing state instead of source routing. A Mesh based multicasting approach is used in GAMER. A mesh is a subset of the network topology that provides multiple paths between the sender and the receiver in the multicast protocols.

System Model: The source is located outside the geocast region, the region where the source is intended to send the packet. A forwarding zone is used to flood geocast packets to the geocast region instead of flooding in the entire ad hoc network. A mesh is used in GAMER to establish a multi-paths route between the source and the geocast region.

Protocol in Detail: In GAMER, a mesh is developed and built while a source periodically geo-broadcasts JOIN-DEMAND (JD) packets. JD insists that all nodes in the geocast region join the geocast group and each node responds by a JOIN-TABLE (JT) packet. When a JT packet reaches the source, a complete path between the source and the geocast region is provided in the JT. There are three forwarding approaches in creating the mesh: FLOOD FA, CORRIDOR FA, and CONE FA. As each of these FAs has its own pros and cons, there is an adaptation between these three approaches which are dynamically chosen during geocast. Then the source starts to send data after a delay which allows time for the creation of the mesh. If a node within the geocast region or mesh region receives a nun-duplicate data packet, it starts to rebroadcast it to its neighbors. The geocast group members use localized flooding algorithm to inform all their accessible neighbors.

Performance Metrics: The data packet delivery ratio, end-to-end delay, control overhead, and network-wide data load are the four performance metrics of this protocol.

Simulation: The simulation takes place in an NS2 environment for 50 nodes within a 300×600 m^2 area. The geocast region is about 100×100 m^2 and is located in the upper right corner of the simulation area. The nodes move in a random manner with the following mean mobility speeds: 1, 5, 10, 15, and 20 m/s. The transmission range of each node is 100 m, and the simulation runs for about 1000 s. The packet length is 65 bytes. There is a 0.875 s jitter time considered for the source to send the data packet after it sends the JD. Each GAMER approach (i.e. FLOOD FA, CORRIDOR FA, and CONE FA), shows different results in the simulation. So, at low speed, GAMER starts using CONE FA, but when speed increases, it switches to two others.

Pros and Cons: One of the advantages of this protocol is the dynamically changing of the mesh that is built. While the nodes are highly mobile, they build a dense mesh. Moreover, when it detects nodes slowly, it creates a sparse mesh. This will increase the transmission accuracy while maintaining the control overhead to a reasonable degree.

J. Anycasting-based Protocol for Geocast Service in Mobile Ad Hoc Networks [31]

GeoTORA is derived from TORA to deliver a message to a specific region. This protocol has two stages. First, to deliver the message to the region, it uses a modification of TORA called anycasting, and within the region, simple flooding is used to inform the geocast group nodes.

System Model: There is an intended region that called geocast region. The source is far from the region but it gets help from other nodes to send the packet through the region and to inform the nodes in the region.

Protocol Description: This protocol has two stages. One is called anycasting, which is an optimal revision of TORA. In this stage, a route has been sent from the source to one of the geocast nodes and through this, the route packets reach the geocast region. The last one is simple flooding within the region. Therefore, GeoTORA has all stages of TORA with some differences. In creating a route, the entire geocast regions nodes have a height of zero, as they are all destinations, and all the zero height nodes will not make a link between each other. In the flooding stage, when the packet reaches one of the nodes within the region, the receiving node starts rebroadcasting to its neighbors. The receiving nodes rebroadcast it again if they are within the region and discard it if they are outside of the region. A node broadcasts a packet only one time.

Performance Metrics: Accuracy (the percentage of informed nodes) and the network overhead (the number of control packets transmitted and not included the number of data packets) are the two performance metrics of this protocol.

Simulation: NS2 has been used for simulation, and the performance of GeoTORA has been compared to pure simple flooding and the LBM [32] algorithm. In simulation the initial coordinates of the nodes are defined using a uniform distribution. The 30 nodes move around a rectangular region of 700×700 unit^2 square. The nodes' speed varies among 5, 10, and 20 units per second. The nodes' transmission range is 250 units. The packet size is about 512 bytes. There is also a geocast region with a size of 200×200 units^2 square with both X and Y coordinates in the range of 500 and 700. The accuracy of GeoTORA is reasonable but it is still not as much as pure flooding and LBM. Nevertheless, the network overhead in GeoTORA is much less than the other two. The network overhead increases while the speed increases in both pure flooding and LBM but, in GeoTORA, the increase is less.

Pros and Cons: This protocol reduces the overhead of the network while the nodes' speed increases with a reasonable accuracy in comparison to pure flooding. The problem is that when the hello packet overhead is taken into account, the network overhead is increased and this will be a significant drawback of the protocol.

K. CGGC: Cached Greedy Geocast [33]

This paper defines a protocol for geocasting in vehicular ad hoc networks to deal with the high velocity of the vehicles. It aims to forward a packet to all of the nodes that reside within a geographical area, called the destination region.

System Model: The source intends to send a packet to a specific region. It includes the region information in the packet, like the centre of the region and its radius. The source is out of the region. The protocol is divided into two steps. First, the packet should reach the region, called forwarding in a greedy manner, and then is disseminated in it, called forwarding in flooding manner. The focus of this paper is the line forwarding part of the geocast.

Protocol Description: A greedy forwarding scheme is used for line forwarding. One of the disadvantages of greedy forwarding is that the node becomes a local maximum called a dead end node. The solution to this drawback is to delay the packet for a short period and then retry to forward it. If this neighbor is no longer available, another node will be selected. This helps increase the delivery ratio in high mobility mobile nodes. The nodes become aware of each other and their position by sending out beacons. The idea is to add storage to the routing layer. This cache works on demand and does not increase the network overhead in contrast with the blind periodically resending attempts. If a new node is detected, the routing layer is informed by a beaconing system and then decides based on the cached packets whether this node is suitable for forwarding or not. The decision is made based on the closeness of the node to the region. There are two cache methods:

Size restricted cache: When a new packet arrives in cache, if the cache is full, the oldest packet is deleted from the cache.

Time restricted cache: All the new packets are stored in the cache, and no other packets are deleted when the packet's expiry time has been expired.

Performance Metrics: Delivery success and delivery delay are the two metrics.

Simulation: The simulation took place in ns2 and the protocol behavior was compared to GPSR [34]. The network size varied from 1000×1000 m² to 4000×4000 m² with the interval of 500 m. There were 100 considered for the network, so the network density varied by network size from 20 to 1.2 nodes respectively. The nodes' wireless transmission range was 250 m. All nodes were uniformly distributed over the area and moved in a random waypoint model. The nodes speed was considered as 50 m/s. One hundred messages were generated in each scenario, and the source and destination were chosen randomly. The destination region radius ranges from 100 to 300 m. The four scenarios run were line forwarding without cache, line forwarding with cache, geocast with cache, and geocast without cache. The line forwarding without cache result was not as good as GPSR, especially when the network size at its maximum size. The line forwarding with cache result for proposed protocol shows improvement even in a large-scale network (i.e. low-density network). The cached geocast result was reasonable as well. In addition, the size restricted cache had a better result than the time restricted cache. For the size-restricted scenario, even with a cache size of two packets, the results were good. On the other hand, the end-to-end ratio indicated that the delay for delivered packet was high.

Pros and Cons: The proposed protocol has a good delivery ratio. As the end-to-end delay is higher than normal, there should be a tradeoff between these two performance metrics.

L. Voronoi Diagram and Convex Hull-based Geocasting and Routing in Wireless Networks [35]

This paper proposes a general algorithm in which a message is forwarded to exactly the best choice nodes using certain criteria. Its intention is to find the best choice nodes that are nearest to the destination region.

System Model: It considers a circle or rectangular area and names the possible location of destination that the destination may locate in this area with a greater possibility of being in the centre. The area size depends on mobility information. The paper proposes a general algorithm to forward a message to those neighbors that may be the best choice for this area. As it is kind of a geocasting, it gets the help of some position detection tools like GPS.

Protocol Description: The protocol tries to reduce the hop count and the flooding rate of the current geocast protocols with an increase in success rate. The source first determines some intermediate nodes that are the best choice for forwarding. Two proposed methods for selecting the best choice nodes are described in the paper. One of them is based on Voronoi diagram [36] that chooses the most nearest node to the destination. The protocol is loop-free, and it memorizes the past traffic of the network. The authors suggest that the protocol has better performance in geocasting short messages but not for long messages. One example of short messages is route discovery messages. In addition, the approach used inside the region is simple flooding. Then the author suggests a dominating approach that reduces the number of pre-determined nodes in a way that also reduces the flooding rate and increases the success rate.

Performance Metrics: These are the success rate, average hop count, and flooding rate.

Simulation: The simulation was run in VC++ with and without a dominating strategy, and in both the static and mobile scenario. For the static network scenario, 200 nodes were selected with the region that constitutes 20% of the nodes. For proactive part, the 200 nodes are located in an area of 640×480 units^2, and the transmission of a R. A random walk model was used. Both the direction and the speed of the nodes were randomly selected.

Pros and Cons: The superiority of this protocol is obvious in the results compared to some current geocasting protocols. However, this superiority is acceptable when the dominating method is used. The dominating approach decreases the flooding rate while maintaining the success rate and hop counts at a reasonable value.

M. GeoGrid : A Scalable Location Service Network [37]

This protocol defines and develops GeoGrid, a geographical location service network for scalable and efficient information delivery and dissemination to a large and growing number of mobile users.

System model: The region consists of N fixed nodes. The region is partitioned to N disjoint rectangles such that each node owns one of them. Each node shares some information related to the entire geographical region with the others. A mobile node connects itself to one of the nodes through wireless or wired connection and requests information. The nodes respond to the requests using their own information or information from other nodes.

Protocol Description: The first step is to create a grid over the geographical area. The protocol creates the whole area as one rectangle cell based on the first node that has been in the area and then continues splitting the area while the new nodes enter the region as each cell is assigned to one node. Therefore, the area has been split to N cells while there are N nodes in the region. For routing, the source sends its packet to its neighbor that is closest to the destination. The intermediate nodes also employ the same strategy and relay the packet to the cell nearest to the cell where the destination is located. It continues until the packet reaches the destination. The last stage defines the simple TCP/IP point-to-point connection for connecting mobile users to the fixed nodes. The protocol also defines the dual peer GeoGrid that assigns each sell to two nodes. This increases the reliability and robustness of the protocol in addition to decreasing the number of cells in an area. For optimization, the protocol requires some load balancing techniques that enable the workload distribution to be dynamically adjacent. Therefore, there is also a dynamic adaptation of the GeoGrid introduces in the paper that helps high workload create a higher workload by joining and splitting the neighbor cells. Some of them are Steal secondary owner, Switch primary owner, Merge with a neighbor, Split a region, Switch primary with the neighbors' secondary owner, Steal remote secondary owner, Switch primary with the remote secondary owner, and Switch primary with remote primary owner.

Performance Metrics: It is the workload of the network.

Simulation: A geographical area of 64 miles × 64 miles with the number of nodes varying from 1×10^3 to 1.6×10^4 was considered for simulation. The simulation took place on the three proposed protocols (i.e. simple GeoGrid, GeoGrid with dual peer, and GeoGrid dynamic adaptation). Each simulation is repeated 100 times on different nodes population.

Pros and Cons: Both dual peer and dynamic adaptation can improve the workload of the network.

N. Multi-Geocast Algorithms for Wireless Sparse or Dense Ad Hoc Sensor Networks [38]

This paper's focus is on defining a new protocol for geocasting a packet within some regions of sparse sensors in a sensor network environment.

System Model: A sink is going to send a packet to nodes that are located in several geocast regions. This protocol considers a set of nodes with the same propagation range of r as a graph while each node is a vertex and the distance between two nodes, say d(m, n), is less than r. A Gabriel graph is used in this protocol.

Protocol Description: The source (sink) starts to broadcast the route request packet that contains the ID of the sink and the coordinates of the region. All the intermediate nodes append their own address to the packet and rebroadcast the route request. The intermediate nodes discard the duplicated route request packets. Rebroadcasting the route request continues until it reaches an intermediate node that is the neighbor of a node within the region. At this point, it does not rebroadcast the route request packet and reply to this packet. After the sink receives the route reply, it starts to send the original packets to the region using the discovered route. There are two difference path selections.

The first is an algorithm with a shared backward path: the sink selects the path whereby the end node (the first-node-outside the region) is approximately close to almost all of the regions. Therefore, it uses a shared path for geocasting.

The second is an algorithm without a shared path: the sink selects multi-paths such that each of them is near to a different region.

These algorithms are for the stage that a packet should reach. After the packet reaches the region, the second stage is started. The nodes inside the region that have access only to the neighbors inside the region simply rebroadcast the packet using simple flooding. The nodes that have some neighbors outside the region and near the border, besides the simple flooding within the region, start to broadcast a packet named according to the content of the original packet. In this case, when a border neighbor comes into the region, it has the packet and it starts to flood it as well. Unfortunately, there is no simulation mentioned in the paper.

2.2. Geocast Comparing Table

Geocast			
	A Highly Adaptive Distributed Routing Algorithm for Mobile Wireless Networks (TORA) [11]	Geocast – Geographic Addressing and Routing [12]	Role-based multicast in highly mobile but sparsely connected ad hoc networks [20]
Using GPS	No	Yes	Yes
RSU/OBU	No	Yes	No
Transmission method/Path strategy	Unicast	Multicasting	Multicasting (upon sensing new node)
Source located outside the region	No	No	No
Require maintaining path from Source to Destination	Yes	Yes	No
Using Delay Tolerant	No	Yes	Yes
Nodes require buffer for storing the message	No	Yes	Yes
Beacon packet	Yes	No	Yes
Routing table/neighboring list	Yes	Yes	Yes
System model	It is kind of a link reversal protocol. A source requests a route to a specific destination through a set of mobile nodes. A set of undirected links are dynamically created.	The area is divided to separate regions each of which has a satellite router. A source in a specific region wants to send a message to all nodes within another region.	A source is willing to inform others of a special accident on the highway. The protocol works on the top of a link layer that is aware of the neighboring.
Performance metrics	1. Time complexity	1. Routing time	1. Delivery ratio
	2. Network overhead		
Variables in experiments	1. Number of nodes	1. The destination region shape	1. Number of equipped node
	2. Network diameter		
Simulation Software	Not specified	C++	SHIFT[1]

Geocast			
	Flooding-based geocasting protocols for mobile ad hoc networks [22]	A Multicast Protocol in Ad-hoc Networks: Inter vehicle Geocast IVG [24]	An adaptive mesh-based protocol for geocast routing GAMER [28]
Using GPS	Yes	Yes	Yes
RSU/OBU	No	No	No
Transmission method/Path strategy	Simple flooding (within the forwarding zone)	Geocast	1. Dynamic source routing (outside the geocast region) 2. Simple flooding within the region
Source located outside the region	Both situations cover	No	Yes
Require maintaining path from Source to Destination	No	No	Yes
Using Delay Tolerant	No	Yes	No
Nodes require buffer for storing the message	No	Yes	Yes
Beacon packet	No	No	No
Routing table/neighboring list	No	No	Yes
System model	A geocast region's nodes are intended to be informed by a source, inside or outside the region. The source defines a forwarding one then starts using simple flooding the packet.	A relevant message is intended to broadcast in a specific area, called risk area. The source and the nodes are all located in this area.	A source, after dynamically creates a route to the geocast region, starts to send packets via the created mesh to the region
Performance metrics	1. Accuracy	1. Reliability	1. Delivery ratio
	2. Network overhead	2. Scalability	2. Control overhead
			3. End-to-end delay
			4. network-wide data load
Variables in experiments	1. Speed	1. Penetration rates of nodes	1. Nodes speed
	2. Simulation pause time	2. Transmission range of nodes	
	3. Number of nodes		
Simulation Software	NS2	Glomosim [26]	NS2

Geocast			
	Anycasting-based protocol for geocast service in mobile ad hoc networks (GeoTORA) [31]	CGGC: Cached Greedy Geocast [33]	Voronoi diagram and convex hull based geocasting and routing in wireless networks [35]
Using GPS	Yes	Yes	Yes
RSU/OBU	No	NO	No
Transmission method/Path strategy	Unicast and flooding	Unicast and flooding	Unicast/Flooding
Source located outside the region	Yes	Yes	Yes
Requir maintaining path from Source to Destination	Yes	Yes	No
Using Delay Tolerant	No	Yes	Yes
Nodes require buffer for storing the message	Yes	Yes	Yes
Beacon packet	Yes	Yes	No
Routing table/neighboring list	Yes	Yes	No
System model	The source outside a region intends to inform all the nodes inside the region of a message. The message reaches the region using a modified TORA and then uses simple flooding within the region.	The source outside the region intends to inform the region nodes a message. The two steps will be done, line forwarding and area forwarding.	It considers a circle or rectangle for the possible location of destination and tries to find the best choice nodes that are more nearest to the region to deliver them the message.
Performance metrics	1. Accuracy	1. Delivery ratio	1. Success rate
	2. Network overhead	2. end-to-end delay	2. Hop count
			3. Flooding rate
Variables in experiments	1. Nodes' speed	1. Network density	1. Static/Mobile topology
		2. Region radius	2. W/Without Dominating strategy
Simulation Software	NS2	NS2	VC++

Geocast		
	Multi-Geocast Algorithms for Wireless Sparse or Dense Ad Hoc Sensor Networks [38]	Geocasting in Mobile Ad Hoc Networks: Location-Based Multicast Algorithms (LBM) [32]
Using GPS	Yes	Yes
RSU/OBU	No	No
Transmission method/Path strategy	Unicast and flooding	Multicast
Source located outside the region	Yes	Yes
Requir maintaining path from Source to Destination	Yes	Yes
Using Delay Tolerant	Yes	No
Nodes require buffer for storing the message	Yes	Yes
Beacon packet	Yes	No
Routing table/neighboring list	Yes	No
System model	The source outside a region intends to inform all the sensors in some regions. The first stage is reaching the region with a proposed protocol and then using simple flooding within the region.	The host S wants to send a message to a group of nodes called multicast region. The multicast region can be a circle or a closed polygon.
Performance metrics	N/A	1. Accuracy of multicast
		2. Network overhead
Variables in experiments	N/A	1. Transmission range
Simulation Software	N/A	MaRS [15]

2.3. Time-stable Geocast Protocols

A. Time-Stable Geocast in Intermittently Connected IEEE 802.11 MANETs [39]

This paper defines a new protocol for a time-stable geocast. Its aim is to broadcast a message within a region and keep up-to-date the new entry nodes for a specific time, especially in sparse mobile ad-hoc networks.

System Model: A large rectangular region of $[0, a] \times [0, b]$ with N mobile users is considered, and a spatial region of R has been selected for disseminating a special message. The message consists of the information, its lifetime and the geographical coordinates of the boundaries of the selected region. To know each other, mobile nodes periodically send a beacon packet and store their neighboring MAC addresses in a table.

Protocol Description: In a sparse network, it is suggested that the message should start to be relayed from an appropriate forwarding distance prior to the actual region. On entering the region, the node uses the packet that was received in the forwarding distance and passes it to an appropriate application. Starting to relay in advance increases the probability that a node will possess its respective message when it enters the region. For calculating the forwarding region, there are some parameters to take into account, like network density, the region size, and the type of desirable service. Moreover, the paper's focus for calculating the region is based on experience. For beacons, a node waits for a specific time, say a specified delay; during the delay, if it does not receive any beacon packet, it transmits its beacon packet. Otherwise, it stores the receiving node's address and resets the delay time. If the node has received the beacon of a node that it does not include in its MAC list of neighbors, it sends the packet to the new node using UDP broadcasting method. The new node sends back an acknowledgement to the sender. If no acknowledgment is received, the sender resends it up to a *maxRetries* variable.

Performance Metrics: There are percentage of nodes in the region that have not been informed when leaving the region.

Simulation: In the simulation, a territory of 3×3 km² was considered with the geocast region located in the middle of the territory. The region was varied in size by changing one of its sidings from 300m to 2700m. The number of nodes was also varied from one to 300. The beacon period is 100ms with MaxRetries of two with a packet size of 1250 Bytes. The starting disseminating region before the actual region was considered as a variable from zero to 500m. By starting to disseminate the packet in advance, the performance metric becomes reasonable even in sparse networks. However, without considering the advancing region, in sparse networks the packet will be lost shortly after the simulation is started.

Pros and Cons: The network overhead is too high as beaconing messages are disseminated between nodes and the acknowledgments that should be received as well. Because of some harsh situations in VANET, too many control packets are transmitted.

B. Time-stable Geocast for Ad Hoc Networks and its Application with Virtual Warning Signs [40]

This paper defines a protocol for disseminating a warning message within a region and for specific time. The focus of this paper is on having the message abide within the region for the specified time. In other words, for the specified time, each node that enters the region is informed of the message.

Common System Model: There is a geocast region, and the source is located inside the region. The source intends to inform all the vehicles that enter the region within a specific time, of being informed of the message. It introduces three different approaches.

Server Approach

System Model: A server is used to store geocast messages.

Protocol Description: The geocast message is first unicast to the server via the pre-defined infrastructure. Upon receiving a new message, the server starts to broadcast the message to the region’s node in two different approaches: periodically or by notification of the nodes. For the periodic approach, the period should be related to the velocity of the nodes. For the notification approach, the nodes should periodically send their positions to the server and keep it up-to-date for the new messages in the coming region.

Election Approach

System Model: Randomly selected nodes store the message. Then, they periodically or by notification relay the message within the region. The hand-over takes place when the node is going out of the region.

Protocol Description: Every node within the region is a candidate for a server. The one with lowest velocity and nearest to the centre of the region is selected. The general election algorithm for distributed networks is used to choose one of the nodes as a server. There is a server within the region at any time. After an event, the source geocasts the message through the region using a geocast protocol. All the nodes and the server as well are informed of the message. After receiving the initiated message from all the nodes inside the region, the election process takes place. By electing the server, from now on, the server starts to inform others in one of two ways described in previous approach: periodic broadcasting or a notification request. For the notification approach, nodes periodically geocast their position to a circular destination region in the centre of the actual region until the server knows their positions.

Neighbor Approach

System Model: Each node stores all geocast messages and all its neighbors' information.

Protocol Description: If a node within the region detects a new neighbor, it delivers to it all the messages related to the region. This delivery can be done by notification. The hand-over will be done on entry. Neighbors inform each other by a relevant unicast protocol.

Performance Metrics: The network load and delivery ratio are the two performance metrics of this protocol.

Simulation: In the NS2 environment, 1000 randomly moving nodes are considered in 5000×5000 m^2 region. The nodes' speed is 50 m/s with a transmission range of 250 m. For the server approach, the two scenarios, with a fixed server and a randomly moving server, were considered. The number of nodes is a variable of this simulation. In all three approaches, in a sparse network, although the network overhead decreases by increasing the nodes density, the delivery ratio decreases significantly as well, a result which is not desirable.

Pros and Cons: This protocol goal is on the abiding geocast and, as it mentions, it does not try to achieve reliability, a desirable performance. Moreover, the server approach is not a feasible solution, as in a large ad hoc network, the network overhead and the infra-structure cost will be unreasonable. In addition, the drawback in the election approach is that in a sparse network, the handover process, giving the server act to another node, is somehow impossible.

2.4. Time-stable Geocast Comparing Table

Time Stable Geocast		
	Time-Stable Geocast in Intermittently Connected IEEE 802.11 MANETs [39]	Time-stable geocast for ad hoc networks and its application with virtual warning signs [40]
Using GPS	Yes	Yes
RSU/OBU	No	Yes and No
Transmission method/Path strategy	UDP broadcasting	Multicasting
Source located outside the region	No	No
Require maintaining path from Source to Destination	No	No
Using Delay Tolerant	Yes	Yes
Nodes require buffer for storing the message	Yes	Yes
Beacon packet	Yes	Yes
Routing table/neighboring list	Yes	Yes
System model	The message wants to disseminate in a region and stay there for a specific time. It means on entering new node, it receive a copy of the packet.	A message should be disseminated within a region for a specific time. The source is inside the region. Three approaches are introduces in this protocol.
Performance metrics	1. Percentage of nodes who	1. Packet delivery ratio
	has not received the packet	2. Network overhead
	while leaving the region	
Variables in experiments	1. Region size	1. The network density
	2. Vehicles density	
	3. Advance region location	
Simulation Software	OMNeT++	NS2

Chapter 3: A New Time-stable Geocast Protocol

3.1. System Model

Disseminating safety messages in urban areas and highways is one of the most important aspects of the ITS. These messages, which help drivers to drive safely and more comfortably, can be disseminated for both accident and other road problems. For example, after an accident on the road, the damaged car’s safety message system can be triggered immediately when its airbag opens. Disseminated within the region behind the incident, this message can prevent chain-reaction accidents because it can be relayed much faster than drivers can react, alerting them in enough time to stop safely. Moreover, drivers who intend to enter the road can be alerted to road problems like traffic jams, construction, bad weather, etc. and take appropriate action. In addition, vehicles entering a certain geographical area can receive specific advertisements and other promotions.

Disseminating a message to a defined region and keeping up-to-date this region for a certain time is the goal of this study. Considering these types of messages, one-time dissemination of information to all vehicles in the geographical region is rather inappropriate. Instead, the possibility to assign a certain lifetime to the information is desirable.

A. Notations

The following notations are used most frequently in this study.

- *Source vehicle (S):* The node that faces the incident, is involved in it or passes it, and tries to originate the message.
- *Intended vehicles (I):* The nodes that are coming toward the event and should be informed in proper time before they have been involved in the problem.
- *Helping vehicles (H):* The nodes that are moving in the opposite lane. They are not interested in the message, but they will help relay and stabilize the message within the region.
- *Leader vehicle:* In a group of the vehicles located in each other's broadcasting range as a cluster, the vehicle that moves in front of a cluster is called the leader vehicle.

B. Description

The network infrastructure is based on ad hoc nodes that are the vehicles with high mobility. There is no roadside unit to help the process of relaying or stabilizing the data within the region. There is a low-density two-way highway with a total breadth of L meters. An event is generated by a source in one lane of the highway. A length of D meters behind the event becomes the intended region, called the geocast region, and the vehicles coming toward the incident are intended to be informed. In addition, the message should be available in this area for a period of T seconds. Therefore, all the vehicles that enter the region during the time T after the event have to be informed. The network is sparse and there are not too many vehicles available in the road. The vehicles are all equipped with tools to indicate their position, like GPS.

As shown in Figure 1, the vehicles that are moving in broadcasting range of each other named a group; group 1 consists of 6 vehicles and so on. The source, vehicles named s, broadcasting range covers only group 1 of the vehicles. The vehicles in a highway usually go at the same speed so they rarely pass each other, especially in sparse networks. So this message cannot be disseminated to group 2 by group 1. Nevertheless, the vehicles in the opposite lane can play a vital role in delivering the message to group 2 and group 3 as well. On the other hand, the vehicles coming toward the events, group 4, will meet neither group 1 nor group 2. As there is no roadside unit available, the message will be discarded and never will be received by the vehicles of group I4.

Although the helping vehicles in the opposite lane, like vehicles in group H4, have left the region, more action is required from them to make message available during that desirable time, T. Therefore, they have to continue relaying the message even if they exit the region for the extra length region that will discuss later.

Every node drops the message and no longer relays it while exiting the region and the extra region for toward-the-event vehicles and opposite-lane vehicles respectively. In addition, they drop the packet when the time T has expired.

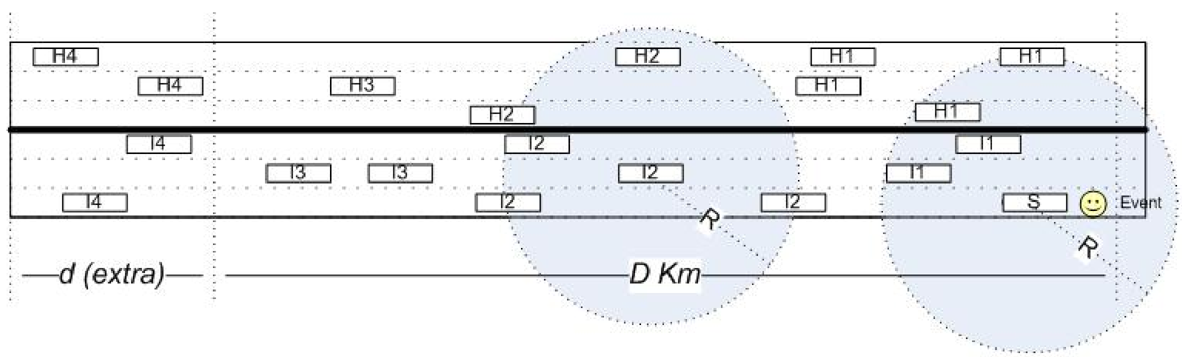

Figure 1: System model

C. GPS Problem

A node in an ad hoc wireless network obtains its position from a system such as Global Positioning System (GPS) [41, 42]. Using GPS is becoming very popular, especially in vehicles. Location availability has a huge impact on application level and network level software. The latitude and longitude are the two vectors used in GPS positioning, so assuming the use of single precision floating point numbers, the eight bytes are enough to address the whole surface of the earth with precision down to 0.1 mile. It is additionally assumed that the nodes in the network have negligible difference in altitude, so that they can be considered roughly on a plane.

D. Geographical Region

There are various approaches to addressing a geographical region, e.g. a point, a circle (its centre and a radius), a closed polygon (point1(x, y), point2(x, y) …). Here, the geographical region is considered as a rectangle. The height of this rectangle is equal to the breadth of the highway and the length of the rectangle is equal to the length of the region in which the safety message must be disseminated. The source is located in one side of the rectangle's height.

E. MAC layer

For modeling the wireless channel, we use a widely deployed simplified model [43]. The MAC in 802.11p has six regular channels and one emergency channel with a high priority in sending. Thus, in this scenario, each node that wants to disseminate an emergency packet delivers a copy to its MAC layer, and the MAC layer's job is to broadcast it to all its neighbors with a minimal collision using CSMA/CA.

On the other hand, the MAC accepts all messages broadcast in this channel and delivers them to the application layer.

F. Message Content

The packet contains the following information: the sender ID/MAC address, a sequence number for the message of each sender, the location of the sender, the location of the event, the date of the event, the time of the event, the message content (possibly a code that all vehicles' applications translate), the expiry of the message (T seconds), the region of the message (D meters), the version of the message, and the pre-stable flag field. It is worth mentioning that the packet size should not exceed the bytes that require more than one transmission to relay.

3.2. Assumptions

Assumptions usually help simplify scenarios. Achieving the goal by playing with these assumptions allows the future work of the research to be derived. Here are the assumptions that are used in this protocol:

- Destination region: the geographic area in which a packet should be delivered to all nodes, D km behind the event location.
- Desired time: the duration that the message should be available in the region after the event has happened, say T hours. This time can be extended or even canceled with the dynamic nature of the protocol.
- Neighbors: all nodes that can be reached without the help of intermediate nodes (i.e. the nodes within the wireless transmission range of a node). These nodes are also called a cluster or group.
- All vehicles have a wireless interface with omni-directional radio antenna with a transmission range of R meters.
- As the 802.11p will be the standard for adding wireless to the vehicular environment, it is assumed that all vehicles will use this standard in their MAC layer.
- All nodes can be the source of a message.
- Only one active warning message should be disseminated.
- Each node is equipped with onboard GPS.
- The nodes in the network have a negligible difference in altitude, so that they can be considered roughly on a plane.
- Vehicles have one-dimensional movement along a road according to a simple mobility model. This model does not account for traffic jams and adjacent vehicle correlations.
- The vehicles will enter the road from two ends as a Poisson distribution with traffic volume of λ vehicles per hour.
- Vehicles move throughout the road at a constant speed.
- Each node has a buffer for storing messages.
- The size of the message should not exceed that of a packet that can be broadcast by one transmission.
- The meeting time of two encountering nodes is long enough that one full transmission can be done.

3.3. Possible Solutions

A. Dissemination Strategies

One of the approaches to address vehicular ad hoc network connectivity involves creating and maintaining a centrally managed geographical location service, which can be queried and updated by mobile users via infrastructure wireless networks. Recently, such an abiding geocast mechanism for disseminating information to all devices any point during a specified lifetime in a defined region has been proposed in the form of static infrastructures like central servers [44]. However, this solution has several drawbacks. First, the response time may not meet the real-time requirements. Second, the access to the infrastructure communication service is expensive. Third, the centralized approach is not robust and is particularly vulnerable to failures and sudden surges of hot spots. Furthermore, there is currently no business model to provide a return-on-investment for setting up and operating such large-scale location-based services.

The other approach is to rely on an infrastructure less network. In this approach, the vehicles, in addition to the source and destination, are rolled as routers in this environment. According to the decreasing density or increasing mobility of the devices, the networks are separated in intermittently connected parts and single devices. Thus, communication with a server or neighboring device may not be immediately possible, and the probability grows that a user will enter a region and resides in it for a certain time before he receives the information. Therefore, depending on vehicles for dissemination poses a particular challenge in mobile ad hoc networks. Although this approach involves some complexity, it is more feasible and much cheaper than the previous approach.

B. Relaying Strategies

Broadcasting is a common operation in many applications (e.g. graph-related problems and distributed computing problems). Due to the host mobility in VANET, broadcasting is also used, especially for paging a particular node, sending an alarm signal and finding a route to a particular node. One of the simplest and most straightforward approaches in broadcasting is blind flooding that it is associated with problems such as redundancy, collision and contention. Reducing the possibility of redundant rebroadcasts and differentiating the timing of rebroadcasts are the two solutions to alleviate these problems. This will prevent some receiving nodes from rebroadcasting the message.

- *Probabilistic Scheme [45]*: After receiving a broadcast packet for the first time, a node rebroadcasts it with the probability of p. To respond to the contention and collision problem, there should be a small random delay in rebroadcasting the packet.
- *Counter-based Scheme [25]*: In this scheme, a counter c is defined in each node and is increased each time that the node has received the same packet. When the variable c becomes larger than a threshold, say C, the node drops off the packet. During this time, after receiving the first packet and before dropping off the packet, the node starts to rebroadcast the packet following a small delay for each re-transmission.
- *Distance-based Scheme [46]*: In this scheme, a relative distance between the hosts is determined for dropping a packet. The receiving node has received many-rebroadcast packets during the waiting time for rebroadcasting. The lowest distance between the receiving node and the senders is named d_{min}. If this $d_{min} < D$, it means that this receiving node cannot cover a reasonably larger area than others can, so it drops the packet.
- *Location-based Scheme [47]*: Using a GPS allows nodes to be aware of their position. By knowing the senders' position of a broadcasted packet, the receiver can calculate its additional coverage more accurately and precisely.
- *Cluster-based Scheme [48]*: The previous schemes are all based on statistical and geometric modeling to calculate more coverage areas. This approach is based on graph modeling. All nodes have an ID and each node knows about its neighboring nodes by periodically advertising its presence. A node with a local minimum ID will elect itself as a cluster head. The other nodes become members of the head cluster. While two heads meet, the one with the higher ID give its role to the other, and they will start to unicast their messages. Within the cluster, only the head rebroadcasts the receiving packet without experiencing any collision. The other nodes do not need to rebroadcast the packet. On detecting a new entry node in the cluster, the head again rebroadcasts the packet.

In this protocol, the cluster-based scheme is not practical based on the assumption that the density of the network is too low. In low-density networks, considerable defragmentation occurs that does not allow clusters to become stable. The other two approaches, distance based and location based, are not practical in this situation. Therefore, in this protocol and situation, the first two schemes can be applied. Although the counter-based approach increases the cost of network more than probabilistic ones, it also increases the probability of delivering the message to more vehicles.

Additionally, with the high speed of the vehicles and in low-density networks, the counter-based approach works better.

C. Beaconing

As a warning of an accident is categorized as a relatively rare event, it seems suitable to define a protocol that works on demand [49]. However, a warning message is not much bigger than the control packet sent during the request phase, so the response phase is avoided and the protocol simply applies flooding to reach the multicast group. Due to the broadcasting nature of the radio waves, a packet sent by one host can reach multiple receivers simultaneously. Therefore, the number of packets sent is increased linearly by increasing the number of hosts, although the number of received packets grows exponentially. As a result, in this protocol beaconing has not been necessary to avoid the huge costs that this kind of packet incurs for the network.

3.4. The New Approach

One of the focuses of this protocol is to disseminate a safety message during a specific region, say D meters, of a highway for a known duration, say T seconds. This approach is called the time-stable geocast protocol. Some studies have been done on it, but this protocol is unique as it works well in low-density networks. A highway has significantly variable density. In rush hour, the density is high, but in the middle of the night, the density is too low. A good protocol should work well in both situations. In low-density networks, the network becomes disconnected.

The author of [49] proposed a general solution for delay tolerant networks (DTNs) like VANETs. He proposed that the relaying node would store the message in its buffer and then try to move toward the destination until the destination is within its broadcast range. Then, it is time to relay the message to the destination. Based on this general solution, for geocasting, our proposed protocol relies on opposite lane vehicles to relay the message through the region.

Although the opposite lane vehicles may not be interested in the message, they can help inform the interested vehicles while they pass by them. In addition, these vehicles, depending on the perceived user density, determine and dynamically adapt an extra distance where they continue relaying the message. Therefore, the opposite lane vehicles, before exiting the extra region, deliver the message to at least one of the vehicles coming toward the event. Moreover, the informed vehicles moving toward the region also deliver the message to at least one of the vehicles in the opposite lane. This extra distance and the exchange of messages between the two lanes vehicles help stabilize the message in the region for the specific time.

Thus, the opposite-lane vehicles are useful for two reasons. First, they increase the probability of the delivery ratio of the message to all vehicles moving toward the event, especially in sparse networks. As shown in Figure 1, two de-fragmentations occur in the vehicle groups in the lane moving toward the event (between group 1 and 2, and between group 2, 3, and so on). The first vehicle in each group is not in the broadcasting range of the last vehicle of the following group. In this case, the opposite-lane vehicles play vital role in message relaying. Second, the opposite-lane vehicles can help maintain the message for duration of time T on sparse roads. Thus, at least one vehicle remains in the region for the entire duration of the time T. (S: the source vehicle, I: the intended vehicles, H: the opposite lane vehicles)

Another focus of this work is a new idea that we call dynamic time-stable geocasting. If the disseminated event has been removed before the expiration of the time T, there should be a way to stop disseminating the message. As this relaying continues until the time T expiry, all the vehicles moving toward the removed event are still being informed, an undesirable situation. There should be a technique to cancel this dissemination. If the problem continues in the region, the stable message should be relayed longer than the expiry of time T. It is also clear that there should be some mechanism to extend the time for relaying of the message within the region.

A simple way to extend the time is to geocast another message just after the expiry of the previous one. Then, this new message can also be stable in the region. This method seems satisfactory, but a good protocol should not only guarantee the delivery of the message, but also lower the network cost. As can be seen in following chapter, the network cost before stabilizing the message in the region, also called the pre-stable period, is too high compared to the network cost of the stable period of the message. This higher cost is related to the fact that before the message becomes stable in the region, every node tries to inform others as soon as possible. This process requires more broadcasting and thus placing more cost on the network. Therefore, this method is unreasonable. Moreover, if the stable message is canceled, broadcasting a new message cannot automatically cancel the previous stable message in the region. Here it is obvious that we need a protocol that overcomes this flaw.

We call this protocol the Dynamic Time-Stable Geocast or DTSG.

3.5. Protocol Parameters

One of the advantages of this protocol is that it tries to dynamically assign some parameters that are used regularly during the protocol lifetime.

A. *Dynamic Sleep Time*

As mentioned before, with the counter-based strategy used in this protocol, a receiving node rebroadcasts the packet periodically until it receives a certain number of the same packets from the other nodes. At this time, it drops the packet. Two parameters should be defined in this protocol.

One of them is the waiting time (i.e. the time that the receiving node should wait until rebroadcast the message). In a sparse network, and especially in this situation, this waiting time depends on the speed of the vehicles. Consider an opposite lane vehicle that wants to help relay the message to the vehicles moving towards the event. This waiting time should be small enough that two vehicles that move toward each other are in each other's transmission range while passing by each other. The delivery ratio has to depend on the maximum velocity of the network's nodes in order to reach all of them. For this purpose, consider the relaying vehicles with a speed of s_r meters per second. The worst scenario is that the vehicle that is coming toward the relaying vehicle moves with the maximum allowance speed, say s_{max} meters per second. At this point, the passing time is at its minimum value. The maximum waiting time should be τ_r seconds, where R is the broadcasting range of the nodes in meters (τ_r can be derived from Formula 1). With this waiting time, the relaying node is certain not to miss any other lane vehicles.

$$\boldsymbol{\tau_r = \frac{2R}{s_r + s_{max}}} \quad \text{(Formula 1)}$$

Moreover, not all of the vehicles that are moving together, in other words moving as clusters, should rebroadcast the message as all of them use a common channel. Thus, the target nodes of the vehicles moving together are almost the same. Therefore, if only one vehicle in this cluster rebroadcasts the message and the rest drop the message, not only will the intended vehicles receive it, but also the network cost will be extremely low. We do not define and categorize an explicit cluster in the protocol, but assign a coefficient to the sleep time that implicitly and dynamically acts as a cluster in dense networks. This coefficient will increase the waiting time for the vehicles behind the leader of the group and, in the drop off strategy, these followers will drop the message as soon as they receive a message from the front vehicle in their lane. As this coefficient is assigned one for the leader, not only will the leader satisfy the condition that was mentioned in the previous paragraph, τ_r, but also its waiting time is lower than its followers and the followers will drop their messages without rebroadcasting, thus reducing the network cost dramatically. The coefficient is defined in Formula 2, where R is the broadcasting range of the nodes in meters, x_s is the position of the source that rebroadcasted the message to the cluster in meters, and x_r is the position of the receiving node in the cluster that wants to calculate its waiting time in meters.

$$\boldsymbol{c = \frac{R}{|x_s - x_r|}} \quad \text{(Formula 2)}$$

By considering the leader of the group as a node R meters far away from the source, the coefficient for the leader would be one. Therefore, the sleep time is equal to $c \times \tau_r$.

B. Dynamic Extra Length

The opposite-lane vehicles perform an important role in both relaying and stabilizing the message in the preferred time. In this protocol, these nodes should keep relaying the message even if they exit the region, but only for a specific length. The length of this extra region varies depending on the density of the network and can be extracted from Formula 3, where γ is the density of the vehicles in one lane (number of vehicles per one km) and D is the desired region for geocasting in meters.

$$\boldsymbol{d_{extra} = \frac{D}{\gamma}} \quad \text{(Formula 3)}$$

This will allow helping vehicles (opposite lane vehicles) to finally find at least one intended vehicle to relay the message to even in a sparse network.

C. Pre-stable and Stable Periods

This protocol has two phases: First, the propagation of the message to the region (called pre-stable period); and, second, stabilizing the protocol within the region (called the stable period).

The first phase objective is to help the message to reach the end of the region. In this phase, the protocol tries to inform the vehicles in the region. It is obvious that the network cost is somewhat high in this phase as all nodes try to inform others of the event as soon as possible. The second phase objective is to keep the message alive during the intended time within the region. In this protocol, the time from when source broadcasts until the first helping vehicle reaches the end of the region is considered as pre-stable period, and the time from when the first helping vehicle reaches the end of the region, until the end of the expected time is defined as the stable period.

The stable period objective is to inform vehicles as soon as they enter the region. In the stable period, as soon as an intended vehicle enters the region, it will be informed of the message.

It is important for a node, the intended vehicle or the helping vehicle, while receiving a message, to determine whether the protocol is in its pre-stable period or in its stable period.

3.6. Protocol Flow Chart

A. Protocol At a Glance

After the source encounters an incident on its way, it broadcasts a message that is appropriate for the event. It keeps rebroadcasting until at least some helping vehicles or intended vehicles receive the message.

After the source broadcasts the message (of course it happens in the pre-stable period), the intended vehicles that receive the message start to rebroadcast the message periodically, with an appropriate dynamic sleep time, until they inform some helping vehicles or they understand that at least a leader vehicle in their broadcasting range is now in rebroadcasting mode. This situation applies for the helping vehicles as well (i.e. the helping vehicles try to inform some of the intended vehicles or they drop the message as soon as they realize that their leader is now in rebroadcasting mode).

In the stable period, both the intended and helping vehicles upon receiving a message, rebroadcast it only once, with an appropriate waiting time and then stop rebroadcasting. This one time rebroadcasting will help inform the sender of the message that at least one vehicle has received it, so the sender stops rebroadcasting. Afterwards, on the one hand, the intended vehicles continue moving until they pass the location of the original source, in other words, the location of the event. At this time, they start rebroadcasting the message until they become sure that at least one helping vehicle receives it. This will happen because the helping vehicles rebroadcast the message once upon receiving it. On the other hand, the helping vehicles start rebroadcasting the message when they arrive at the extra length region until they are certain that at least one intended vehicle has received the message.

We adjust a control variable, which is the number of vehicles that a relaying node should inform before it stops rebroadcasting, for the both pre-stable and stable period. For stable period, it is assigned to 1 and named k as the relaying nodes have to be make sure that at least one informed node exists in the region. For the pre-stable period it is named l, the 3 informed nodes is an experimental result that originally comes from simulation's runs and it an optimum number that makes a balance between the two performance metrics of the protocol.

B. The Source Vehicle

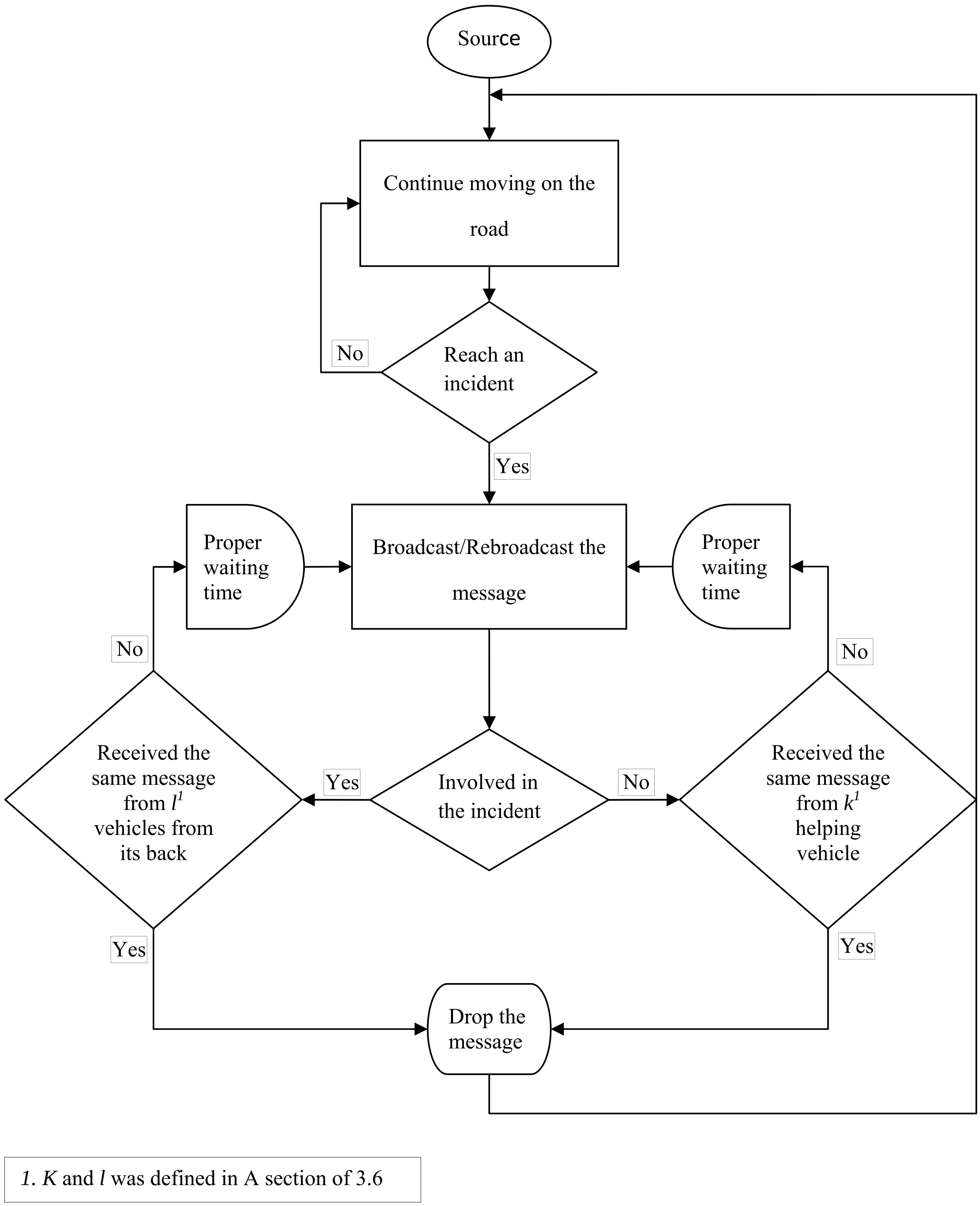

Figure 2: Protocol flow chart for source

C. *Helping Vehicles*

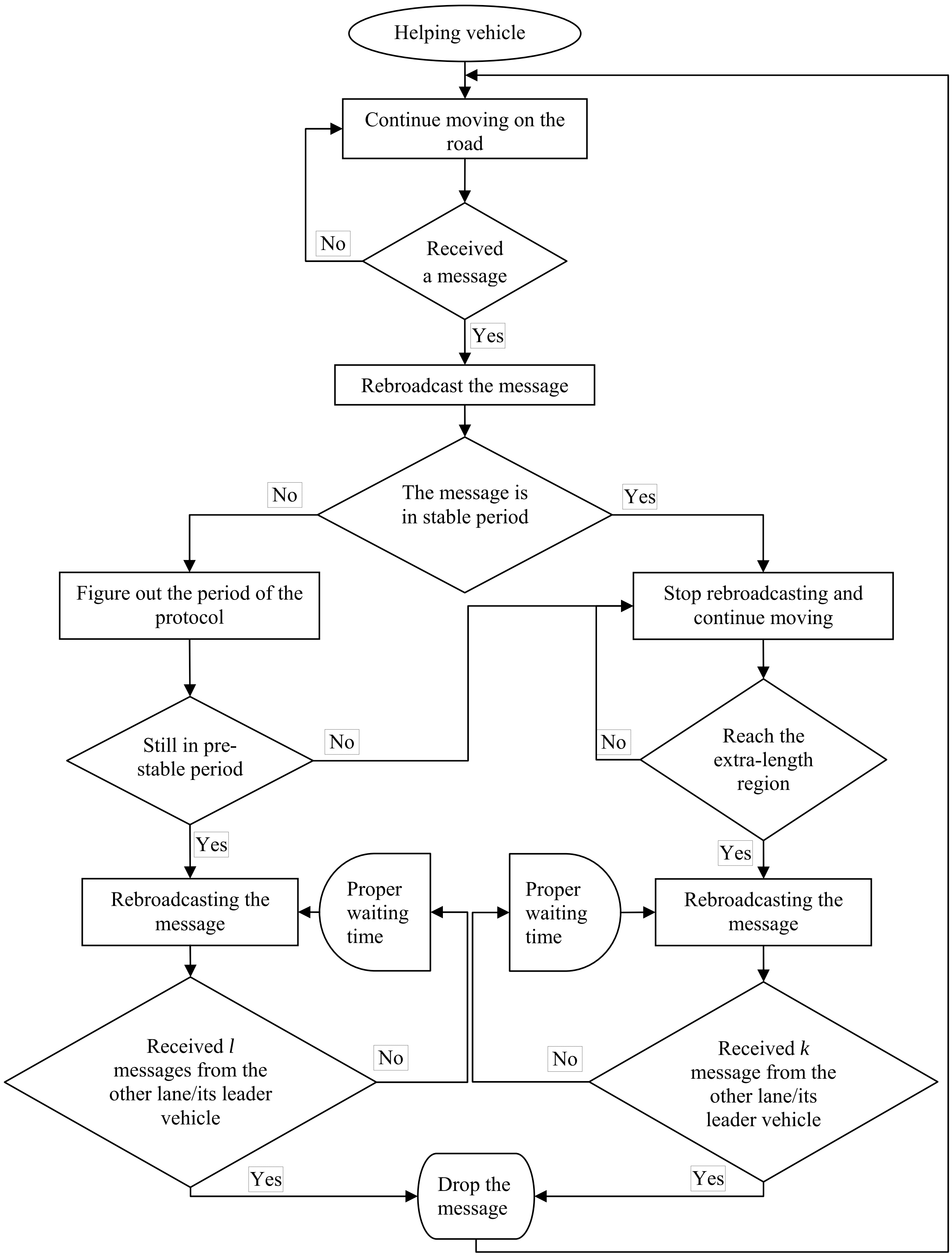

Figure 3: Protocol flow chart for helping vehicles

D. *Intended Vehicles*

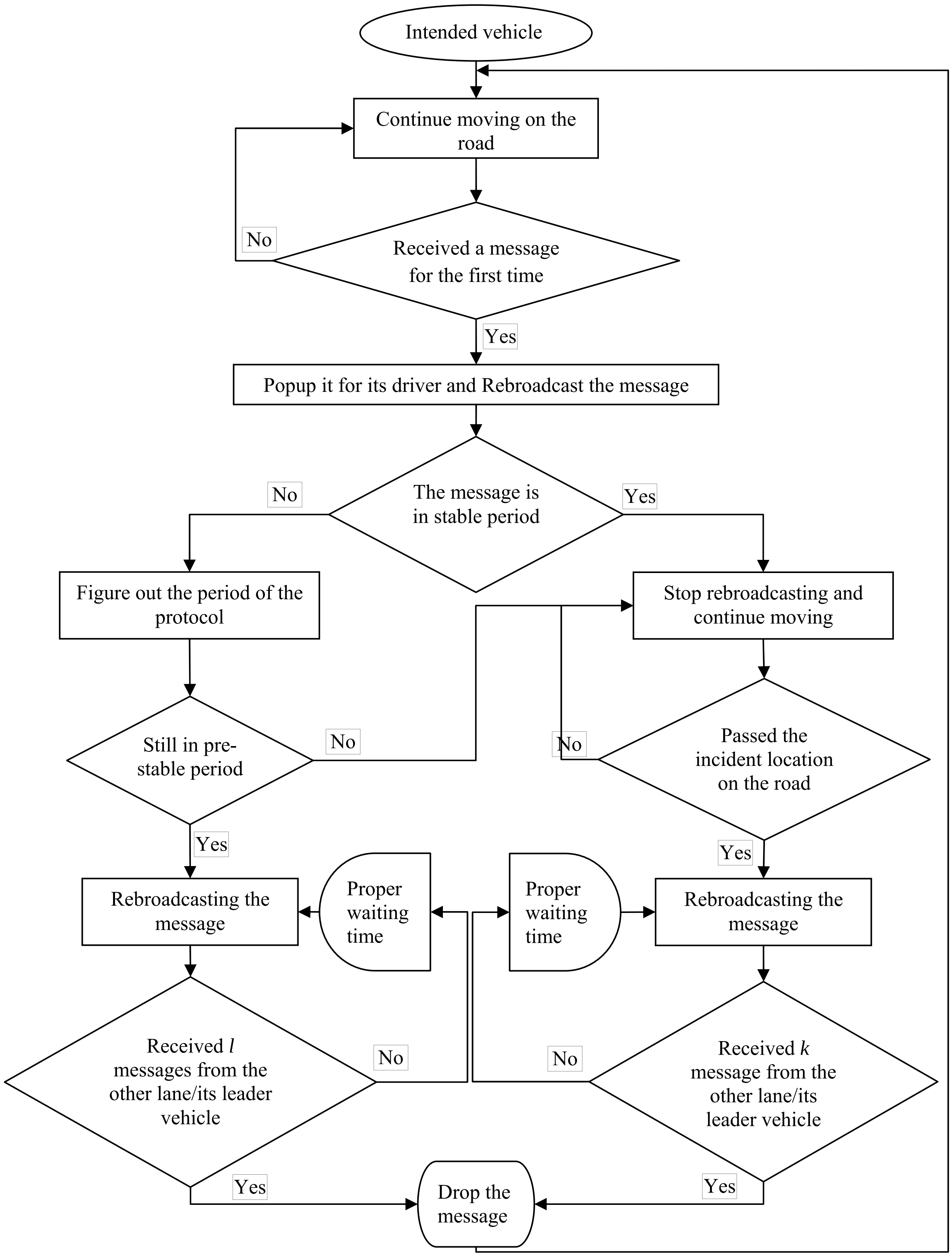

Figure 4: Protocol flow chart for intended vehicles

3.7. Protocol Description

The protocol follows a different algorithm in each period. In pre-stable period, it tries to inform the vehicles that are located in the region as soon as possible. However, in a stable period, it tries to inform intended vehicles as soon as they enter the region.

A. Pre-stable Period

This period lasts from the first broadcast of the message by the original source until the first helping vehicle reaches the end of the region.

The Source Vehicle: The source generates a message upon encountering an event (e.g. sudden braking or an accident). This message broadcasts immediately in the form of only a packet. It contains all the information previously mentioned in the assumptions. This vehicle broadcasts the message periodically, say each τ_s second, until its drop off strategy is satisfied. The source vehicle's sleep time for rebroadcasting is calculated from formula one and does not have a coefficient.

There are two possible scenarios for the source vehicle: First, the source vehicle has to stop as it is involved in incident; second, this vehicle is not involved in the incident and it will continue moving. In these both scenarios, it has to rebroadcast the message, but its drop off strategy will be different in each of them.

The source vehicle has two drop off strategies, depending on whether it is stopped in the road or continues moving. If it is stopped, it should rebroadcasts the message until it receives the same message from at least three intended vehicles coming from behind and at this point it drops the message. If it continues moving, it should continue rebroadcasting the message until it receives at least one message from the vehicle in the opposite lane. At this time, it drops the message, as it is sure that at least one helping vehicle is equipped with the message.

Intended Vehicles: They are also called the vehicles coming toward the event. The protocol goal is to guarantee delivery of the message to these vehicles. While receiving a packet, these vehicles first determine whether this event is in their lane. While intended vehicles receive a packet that is related to their own lane, if they have not received it before, they first warn the drivers, by popping up a safety massage about the event in front of the driver's face.

The intended vehicles strategy for rebroadcasting is different during the two phases of the protocol. If the protocol is in the pre-stable period, the intended vehicle that received the message starts to rebroadcast the message periodically, each τ_r that is calculated from formula three, until its drop off strategy occurs.

They continue rebroadcasting the message until one of these two conditions is satisfied. First, they receive the same copy from the front vehicle in the same lane. This will happen because the coefficient of the sleeping time helps nodes that are moving in a group or cluster not to rebroadcast since their leader can do the job, thus dramatically reducing the cost. Second, they stop rebroadcasting when they receive the same copy three times from one of the other-lane vehicles, the helping vehicles. Thus, they inform at least three of the helping vehicles. The number three is extracted from the simulation results and it is the optimum.

Helping Vehicles: While helping vehicles, opposite-lane vehicles, receive a packet for the first time, they start to rebroadcast it periodically, each τ_o. This waiting time is calculated from formula 3, the sleep time with the coefficient. This happens when the protocol is still in its pre-stable period.

They continue rebroadcasting the message until one of these two conditions is met. First, they receive the same copy from the front vehicle in the same lane. This will happen because of the coefficient of the sleeping time. This coefficient helps nodes that are moving in a group or cluster not to rebroadcast while their leader can do the job. This dramatically reduces the cost. Second, they stop rebroadcasting when they receive the same copy three times from one of the other-lane vehicles, the intended vehicles. Thus, they inform at least three of the intended vehicles. The number three is extracted from the simulation results and it is the optimum.

Period Detection: Although there is a field in the message that shows which period the protocol is now in, all the receiving nodes should evaluate the following criteria while they receive a message that indicates the protocol is in its pre-stable period. If a node detects that, the protocol is in its stable period, it changes the pre-stable field of the message.

For intended vehicles, if they receive the message while they are located in the region, the protocol is still in its pre-stable period. However, when they receive it before they enter the region (i.e. they are in the extra length region), the protocol is in its stable period. All of these data, the event location and the region, can be extracted from the message content.

For helping vehicles, if they receive the message from other nodes, not the original source, before their arrival at the event location, the protocol is in its stable period. Nevertheless, if they receive it while they are passing the event or they have passed the event, the protocol is in its pre-stable period.

B. Stable Period

This period starts when the first helping vehicle reaches end of the region. By then, almost all of the intended vehicles located in the region have been informed of the incident. From now on, the protocol follows a different algorithm. In this period, all the vehicles, upon receiving the message for the first time, first rebroadcast it once, stop rebroadcasting it, and then continue rebroadcasting it until they reach a certain location. More details are as follows.

Intended Vehicles: In the stable period, the receiving nodes first rebroadcast the message only once with the sleep time mentioned before. This always happens for intended vehicles in the extra length region, because they are always informed by a helping vehicle that entered the extra length region and started rebroadcasting. This single rebroadcasting allows the helping vehicle to be sure that at least one intended vehicle has been informed. Then the intended vehicles stop rebroadcasting the message and continue moving until they pass the incident position. At this time, they start rebroadcasting the message periodically, each τ_r, as long as their drop off strategy allows them.

They start rebroadcasting the message for the second time (i.e. when they have passed the event location), until they receive at least one of the same messages from other lane vehicles or from one of the front vehicle in their lane. This second condition is the result of the effect of the coefficient in sleep time. In addition, all vehicles will periodically check their own buffer and delete any packet whose its lifetime has expired, or they exit the packet's intended region.

In real highways, these vehicles are more likely to exit the road with one of the available exits before the event location to avoid the problem. At this time, the intended exiting vehicles should try to rebroadcast the message periodically as long as their drop off strategy allows them.

The intended vehicles receive the message in the stable period while they are located in the extra length region. Therefore, their first time rebroadcasting will inform the sender, the helping vehicle in the extra length region that at least one intended vehicle has received the message, and the helping vehicle can determine its drop off strategy. The waiting time for each rebroadcasting is dynamically calculated from the sleep time formula.

Helping Vehicles: If the helping vehicles receive a message for the first time and the protocol is in the stable period, these vehicles rebroadcast the message once. Then, they stop rebroadcasting the message until they reach the end of the region and enter the extra length region. At this time, they start to rebroadcast the message until the drop off strategy stops them. For these vehicles, the exiting strategy also applies for the same reason mentioned in previous paragraph. It means that the exiting vehicles from the road should try to rebroadcast the message periodically as long as their drop off strategy allows them.

The helping vehicles receive the message in the stable period while they have not still arrived at the location of the event. Therefore, their first time rebroadcasting will inform the sender, the intended vehicle, when it passes the event location, that at least one helping vehicle has received the message, and the intended vehicle can determine its drop off strategy.

They rebroadcast the message for the second time (i.e. when reaching the extra length), until they receive at least one of the same messages from other lane vehicles or from one of their front vehicles, the leader vehicle, in the same lane. The reason for second condition involves the effect of the coefficient in sleep time. In addition, all vehicles will periodically check their own buffer and delete the packet whose lifetime has expired, or they exit the packet's intended region.

Dynamic Time-stable: This protocol is called as dynamic time-stable geocast, because the time of the stable message can be easily reduced or extended without any additional cost for the network. In other words, the message can be down and not stable in the region before its expiry time, if the event or incident has been removed sooner. Alternatively, the message can be stable longer in the region if the event continues to be in the region.

For this purpose, the original source of the message or the node that is responsible for this cancelation or extension should broadcast a message. This message is similar to the original message except that the new time should be considered instead of the previous time; for cancelation, the time should be zero. In addition, the revision of the message should be increased by one. We called this message the supplementary message. It should broadcast until the drop off strategy for the source node stops it from rebroadcasting (the same strategy for the original source).

As we will see in simulation chapter, the pre-stable period is too short compared to the stable time. Therefore, this cancelation or extension will most probably occur in the stable period. In the stable period, the nodes do not try hard to inform others; they try only in extra length region or around the incident location. Therefore, the network cost would be dramatically lower than in the pre-stable period. This is a dominant advantage of using dynamic time-stable protocol instead of sending a new message with a regular time-stable protocol. After the supplementary message is broadcasted, two scenarios should be considered.

In the first scenario, when the new time was assigned to zero, it means the message should be cancelled. The intended vehicles, when receiving this message, will not pop it up for their drivers as the incident has been removed. They continue moving until they arrive at the incident location. From now on, if they receive even one of the previous version of this message, the original message with a lifetime greater than zero, they start to rebroadcast the new message until their drop off strategy stops them. The helping vehicles, upon receiving the supplementary message, continue moving without rebroadcasting it until they reach the extra length region. In the extra length region, they start rebroadcasting the message if and only if they have received the original message from other nodes while they were moving in the region. Of course, when they stop rebroadcasting should be depending on their drop off strategy.

The second scenario happens when the new lifetime is less or more than the original time; it means that there has been a reduction or extension of the incident's time. The intended vehicles and helping vehicles consider this new revision of the message as the new message but in its stable period. Thus, they are following the rules of rebroadcasting and dropping a message in the stable period. Nevertheless, while they stop rebroadcasting, if they receive the original message from a node, they start rebroadcasting the new message as it is in its stable period but with the drop off strategy of the pre-stable period. This last condition will happen rarely.

Chapter 4: Simulation

To validate the proposed protocol and determine how well it predicted its performances, a precise simulation has been done, in .NET framework using code developed in C#.

This is a discrete event simulation, and a class called VNode, which contains all protocol details, has been modified in .NET environment. If the intended time of the geocast is T minutes, the simulation starts T/4 minutes earlier to be sure that the simulation reaches its steady state situation. Passing the steady state time, the message is generated near the end of the region, at a random location by a random vehicle at a random time.

The simulation has two parts: The first generates the road traffic, and the second runs the protocol in a wireless situation, depending on the nodes' movement.

4.1. Generating Road Traffic

The main parameter of traffic is the density of the road, which includes the number of vehicles that enter the road in each line of each lane, and the time between two vehicles that enter.

A. Random Traffic vs. Real Traffic

Speaking about traffic movement on the road brings to mind the idea of randomness. In other words, someone might suppose that the vehicles enter the road in a random way and they move in a random fashion as well. However, this is not the case. Many studies in civil engineering show that the vehicles on the road do not enter or move randomly. Not only they enter the road with some well-known distributions, but also they move, maneuver, brake, and accelerate according to some sort of mathematical modeling. So, for better results, real traffic has been considered for the simulation.

B. *Poisson and Exponential Distribution*

In probability theory and statistics, Poisson distribution is a discrete probability distribution that expresses the probability of a number of events occurring in a fixed period if these events occur with a known average rate and independently of the time since the last event.

In probability theory and statistics, exponential distributions are a class of continuous probability distributions. They describe the times between events in a Poisson process (i.e. a process in which events occur continuously and independently at a constant average rate).

In an event, if the number of occurrences follows a Poisson distribution, the time between each two consecutive occurrences follows Exponential distribution.

A conceptually very simple method for generating exponential variates is based on inverse transform sampling. Given a random variate U drawn from the uniform distribution on the unit interval (0,1), one can generate exponential variates as $T = \frac{-Ln\ U}{\lambda}$, where λ is the rate parameter of the distribution.

C. *Vehicles' Entrance*

Here it assumed that the traffic entrance on the road follows a Poisson distribution. As mentioned in the previous paragraph, the time between two consecutive vehicles follows the exponential distribution. Now, consider that the road density is γ vehicles per km and v m/s is the vehicles speed. The entrance rate would be λ vehicles per second as extracted from the following formula:

$$\lambda = \frac{\gamma \times v}{1000} \quad \text{(Formula 5)}$$

Determining the rate allows the exponential distribution to generate the time between two consecutive vehicles regarding to their speed and road density.

4.2. Simulation Parameters and Variables

Three different parameters are considered for the simulation: the vehicles' broadcasting range, the speed of the vehicles, and the density of the road. Table 1 contains a table that indicates the range of each parameter along with its unit of them.

<table>
<tr><td colspan="13">The broadcasting range</td></tr>
<tr><td>Meters</td><td colspan="4">100</td><td colspan="3">250</td><td colspan="5">400</td></tr>
<tr><td colspan="13">Speed</td></tr>
<tr><td>Km/h</td><td>5</td><td colspan="2">10</td><td>30</td><td>50</td><td colspan="2">90</td><td colspan="2">100</td><td colspan="2">150</td><td>200</td></tr>
<tr><td colspan="13">Density</td></tr>
<tr><td>Vehicles/km</td><td colspan="2">0.5</td><td colspan="2">1</td><td colspan="2">5</td><td colspan="2">10</td><td colspan="2">50</td><td colspan="2">100</td></tr>
</table>

Table 3: The simulation's parameters (range, and unit)

4.3. Simulation Scenarios

A. *Simplifying Assumptions*

For simplicity, it is considered that vehicles move on the road with a constant speed (i.e. although they may enter the road at different speeds, they will not change their speed until they exit the road). In addition, no maneuvering, braking, or even acceleration occurs during the simulation.

Moreover, the geocast region is considered as a two-way highway, where each way has three lanes. Each lane's breadth is 3 meters. Therefore, the total highway breadth is 18 meters. The intended region before the incident is fixed as 20 km, and the message should be stable within the region for about 3 hours.

Each of the three scenarios runs 10 times in simulation and the results are be the average of these 10 runs. In the first scenario, the protocol's performances are compared to those of another geocast protocol. However, in the other two scenarios, the performances of the protocol are compared with different parameters to determine how it well works.

B. *Scenario 1*

The first scenario tries to introduce the advantages of this protocol compared to other geocast protocols. This comparison is common among the routing protocols that show their advantages by doing a good job while others do not. Unfortunately, only a few time-stable protocols have been introduced. Therefore, we decided to compare our proposed protocol with simple flooding which guarantees the delivery ratio of the message but incurs a high cost for the network. If the proposed protocol guarantees the delivery ratio while simple flooding cannot, or guarantee the delivery ratio at on extremely lower cost, it will provide a dominant advantage.

In this scenario, the vehicles' broadcasting range is fixed of 250 meters. Their speed is randomly chosen between the only two ranges that Table 1 shows (i.e. 50 and 100 km per hour) with a normal distribution while the density of the network varies between 0.5 and 100 vehicles per km.

These six scenarios run in both the DTSG and simple flooding protocol in this category. For simple flooding, another simulation with the same characteristic of DTSG has been conducted. The difference is that the opposite vehicles will not help relay the message, and the extra length region has been removed. In addition, the nodes follow the simple flooding rule with the counter-based scheme. For simple flooding, there is no pre-stable period identified.

C. *Scenario 2*

In second scenario, the broadcasting range is fixed at 250 meters. The vehicles' speed varies from five to 200 km per hour. Therefore, each scenario runs with one of these vehicles' speed. For each speed, the density of the network varies from 0.5 to 100 vehicles per kilometer. Therefore, 48 scenarios have to be run in this category.

D. *Scenario 3*

In the third one, the speed is fixed at 100 km per hours. The density varies among 0.5, 10, and 100 vehicles per km and the vehicles' broadcasting range also varies among 100, 250, and 400 meters. Therefore, nine scenarios have to be run in this category.

4.4. Simulation Results

The outputs of the simulation consist of the two performance metrics of the protocol along with the stabilized time and the informed time. For each scenario, the delivery ratio as well as the network cost for both pre-stable and stable period have been shown. The stabilized time shows how long it takes the protocol to reach its stable period. The average informed time shows how long it takes, during stable period, for a vehicle to be informed once it enters the region.

A. Results for Scenario 1

Figures 5, 6, and 7 show the delivery ratio, the broadcasting cost, and the receiving cost of the pre-stable period, stable period, and simple flooding protocol.

The pre-stable period delivery ratio for all densities is more than 92%. It increases while the density increases. This ratio for the stable period is in almost the highest value for all densities.

In these periods, the broadcasting cost decreases while the densities increase, but the receiving cost increases. In the density of 0.5, the broadcasting cost is high but it is not counted as a drawback of this protocol. In other words, although the broadcasting cost is high, the receiving cost is reasonably low, because the density of the road is too low, so the nodes dynamically try broadcasting more to keep the message alive within the region. The low receiving cost shows that the channel is not usually busy in low densities. This is one of the best advantages of this protocol: a very high delivery ratio with low network cost in a sparse network.

In high densities, the broadcasting cost is reasonable and is predictable by the protocol theory in the stable period. In densities of more than 30, each node rebroadcasts only twice, first, after receiving the message for the first time and, second, reaching the extra length region or the event location for helping vehicles and intended vehicles respectively. Here also it is obvious that the cost in the stable period is lower than the cost in pre-stable period, and this is an advantage of this protocol in expanding or canceling the stable message's duration by its dynamic notion.

Simple flooding fails to deliver the message for the densities of less than 5. The delivery ratio increases while the density increases until it reaches a reasonable value for densities of more than 40. The broadcasting cost of simple flooding is high, especially in high-density networks, compared to the DTSG's performance.

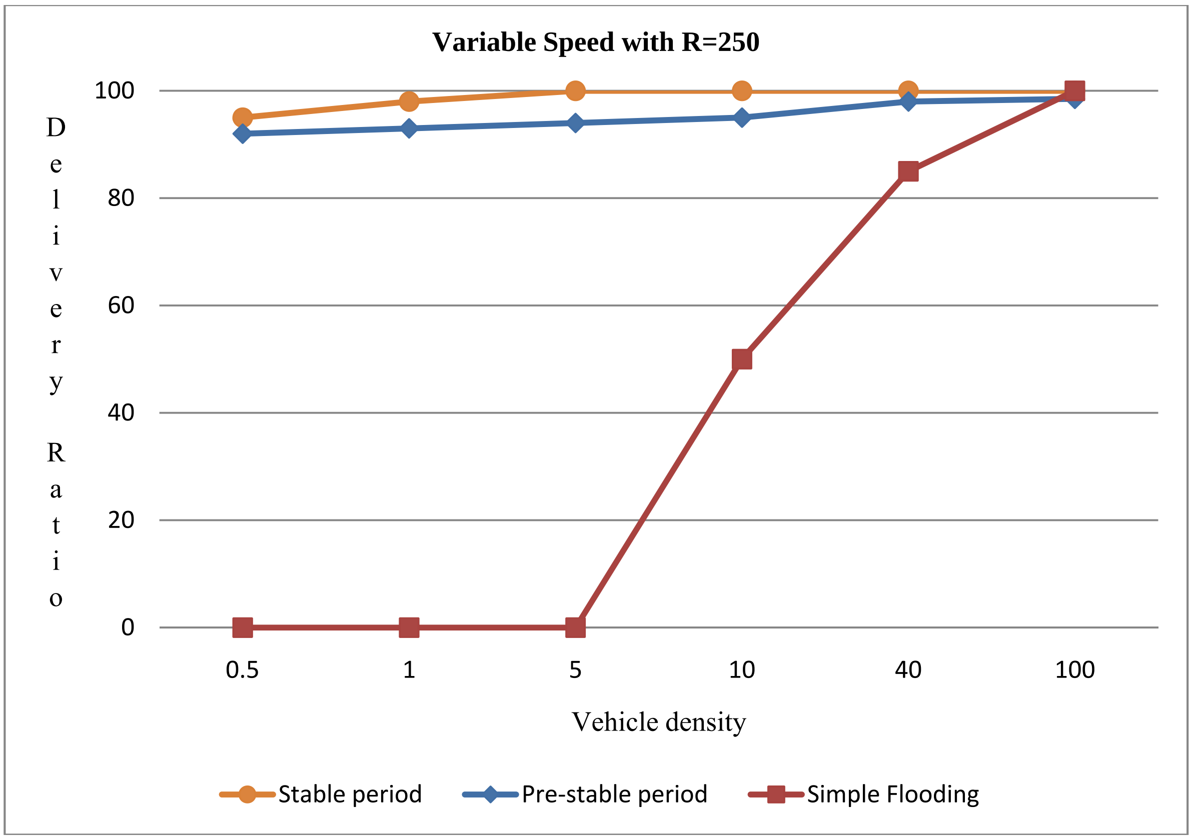

Figure 5: First scenario (variable speed, delivery ratio vs. density)

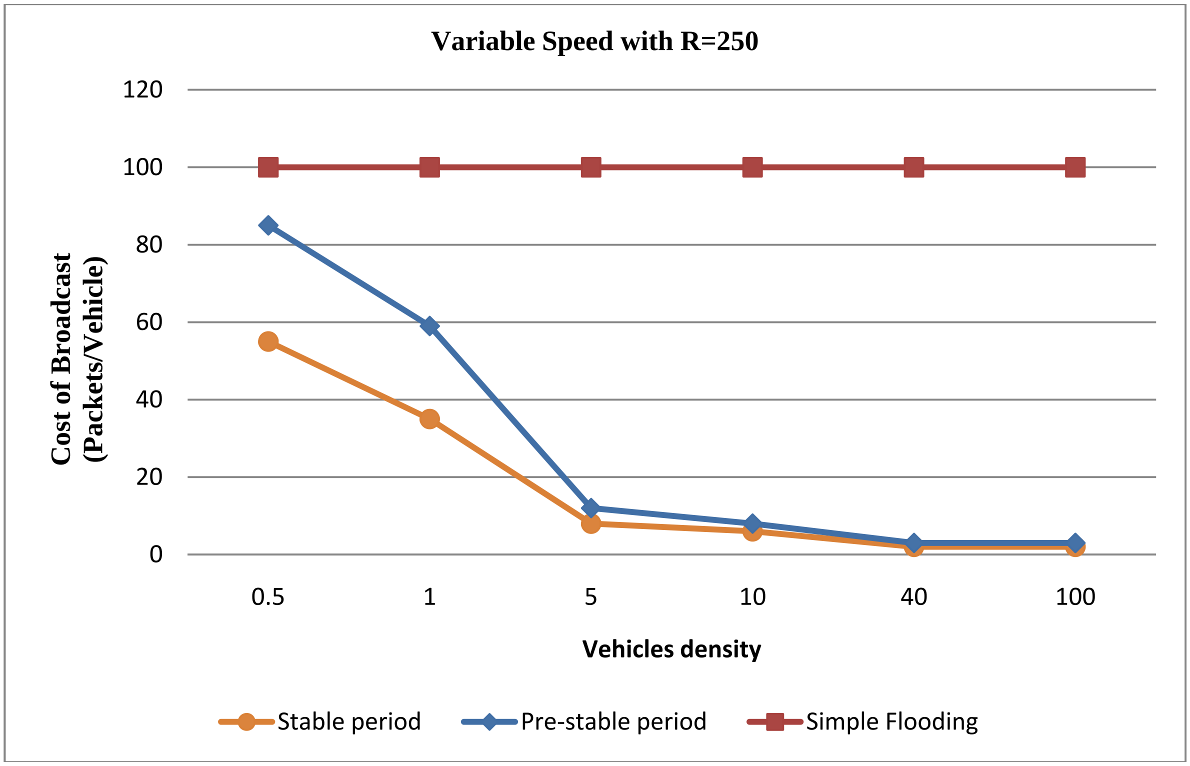

Figure 6: First scenario (variable speed, broadcasting cost vs. density)

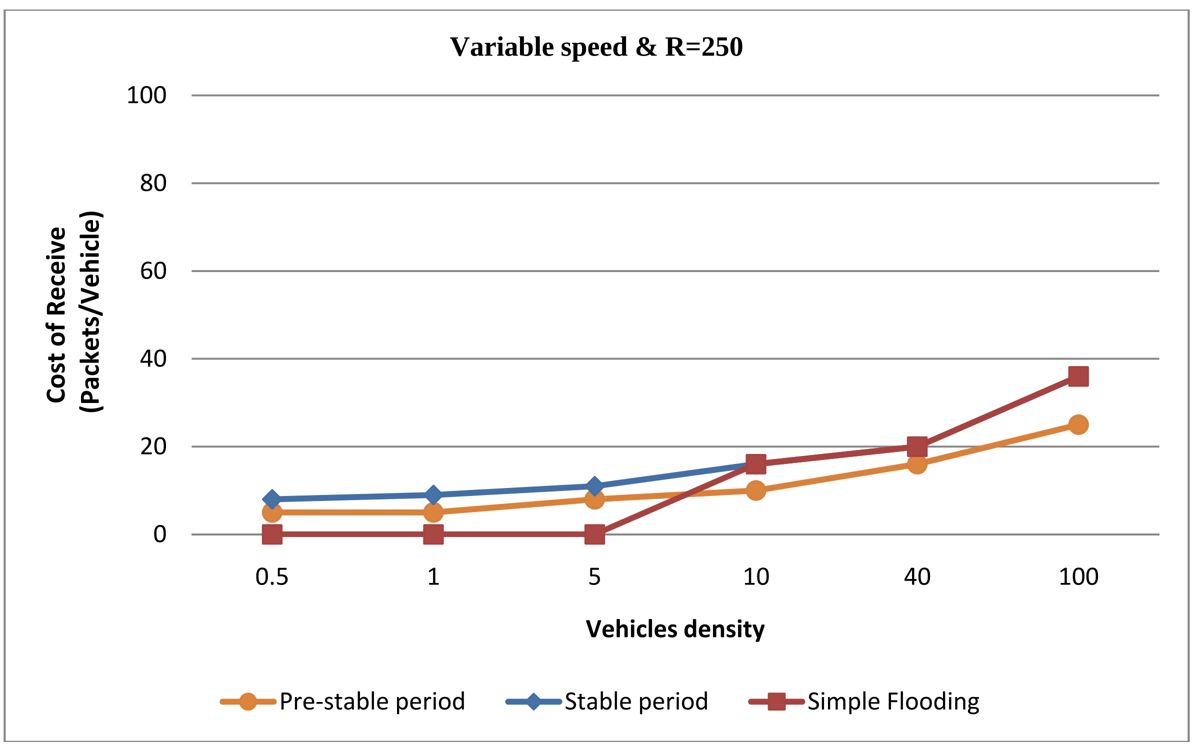

Figure 7: First scenario (variable speed, receiving cost vs. density)

B. Results for Scenario 2

Figures 8, 9, 10, 11, 12, and 13 show the result for each pre-stable and stable period of DTSG while the speed and density are variable with a fixed broadcasting range, R=250 meters.

The delivery ratio of both pre-stable and stable periods (Figures 8, 9) is high but reasonable. While the pre-stable period delivers message from a range of 92-98%, the stable period does a better job and delivers the message up to 100%. It is worth mentioning that although the delivery ratio increases while density increases, in a fixed density, the delivery ratio does not depend on the vehicles' speed. The main reason for this observation is that all the vehicles are moving with the same speed. Therefore, the topology of the network does not change with the increase in speed. This is one of the other advantages of the protocol as it is independent of the nodes' speed. This advantage exists because of DTSG's dynamic sleep time and its coefficient. Most of the other protocols fail because of the nodes' high mobility.

The broadcasting cost (Figures 10, 11) seems to be reasonable and theoretically predictable in high-density networks in both periods. For example, for the stable period with a density of more than 50, it is two messages per vehicles. However, while the receiving cost (Figures 12, 13) is taken into account, in the mentioned example, the receiving cost is high. These two costs, receiving and broadcasting cost, for a broadcasting protocol should be compared.

On the other hand, for sparse networks, as mentioned before, although the broadcasting cost seems to be high, the receiving cost is low and reasonable. This collaboration results from the density of the network and shows that this does not impose too much cost on the network.

These costs are also independent of the speed in each density. The unusual result is the broadcasting cost of the protocol in two low-density networks, 0.5 and 1, in the pre-stable period. The cost decreases while the speed increases. However, it should be vice versa.

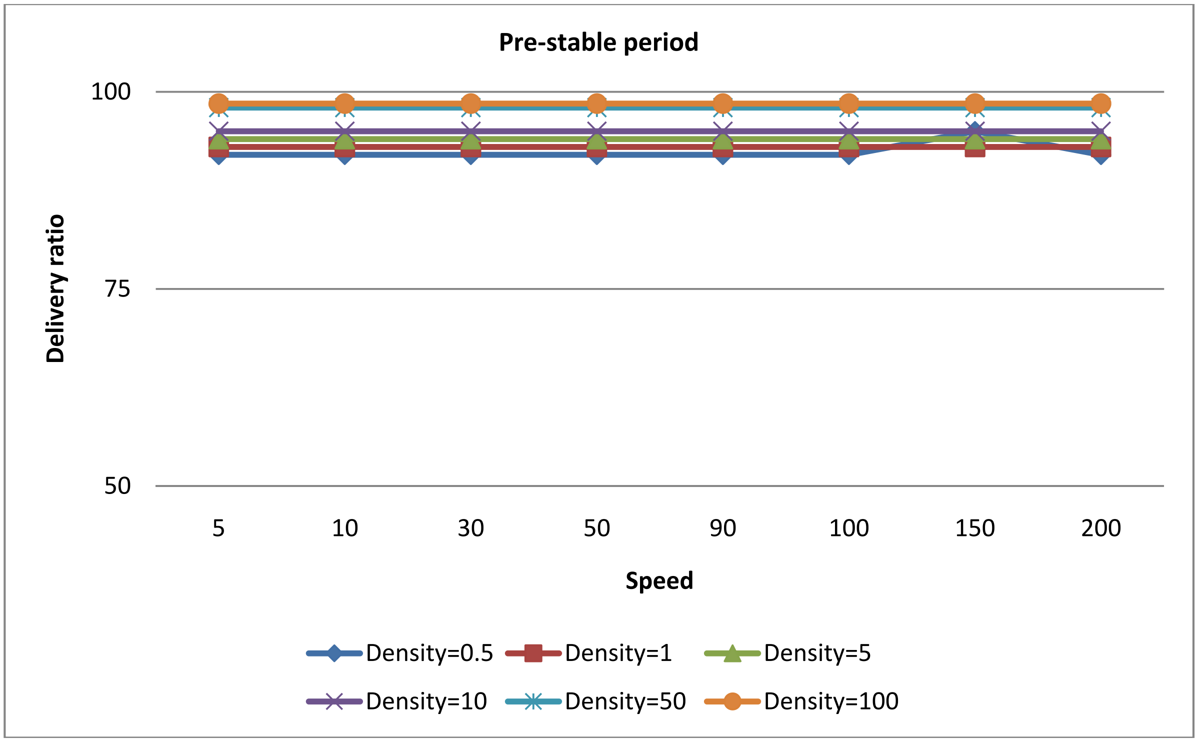

Figure 8: Second scenario (pre-stable period, delivery ratio vs. speed)

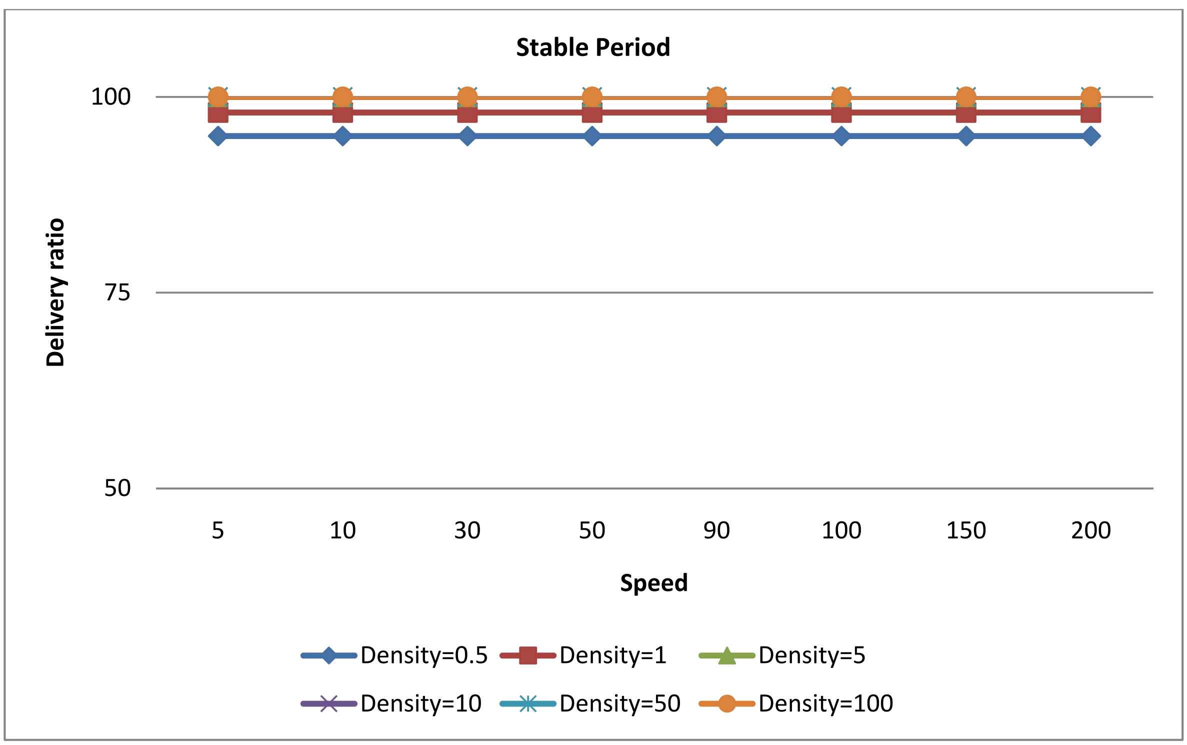

Figure 9: Second scenario (stable period, delivery ratio vs. speed)

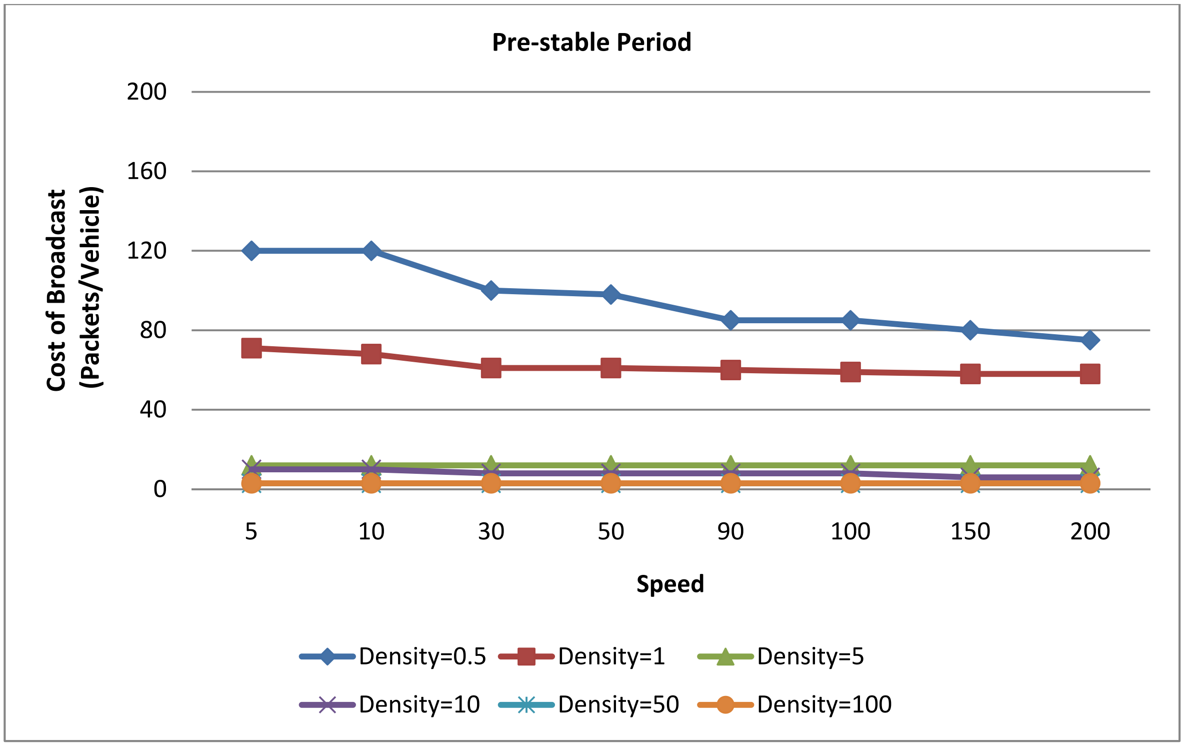

Figure 10: Second scenario (pre-stable period, broadcasting cost vs. speed)

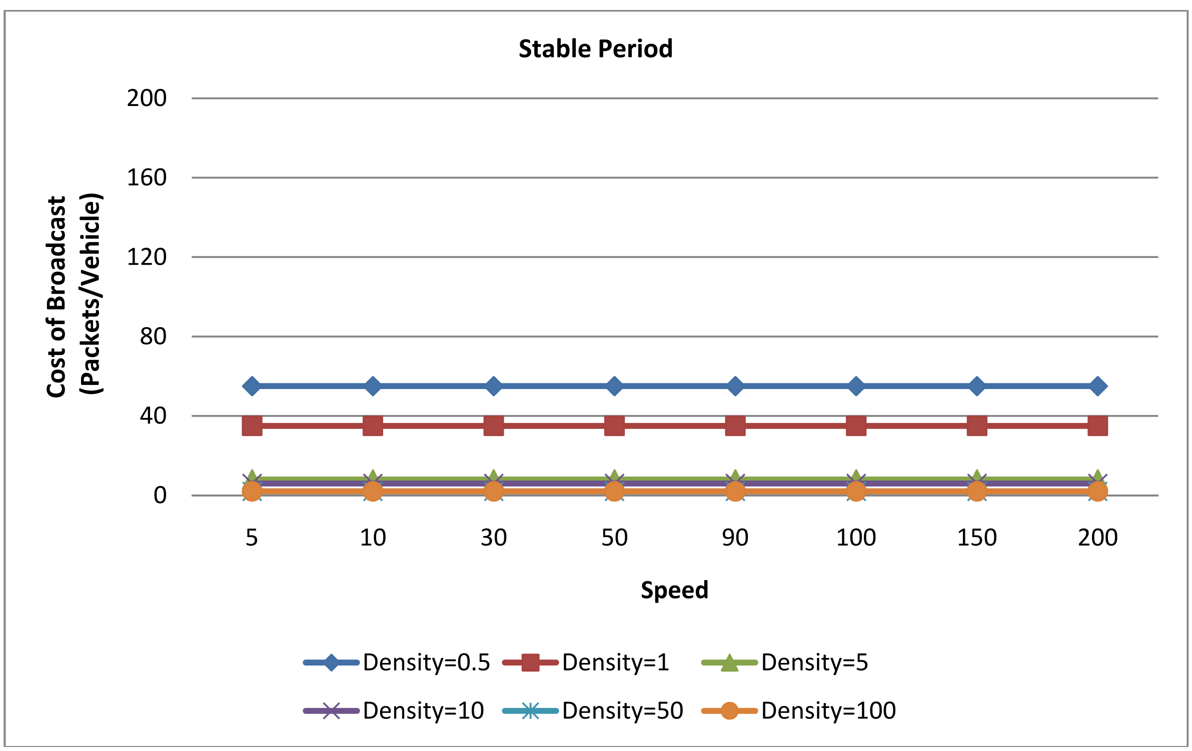

Figure 11: Second scenario (stable period, broadcasting cost vs. speed)

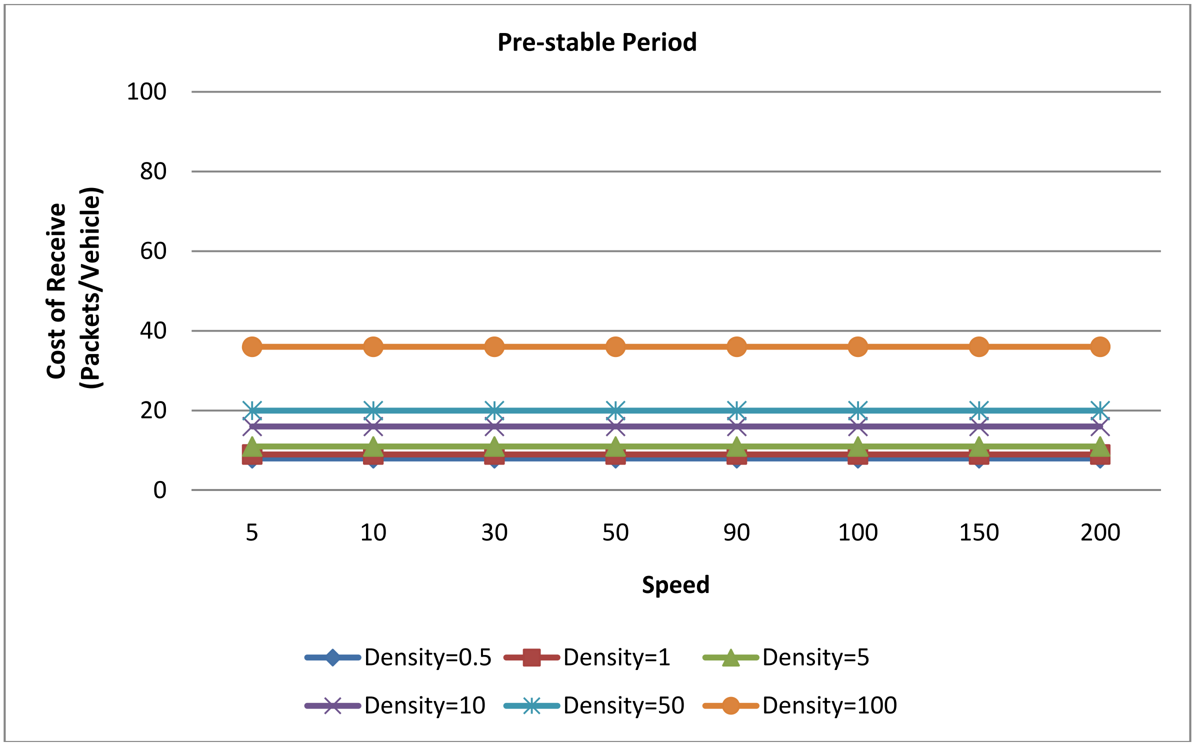

Figure 12: Second scenario (pre-stable period, receiving cost vs. speed)

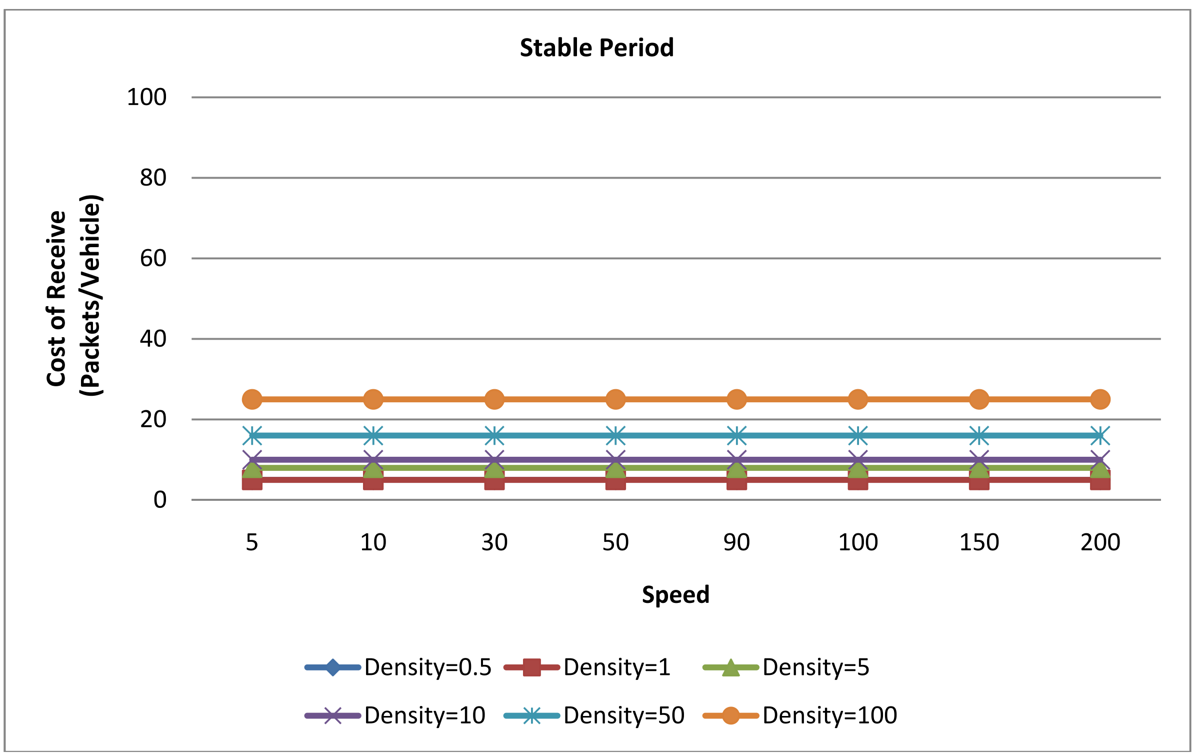

Figure 13: Second scenario (stable period, receiving cost vs. speed)

C. *Results for Scenario 3*

Figures 14, 15, 16, and 17 show the delivery ratio and broadcasting cost for pre-stable and stable periods while the speed is fixed, 100 km/h, the density varies among 0.5, 10, and 100, and the broadcasting range also varies among 100, 250, and 400 meters.

In both periods, the delivery ratio increases while both density and broadcasting range increase. Nevertheless, the cost in both periods decreases whereas broadcasting range increases. This result is also predictable because the sleep time is related to R. While R is high, the sleep time in high as well. Therefore, the nodes rebroadcast less with a longer sleep time in higher broadcasting range.

D. *Stabilized Time*

Stabilized time depends on the vehicles' speed. It is defined as the time that the first informed helping vehicle requires to reach the end of the region. At this time, the protocol works in the stable period, and its goal is to deliver the message to each intended vehicle as soon as it enters the region.

For the 20 km region with the 2 hours of geocasting, for sparse network this time is 24, 12, and 10 minutes for 50, 100, and 120 km/h speeds respectively. In sparse networks, since most of the protocols like simple flooding fail to even geocast, this stabilized time in the DTSG protocol is reasonable.

In dense networks, the stabilized time is 12 minutes approximately for all speeds. As the pre-stable period's performance metrics in high-density networks is good, this will not be considered as a flaw of the protocol.

E. *Informed Time*

The informed time, how long it takes a vehicle to be informed as soon as it enters the region in the stable time, is zero for all the vehicles in all densities and all speeds. It is because all the vehicles will be informed in advance in the extra length region and they were informed as they enter the region.

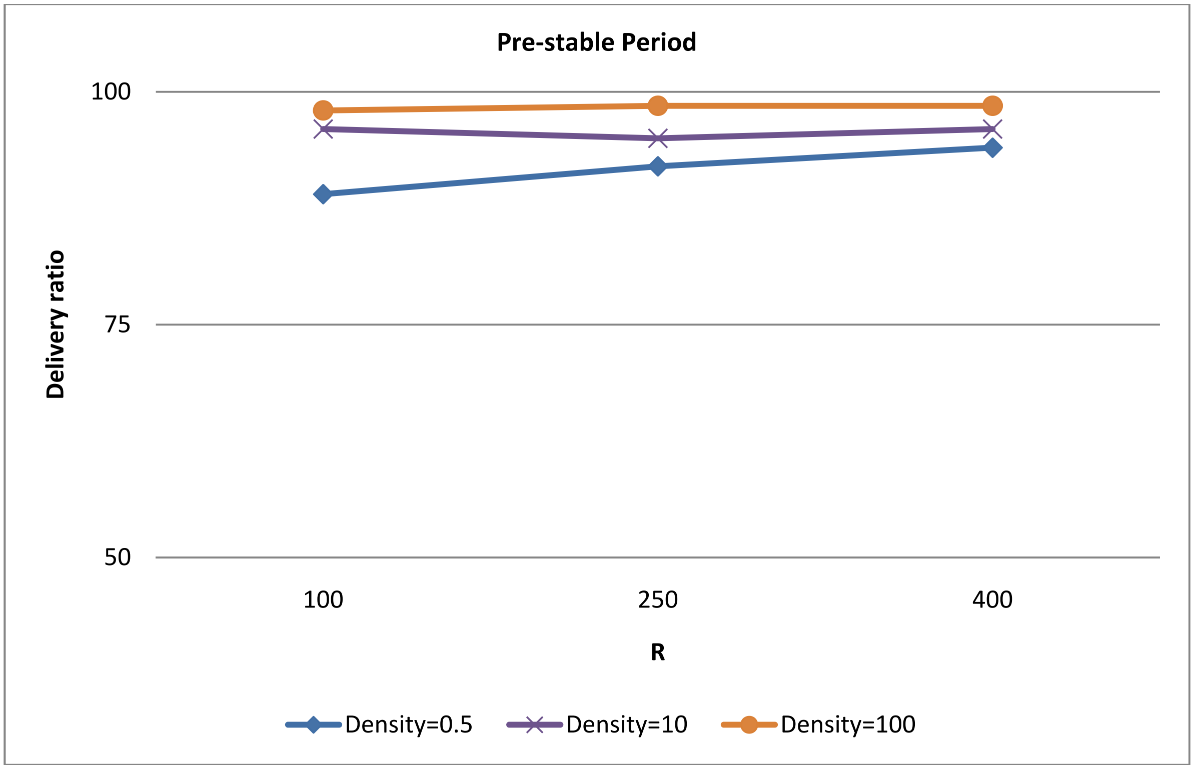

Figure 14: Third scenario (pre-stable period, delivery ratio vs. R)

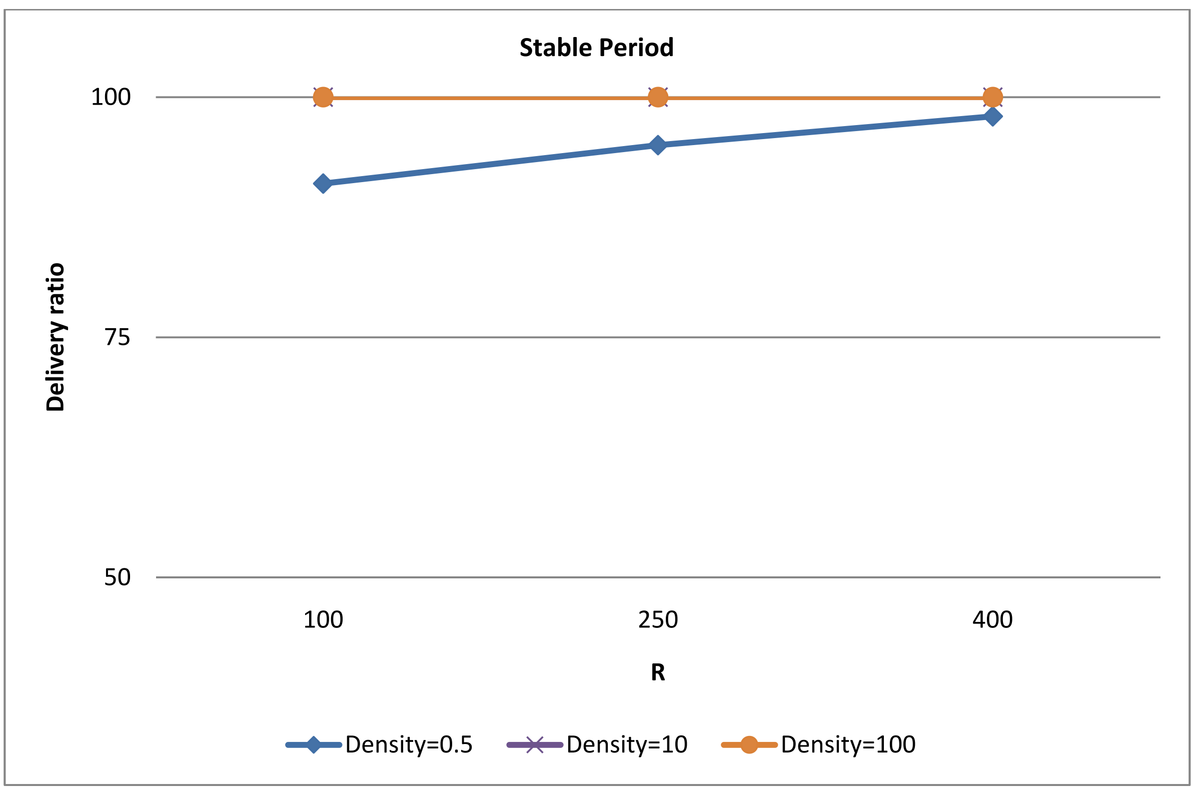

Figure 15: Third scenario (stable period, delivery ratio vs. R)

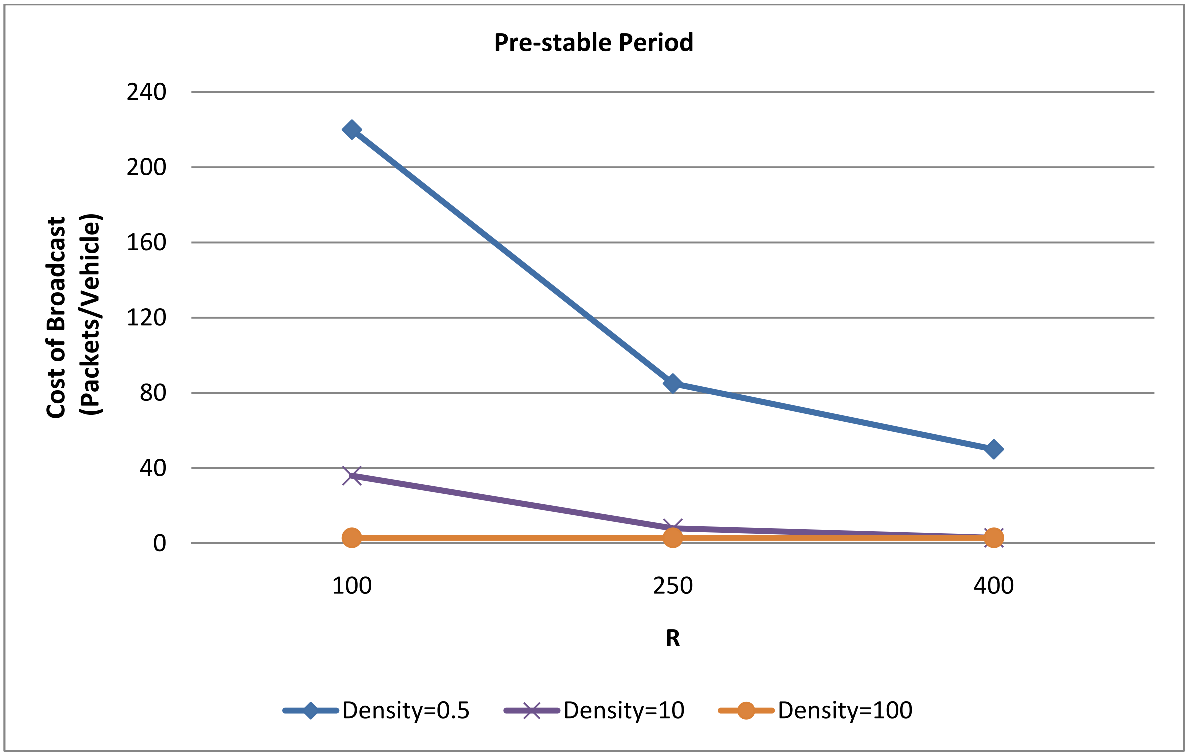

Figure 16: Third scenario (pre-stable period, broadcasting cost vs. R)

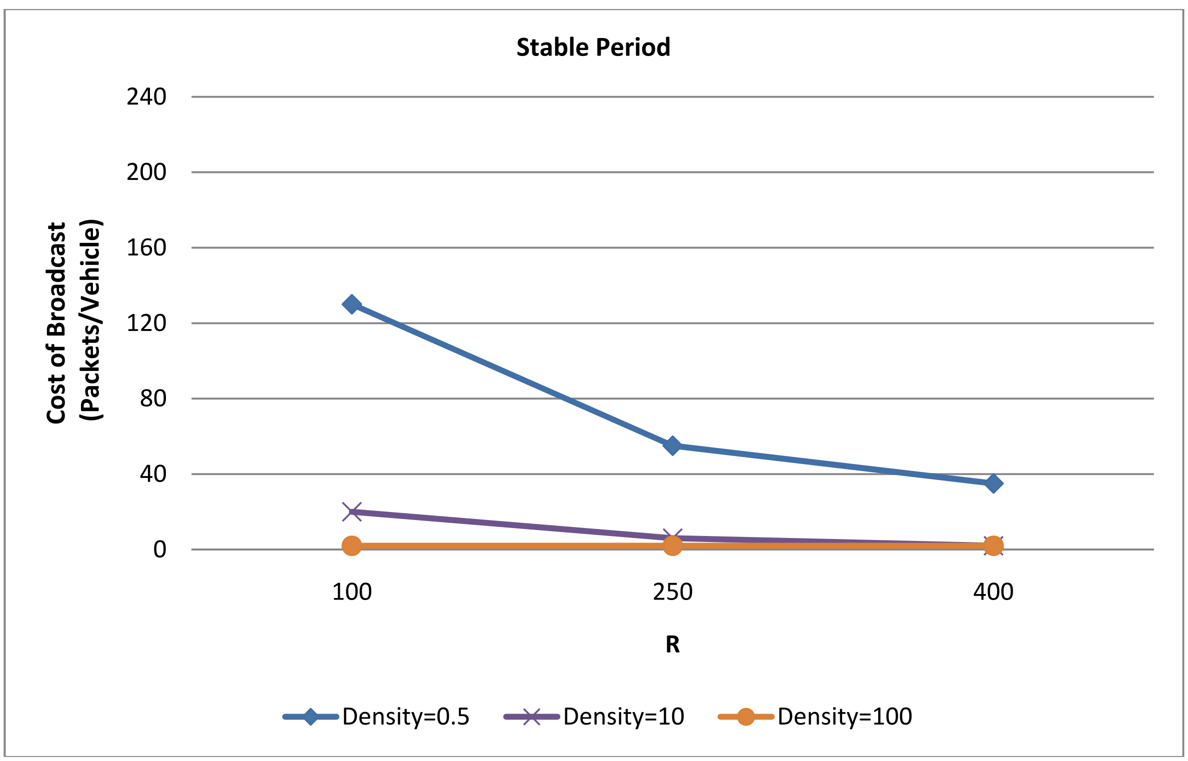

Figure 17: Third scenario (stable period, broadcasting cost vs. R)

4.5. Simulation Conclusions

A. Results at a Glance and Protocol Advantages

As the results show, many advantages make DTSG a promising protocol that works well in all densities and all speeds. Some of them are summarized here.

- In a sparse network, DTSG guarantees delivery of the message to the vehicles with a low receiving cost but without using any roadside units while simple flooding fails in densities lower than five vehicles per km.
- The delivery ratio in stable period is very high in all densities, especially in a sparse network. In higher densities, simple flooding can also deliver the message with a reasonable ratio. Nevertheless, with only one defragmentation in the network, which is very common even in dense networks, simple flooding fails. The DTSG does not have this flaw as it employs the helping vehicles in disseminating the message to the region.
- DTSG's delivery ratio is independent of the vehicles' speed. Most of the protocols lack this dominant advantage at higher speeds. This is theoretically predictable because DSTG's sleep time dynamically changes with the nodes' speed.
- Although DTSG works better when the nodes' broadcasting range, R, is higher, its delivery ratio is also independent of R and of the density of the network. It is independent of the R because the sleep time dynamically adapts itself by R while the DTSG is independent of network density because the coefficient of the sleep time does not allow all the vehicles in a group to rebroadcast.
- The DTSG's delivery ratio and network cost is better in the stable period. As expanding or canceling previously stable message occurs in stable period, this also becomes an advantage of the protocol. Its dynamic notion allows the stable time of the messages to be easily expanded or canceled without imposing any additional cost on the network.
- The informed time of the intended vehicles is approximately zero in the stable period. In other words, they are informed as soon as they enter the region.
- In the stable period, the nodes rebroadcast the message in only two parts of the region. The helping vehicles rebroadcast it in the extra length region while the intended vehicles rebroadcast it after they have passed the incident location. Therefore, the network cost affects only these two locations and the entire intended region is not affected by this protocol.

B. *Protocol's Drawbacks*

Despite the many advantages of this protocol, its performance is not reasonable in the pre-stable period. Although the main goal of this protocol is to be a good time-stable protocol (i.e. working well in stable period as it does), it has a drawback of high network cost in dense networks in its pre-stable period.

Chapter 5: Conclusions and Future Work

5.1. Conclusions

DTSG is a dynamic time-stable geocast protocol that guarantees delivery of the message to the intended vehicles entering the region for a certain amount of time. This time can be expanded or canceled by the dynamic characteristic of this protocol. This is done by the supplementary message without any new effect on the network cost. In addition, some dynamic variables help the protocols to reduce the cost of communication while making it independent of the speed, density and broadcasting range of the vehicles. This protocol also employs other-lane vehicles, as helping vehicles, allowing the protocol to work even in a too sparse network.

This study has some main characteristics: First, the dynamic nature of the protocol that allows the stable message to be extended or canceled during its lifetime. Second, the pre-stable and stable period with the zero informed time for intended vehicles in stable period. Third, it employs other-lane vehicles with some dynamic broadcasting parameters.

At last, it dynamically introduces an extra length region that the other-lane vehicles use it for better performance.

5.2. Future Work

One of the future studies should focus on solving the drawback of this protocol. It means coming up with a way to make DTSG work better in its pre-stable period. Also in high-density networks, the high receiving cost should be considered in any future revision of this protocol.

The extra length region of the helping vehicles is considered as the protocol works well in stability of the message. This extra length can be extended to the intended vehicles that have passed the incident location. However, the current definition of the extra length region may not be applicable for them.

As mentioned before, many of the intended vehicles and some of the helping vehicles may exit the region when informed of the message. The protocol predicts that at this time they will try to inform at least one other-lane vehicle. The drop off strategy and the determination of when they should start informing the other-lane node are not as robust as they should be. Therefore, they require revision. In addition, determining how the protocol knows that they are going to exit the region also requires some thought.

One of the simplifying assumptions of this protocol is that only one message should be broadcast in order to be stable in the region. This assumption is not realistic in real situations. In real situation, more messages need to be stable in the region at the same time. So, this new assumption's results should be observed, as they may affect both the delivery ratio and network cost.

One of the other simplifying assumptions is that vehicles move on the road with a constant speed (i.e. although they may enter the road with different speeds, they will not change their speed until they exit the road). In addition, no maneuvering, braking, or even acceleration occurs during simulation. These assumptions are also not realistic. The affects of these changes should also be considered.

This protocol is implemented in a two-way highway. However, this protocol has this capacity to be applied to other situations. For example, it can be developed in urban and rural areas with complex road traffic modeling. In addition, regular geocast protocols are too general to consider the intended region in every shape possibly. However, this protocol seems to work in these situations with minor changes.

In addition, VANETs have different kinds of protocol for different purposes (i.e. a protocol for safety messages, another one for comfort messages). As all of these protocols should be gathered in one onboard unit, an intensive study should be done to combine all of these protocols. Many of these protocols, when combined with each other, help the others and reduce some of the costs of a single protocol.

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