Design and Performance Evaluation of Data Dissemination and Hovering Information Protocols for Vehicular Ad Hoc Networks (VANETs)

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of

Masters of Science

in

Computer Science

The Faculty of Business and Information Technology
University of Ontario Institute of Technology

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July 2017

Abstract

Robust and efficient communication protocols for *Vehicular Ad Hoc Networks (VANETs)* are still an open topic in the literature. Because of that, our attention has been gathered by the *Data Dissemination* and the *Information Hovering* protocols for VANETs. For most of the VANETs' applications the data dissemination is a crucial process. Also, for many of them the availability of information over some time in a bounded region, or a *Hovering Information* protocol, is a key feature. Hence, in this thesis we are proposing two data dissemination protocols and one information hovering protocol for VANETs.

While disseminating data within a certain area of interest, the Flooding scheme provides the best delivery ratio, but it suffers from generating too many redundant packets, channel contentions and packet collisions. To this end, we have proposed the protocol called *DTP-DDP*. It takes advantage of the *Global Positioning System (GPS)* with integrated maps. Using the data from a map together with its predictive mechanism, the data sender selects the further nodes that will rebroadcast the information. In addition, the protocol works in both urban and highway scenarios. However, it requires one-time snapshot of the first-hop vehicles, but there are no other beacon messages. Once it has the snapshot, the sender chooses the further rebroadcasting vehicle. A low signal handling mechanism was developed to handle the cases in which the reply-response messages cannot be delivered.

Even though *DTP-DDP* achieves similar or higher delivery ratio than compared protocols with a smaller number of retransmitted packets, it has higher delay than the selected protocols. Also, we have realized that the number of retransmission packets could be reduced even more. As a result of these reasons, we have proposed *E-BED*. By exploiting the distance and the encountering probability of the vehicles to the event, *E-BED* is capable of performing an efficient data dissemination in both urban and highway scenarios. As shown in the simulation experiments' results *E-BED* achieves much better results than its predecessor *DTP-DDP* in terms of end to end delay and the number of retransmitted packets.

Furthermore, in order to keep an event alive in a bounded region we have proposed a *Hovering Information* protocol called *CHIP*. *CHIP* introduces a whole new concept, which to our best knowledge has not been discussed in the literature yet. Instead of sending constant beacon messages, *CHIP* is periodically disseminating the data. Also, in the case when the vehicle that has detected the event does not remain at the event place, *CHIP* selects new vehicle to restart the dissemination process after certain repetition period. To this end, we are also proposing a scheme to calculate the optimum repetition time for the dissemination. As can be seen in the simulation experiments' results, *CHIP* outperforms the beaconing approaches in terms of transmitted packets by consuming approximately two to three hundred times fewer packets. At the same time, it achieves similar informative ratio for the new vehicles that are entering the hovering information region. However, the average time to receive the event information after entering the zone is higher while using *CHIP*. Nevertheless, even though higher, the *CHIP's* delay is short enough to ensure that the vehicles will be informed about the event in advance.

Acknowledgements

I am sincerely thankful to my supervisor Dr. Richard Pazzi for his flawless guidance, constant encouragement and unconditional support during the completion of this thesis and my degree.

I would also like to express a deep gratitude to my mother and father who were supporting me financially. They, together with my wife, my brother, my whole family and friends were constantly motivating and encouraging me throughout the completion of my degree.

And my acknowledgments also go to the Natural Science and Engineering Research Council of Canada (NSERC), Discovery Grants Program, for their financial support.

Also, I am very thankful to the Faculty of Business and Information Technology (FBIT) and the Dean for the provided financial support during the process of competition of my degree.

Publications

- Tomo Nikolovski, Richard W. Pazzi. A Lightweight and Efficient Approach (LEA) for Hovering Information protocols. In Proceedings of the 7th ACM Symposium on Development and Analysis of Intelligent Vehicular Networks and Applications (DIVANet). ACM - Miami Beach, USA. (Submitted)

- Tomo Nikolovski, Richard W. Pazzi, Ademar T. Akabane, Leandro A. Villas. Comprehensive and efficient Hovering Information Protocol (CHIP) for Urban and Highway Vehicular Ad Hoc Networks (VANETs). ELSEVIER Vehicular Communications. (Submitted)

- Tomo Nikolovski and Richard W. Pazzi. 2017. Efficient Encounter-based Event Dissemination Protocol (E-BED) for Urban and Highway Vehicular Ad Hoc Networks. In Proceedings of the 22nd IEEE Symposium on Computers and Communications. IEEE, Heraklion, Crete - Greece. Pages 1088-1093. (To Appear)

- Tomo Nikolovski and Richard W. Pazzi. 2016. Delay Tolerant and Predictive Data Dissemination Protocol (DTP-DDP) for urban and highway vehicular ad hoc networks (VANETs). In Proceedings of the 6th ACM Symposium on Development and Analysis of Intelligent Vehicular Networks and Applications (DIVANet). ACM, Valletta - Malta. Pages 67–74. https://doi.org/10.1145/2989275.2989280

- [Poster] Tomo Nikolovski, Mauricio Bertanha, Ricahrd W. Pazzi. 2016. Heterogeneous (DSRC and LTE) Event-Based Data Dissemination Protocol for VANETs. In proceedings or the 6th Developing Next Generation Intelligent Vehicular Network and Applications (DIVA) Workshop. ACM, Ottawa, ON - Canada.

- [Poster] Mauricio Bertanha, Tomo Nikolovskim Ricahrd W. Pazzi. 2016. Geographic Sleep Scheduling in Duty-Cycled Wireless Sensor Networks. In proceedings or the 6th Developing Next Generation Intelligent Vehicular Network and Applications (DIVA) Workshop. ACM, Ottawa, ON - Canada.

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Chapter 1

Introduction

The *Vehicular Ad Hoc Network (VANET)* is a network made up of vehicles which are capable of transmitting and receiving data messages. In general, it represents a sub-group of the *Mobile Ad Hoc Networks (MANETs)* which are networks comprised of static nodes with communication capabilities. Unlike in MANETs, in VANETs the nodes are constantly changing their position and cause frequent topology variations which represents additional challenge while establishing the communication links. Moreover, two different VANET architectures are known in the literature, *Vehicle-to-Vehicle (V2V)* and *Vehicle-to-Infrastructure (V2I)*. A third hybrid type is the *V2X*, which represents a combination of the V2V and V2I architectures. Nevertheless, in this thesis we are considering just the pure V2V structure. In this case, the vehicles exchange information just among them and no other third party infrastructure, like a cellular network, is included in the communication. In *V2V* the packets transmission is facilitated by the *Dedicated Short Range Communication (DSRC)* [15] technology and the set of standards called *WAVE (Wireless Access in the Vehicular Environment (WAVE)*. WAVE is comprised of two other different classes of standards. Those are the *IEEE 802.11p* standards. [14, 38], which defines the parameters for the physical and the medium access control (MAC) layers and the *IEEE 1609* [43], which defines an architecture to enable secure V2V wireless communication. Therefore, the vehicles that are part of the VANET have to have a DSRC radio with its parameters set up as per the WAVE standards. Moreover, the VANETs' radios have been allocated a spectrum of 75 MHz at the 5.9 GHz band. The spectrum is divided into seven 10 MHz channels and a 5 MHz gap. These seven channels include a service channel (SCH) reserved for safety communications, four control channels (CCHs) used for safety and non-safety purposes and two channels for special uses. The transmission range of the radios can be up to 300m [9].

The VANETs applications vary a lot. They differ from data dissemination [2, 7, 25, 27, 33, 47, 52], keeping an information alive within certain region [21, 48–50], routing of data [12], advertising, gaming, social media, etc. Because of the huge scope of applications and in order to provide safer, easier and more entertained driving, VANETs have gathered the attention of the researchers and the automobile industry. However, in this thesis we are going to concentrate on designing a solution for the following two applications: *Data Dissemination* and *Keeping an Information Alive within certain region*. Some common examples for which the data dissemination and the data availability over time for VANETs would be useful are: dissemination and availability of accident, congested roads, slippery roads, various disaster areas or animals on the road information. Also, peer-to-peer gaming, social media, multimedia exchange, and various other entertainment applications.

1.0.1 Problem Statement

An interesting fact is that more than 100 million people die as a result of traffic accidents, with a cost of more than $500 billion every year on a global level [52]. Because of that, while working on this thesis our goal was to design data dissemination protocol that will satisfy the constrains for an emergency data dissemination. Also, another challenge for us was how to keep the events' information alive within certain region over some specified time. With that the other new vehicles that are arriving in the region could become aware about the event.

The most common data dissemination protocol for VANETs is Flooding [11]. In Flooding, every vehicle that receives a message is replicating and retransmitting it one more time. Even though this kind of dissemination achieves high delivery ratio, it over-saturates the network with redundant packets while operating in dense networks [40]. In a high density VANETs when multiple vehicles attempt to transmit at the same time, they cause high data traffic, network congestion, packet collisions and extra delay at the medium access control layer. Also, many messages are being discarded as they contain bit errors caused by the above mentioned reasons. Therefore, a technique to suppress the number of regenerated packets is needed. Nevertheless, this represents a highly challenging task, because with lowering the number of vehicles that retransmit the message the overall delivery ratio is decreasing too. One way to tackle this problem is to select the most efficient vehicles to retransmit the data, hence reducing the number of regenerated packets, but still preserving satisfactory delivery ratio. However, in dynamic networks with frequent topology changes, as the VANETs are, the efficient data dissemination is an even more challenging issue. To this end, we have proposed two dissemination protocols to address the problem with the increased number of regenerated messages. They are efficiently selecting the next vehicles to retransmit the data and with that the number of retransmitted messages is lowered while keeping a satisfactory delivery ratio.

On the other hand, the keeping information alive within a bounded region is a task which has been addressed in the literature under the term *Hovering Information* [5, 10, 17, 21, 34, 45, 48–50]. Other works for MANETs that are aiming to solve the same problem appear under the name *Floating Content* [4, 13, 29]. All of these works have one common goal and that is to make a piece of information to float or to hover within a predefined region. Hence, the nodes that are in this zone can consume the available information and become aware of a certain event or other content. In general, the existing protocols employ vehicles that broadcast periodic beacon messages. These beacons contain the events' data for which the vehicle is aware of. If the receiver of the beacon holds data for which the vehicle that broadcasted the beacon is uninformed, the receiver broadcasts this packet. These schemes successfully keep the event data alive. However, they induce high bandwidth usage as a result of the frequent beacons. To avoid the periodic beaconing, we have developed a *Hovering Information* protocol which uses a whole different approach to address the mentioned issue. Instead of constant beaconing our approach operates by periodical execution of a hovering optimized data dissemination protocol.

1.0.2 Thesis Contribution

The main contributions of this thesis are two data dissemination protocols and one hovering information protocol for VANETs.

The first dissemination protocol is called *Delay Tolerant and Predictive Data Dissemination Protocol (DTP-DDP) for Urban and Highway Vehicular Ad Hoc Networks (VANETs)* [26]. It minimizes the number of regenerated packets while sustaining almost same delivery ratio as the Flooding protocol.

The second dissemination protocols is called *Efficient Encounter-based Event Dissemination Protocol (E-BED) for Urban and Highway Vehicular Ad Hoc Networks.* It is a modification and improvement of its predecessor DTP-DDP. The E-BED's shows satisfactory delivery ratio and reduced number of retransmitted packets while also reducing the end to end delay when compared to DTP-DDP.

The hovering information protocol is called *Comprehensive and efficient Hovering Information Protocol (CHIP) for Urban and Highway Vehicular Ad Hoc Networks (VANETs).* It has not been published yet, but its journal paper has been already submitted. As mentioned above, CHIP is based on approach which to our best knowledge is first of its kind in the literature. Because of that, it achieves similar informative ratio as the other relevant protocols and in the same time it consumes around two to three hundred packets less than those protocols.

For all of proposed works, we have done an extensive sets of simulation experiments and gathered their relevant operational parameters. Also, we have compared those results with other relevant protocols in the literature. With that, we prove the effectiveness and the improvement of our solutions over the other selected works.

1.0.3 An overview of the proposed data dissemination and hovering protocols

In this subsection we are going to provide a brief outline of the proposed works. Their detailed description and evaluation results are shown in Chapters 3 and 4. The following data dissemination and hovering protocols for VANETs have been proposed:

- *Delay Tolerant and Predictive Data Dissemination Protocol (DTP-DDP) for Urban and Highway Vehicular Ad Hoc Networks (VANETs)* [26]. DTP-DDP has the ability to operate in both urban and highway environments. It takes advantage of the Global Position System (GPS) and the map integration. Thus, it can intelligently choose the next data forwarding nodes that should spread the data further. Besides the fact that there is a small delay because of the next forwarder selection mechanism, this algorithm could be used for emergency information dissemination, as well as for some other VANET applications mentioned above. Also, the protocol does not use beacons and requires just a one-time topology snapshot of the first-hop neighbors. Afterwards, using the integrated mechanism, it predicts the eventual next topology state and chooses the most efficient nodes to rebroadcast the data. The prediction of the next topology state is crucial in dynamic networks such as VANETs and that has driven the design of the proposed protocol. Moreover, with DTP-DDP the vehicles that have received the event message with a low signal strength will automatically retransmit the message, since their communication with the sender might be impossible because of the weak signal.

- *Efficient Encounter-based Event Dissemination Protocol (E-BED) for Urban and Highway Vehicular Ad Hoc Networks* [27]. E-BED is a data dissemination protocol for both urban and highway scenarios. The protocol is aware just of the most recent network topology, i.e. when the event packet is generated or when the forwarders perform the later dissemination. Basically, it efficiently uses the minimum number of forwarding vehicles, while still offering satisfactory results in terms of delivery ratio and delay. Unlike in DTP-DDP, once the event packet is broadcasted, just some of the first hop neighbors send response packet to the sender. Then, the sender calculates a utility value for each of these nodes. In order to do that, it measures the distance between itself and the neighbors that replied with their position. Also, the sender calculates the probability that the receiver vehicles will encounter the sender node or the event, as well as their moving direction. After that, the algorithm chooses one node on each different street and in each different direction. Then, some of the chosen nodes are eliminated based on their inter-vehicular distance with the other selected forwarders, which is not a case in DTP-DDP. Finally, a command for retransmission is sent to nodes which passed through the selection criteria.

Also, E-BED avoids the low signal handling mechanism that is a case in DTP-DDP. With E-BED, the sender or the forwarder of the event packet has lower waiting time for the response messages of the neighbors. Hence, even the nodes that are far have time to respond and be assigned a retransmission command if they are selected as forwarding nodes.

- *Comprehensive and efficient Hovering Information Protocol (CHIP) for Urban and Highway Vehicular Ad Hoc Networks (VANETs).* CHIP is a combination of a data dissemination and dissemination initiation algorithms. The data dissemination schemes will spread the data throughout the region of interest. The dissemination initiation mechanisms will select a new vehicle to restart the data dissemination process at a later time in order to inform the new vehicles entering the event zone. Moreover, CHIP can operate in both urban and highway scenarios, making it one of the first protocols of its kind in the literature. According to the simulation experiments, CHIP maintains the same vehicles' information packet ratio as the other selected protocols, while generating two to three hundred times fewer packets than them.

1.0.4 Thesis Organization

This thesis is composed of five chapters. Chapter 1 gives an introduction for the VANETs and their applications. Furthermore, it states the problems that we tried to solve, the thesis's contribution and a brief outline of the proposed solutions. In Chapter 2 we present some of the existing literature on data dissemination and hovering information work. Chapter 3 is discussing the details of the proposed solutions. Chapter 4 shows the simulation experiments' results of the proposed and the other compared protocols. Finally, Chapter 5 provides the conclusion of this thesis.

Chapter 2

Literature Review

In this chapter we are going to provide a review on some of the existing work on data dissemination and information hovering for VANETs. As mentioned in Chapter 1, the keeping of an information alive is a topic that has been addressed under two different names i.e. *Hovering Information* and *Floating Content*. Also, some authors have considered this problem as part of their whole solution. To provide a comprehensive review, we are going to discuss works for all of the three mentioned cases.

2.1 Data Dissemination in VANETs

As mentioned in Chapter 1 of this thesis, two types of communication are known in VANETs. Those are *(Vehicle-to-Vehicle) V2V* and *(Vehicle-to-Infrastructure) V2I*. V2V is the pure communication among the vehicles where no third party infrastructure is involved. The V2I communication is the one between a vehicle and an infrastructure. In the VANETs literature the most common communication infrastructure is the *Road Side Units (RSUs)*. The RSUs are stationary units which have the same communication capabilities as a vehicle that is part of a VANET, i.e. DSRC radio set up according to the WAVE standards. Usually, the RSU is connected to a central server. Its purpose is to fetch information from the servers and distribute it on the streets, as well as feeding the servers with the information from the streets. Also, the RSUs help to disseminate the data in low traffic regions and inform the new vehicles that come in the region about certain events. A very important characteristic of a VANET composed of vehicles and RSUs, is the RSUs' location. Because of that, many authors have worked on this issue and aimed to design an optimal RSU placement scheme [6, 8, 20]. The presence of the RSUs in the VANET can be beneficial and because of that many works have addressed the data dissemination challenge for VANETs with the assumption that a RSUs are present on the streets [3,22,30,37,51]. However, their wide deployment, configuration and maintenance can be very costly and unaffordable for many budgets. Because of this reason, while developing our data dissemination schemes we have considered just a pure V2V communication without presence of any kind of infrastructure on the streets. Therefore, in the following subsections of this chapter we are going to classify and discuss only the data dissemination protocols which operate without RSUs. Furthermore, the VANETs topology and challenges can differ a lot for urban and highway scenarios. Hence, some authors have worked solely on data dissemination for urban or highway VANETs. Some of the protocols are addressing both scenarios. For a better clarity we classify them based on that criteria. Moreover, some common terms in the data dissemination for VANETs literature are:

- *Dissemination Region Radius.* A radius which defines the air distance between the event coordinates and the furthest point by which the event should be disseminated.

- *Dissemination Region.* A predefined region where the event packet should be disseminated. It is defined by a *Dissemination Region Radius.*

- *Forwarder.* A vehicle that is retransmitting the event packet. With that, it helps to spread the information further and to the vehicles that have not received the packet before.

2.1.1 Data Dissemination Protocols for Urban Scenarios

2.1.1.1 Adaptive delay-based geocast protocol for data dissemination in urban VANET

In [31] the authors have proposed the *Urban Geocast based on Adaptive Delay (UGAD)* for urban VANETs. The protocol operates under the assumption that all of the vehicles have *Global Positioning System (GPS)*. Moreover, all of the vehicles that receive a message calculate a forwarding waiting time. For that purpose, two different forwarding modes have been proposed. They are a *Greedy Forwarding (GF)* and an *Intersection-based Forwarding (IF)* mode. Once the vehicle receives the event packet it selects one of these two modes based on its position. If the vehicle is inside the *Dissemination Region (DR)*, it will operate according to the IF mode. If the vehicle is outside of the DR it will choose between the IF or the GF based on its angle of movement whose details are discussed in [31]. Basically, if the vehicle is heading towards the DR then it selects the GF. That is because outside of the DR the dissemination of the packet to more vehicles is less important than forwarding the packet back to its DR. On the other hand, with the IF it higher priority to the vehicles that are at the intersections is given and have better transmission efficiency because of the obstacles free environment. The vehicles that are on the streets are usually bounded with buildings from the sides and with that their propagation effect is decreased. With the GF the retransmission time is calculated as follows:

$$T_{GF\_i} = \left\{ T_{max\_R} \times (\frac{R-d_{ij}}{R}), \right. \tag{2.1}$$

where T_{max_R} is the maximum waiting time before the retransmission. R is the transmission range of the DSRC radio and d_{ij} is the euclidean distance between the sender and the receiver vehicle. With this equation the vehicles that are further from the sender will have shorter waiting time and retransmit the packet sooner. When the other nodes that have higher waiting times receive this message they will cancel their retransmissions since the packet has been broadcasted by another node that has larger distance from the sender than them. In the simulation experiments of this paper T_{max_R} is set to 1 second.

The IF is given by the following equation:

$$p = \begin{cases} T_{max\_I} \times \frac{R-d_{ij}}{R}, Intersection \\ T_{max\_I} + T_{max\_R} \times \frac{R-d_{ij}}{R}, Otherwise, \end{cases} \tag{2.2}$$

where T_{max_I} is the maximum waiting time for the vehicles that at the receiving time are at intersections. T_{max_R} is the maximum waiting time for the vehicles that are not at intersections. R is the transmission range of the DSRC radio and d_{ij} is the distance between the sender and the receiver vehicle. As mentioned in the above paragraph, in the simulation experiments of the paper the T_{max_R} is set to 1 second. On the other hand, T_{max_I} is set to 0.1 seconds which gives much higher priority to the vehicles that are at intersections once the IF mode of operation is selected.

2.1.1.2 Evaluating the Impact of a Novel Warning Message Dissemination Scheme for VANETs Using Real City Maps

In [25] the authors present a protocol named *Enhanced Street Broadcast Reduction (eSBR)*. It operates with the assumption that every vehicle has a GPS with embedded maps. Also, they make use of the Distance-based scheme [41] which evaluates the distance as a parameter while deciding for a rebroadcast. The justification for that is the greater additional coverage that the furthest nodes have. In eSBR the vehicles send two types of messages, warning and normal messages. The warning messages are the ones that contain information about a certain event and those are given a highest priority at the MAC level. The normal messages are periodic beacons which the vehicles exchange to get information about their neighboring vehicles' speed, position, etc. With the beacons, every vehicle is able to maintain a list of all of its neighbors. Once an event happens, the vehicle that initiates the dissemination will broadcast a warning message. The other nodes that receive this packet will rebroadcast the message only if: the message is not a duplicate, the distance between the sender and the receiver is greater than a certain threshold and if the sender and the receiver node are on different streets. With these conditions the authors aim to choose forwarders that are far and on a different street. Being far from the previous forwarder increases the additional coverage of the broadcast. On the other hand, being on a different street helps to overcome the signal degradation caused by the obstacles. For example, when a vehicle broadcasts a packet, the other nodes that are on the same street are more likely to receive the message than the ones that are on the other streets because of the obstacles that are usually separating the streets. The main drawback of this protocol is the frequent beacon messages that it uses. Many of those beacons are redundant and overhead packets which waste and saturate the network and waste its bandwidth.

2.1.1.3 Data dissemination in urban vehicular ad hoc networks with diverse traffic conditions

The authors in [23] have also proposed a protocol for data dissemination in urban scenarios named *HyDiAck*. The protocol is composed of two components. The first one is a dissemination mechanism that will spread the data through the dissemination region. The second component is a store-carry-forward mechanism that helps to connect the intermittently connected VANET. The details of the dissemination scheme are as follows. Once a vehicle receives the event packet it calculates a waiting time before it retransmits. The vehicles with a shorter retransmission time will broadcast sooner and cancel the timer of the other vehicles that have larger retransmission timer. The waiting time is determined according to the following equations:

$$T_{S_{ij}} = S_{ij} \times t \tag{2.3}$$

$$S_{ij} = \begin{cases} [N_s \times (1 - [\frac{min(D_{ij},R)}{R}])], & if \quad in \quad forwarding \quad zone \\ [N_s \times (2 - [\frac{min(D_{ij},R)}{R}])], & otherwise \end{cases} \tag{2.4}$$

In Equation 2.3 $T_{S_{ij}}$ is the total waiting time and t is a preset minimum delay. S_{ij} is calculated as shown in Equation 2.4.

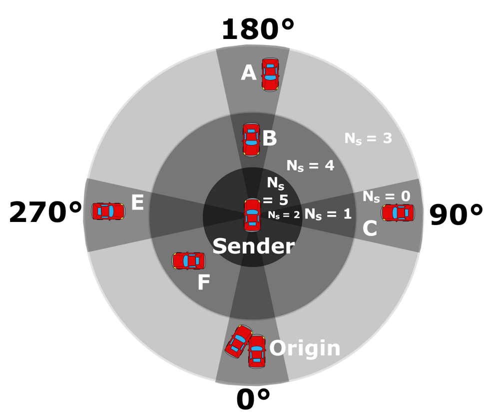


Figure 2.1: HyDiAck's Forwarding Zone

Furthermore, the value of N_s is determined as shown in Figure 2.1. As can be seen, the authors of this paper have defined the zones of 0°, 90°, 180° and 270° to be preferred zones for the next forwarder. With that they give forwarding priority to the nodes inside these areas. More information about the exact angle determination can be found in the aforementioned paper. Later on, despite the preferred forwarding zones, the authors split the transmission range of a sender vehicle into three different zones. The closest zone is the one that is given the lowest forwarding priority. The furthest zone is the one with a highest priority. Because of that the value of N_s represents a combination for these two types of zones. For example, in Figure 2.1, the N_s value for vehicle 'C' is 0 because it is in the furthest preferred forwarding zone. With the value of 0, the waiting time of vehicle 'C' according to Equation 2.4 will be lower. In the same Figure, the N_s value of vehicle 'B' is 1 and the value of vehicle 'F', which is outside of the preferred forwarding zone, is 4. Moreover, D_{ij} is the euclidean distance between the sender and the receiver and R is the transmission range of the DSRC radio of the vehicles. The ratio of the distance between the vehicles and the transmission range is subtracted from 1 or 2 depending on whether the vehicle is inside the preferred forwarding zones or not. In the same fashion it is determined the $T_{S_{ij}}$ rebroadcast waiting time. Furthermore, the store-carry-forward mechanism of the HyDiAck protocol works as follows. Once a vehicle receives a message, it places its ID into a list. After that, the vehicle broadcasts periodic beacon messages containing all of the message IDs that it has previously received. The beaconing is stopped if the vehicles leave the defined dissemination zone or if the lifetime of the message expires. Other nodes receive these beacons and if they find a message ID that they hold, but the sender of the beacon does not, they will broadcast this message after a waiting time computed as in Equation 2.3. However, in this case the waiting time is calculated as all of the nodes are into a preferred forwarding zone. As the authors mention in the paper, this mechanism is mostly used for sparse scenarios in which the number of vehicles is low, and that is why the waiting time should be smaller. The disadvantage of using this protocol comes from its predefined preferred forwarding areas which are set for vehicles operating in urban grid scenarios. For a real world scenarios, where the street composition is not always regular and the obstacles cause a huge signal degradation, those preferred zones would not always apply. Also, in the store-carry-forward mode of the protocol, the vehicles would produce a huge amount of redundant messages.

2.1.2 Data Dissemination Protocols for Highway Scenarios

2.1.2.1 A directional data dissemination protocol for vehicular environments

The authors in [32] are proposing a V2V protocol in a work named *A directional data dissemination protocol for vehicular environments* that can operate on a highway only. They claim that for the eventual urban operation the protocol would require spatial knowledge with a map integration for the means of the streets composition. Obviously, the irregular street topology and the curvy roads are the limitation that cause a problem. The protocol itself uses the moving direction of the vehicles as a main parameter for deciding the next relay node. Moreover, the authors make use of the *slotted1-persistence* scheme, which initial work is presented in [47]. Briefly, Slotted1-persistence is a synchronization algorithm which assigns rebroadcast time slots to the vehicles according to their distance from the sender of the information. Therefore, the most distant vehicle will transmit earlier and cancel the other scheduled data transmission. Furthermore, the authors modify this idea in order to optimize it specifically for highway environments. They also propose a store-carry-forward mechanism to achieve better delivery ratio in cases when the VANET is intermittently connected. The name of the proposed protocol is *Simple and Robust Dissemination protocol (SRD)*. The broadcast suppression mechanism works in the following fashion. Once a vehicle receives an event packet it calculates its retransmission waiting time according to the following equation:

$$T_{S_{ij}} = S_{ij} \times st \tag{2.5}$$

$$S_{ij} = \begin{cases} [NS \times (1 - [\frac{min(D_{ij,R})}{R}])], & if \quad v_{dir} \neq hp_{dir} \\ [NS \times (2 - [\frac{min(D_{ij},R)}{R}])], & v_{dir} = hp_{dir}, \end{cases} \tag{2.6}$$

where $T_{S_{ij}}$ is the total retransmission waiting time. st in Equation 2.5 is the maximum retransmission waiting time which should include the propagation and channel switch delay. The value for S_{ij} in Equation 2.5 is calculated as shown in Equation 2.6. The authors of the paper have divided the transmission range into high and low priority zones. The high priority zone is the one where the vehicles move in opposite direction from the sender. According to the mentioned equation, the vehicles in a high priority direction are given shorter retransmission times. The value of NS in the same equation represents the time slot number of the vehicle. More information about determining the time slot number of the nodes can be found in [32]. Moreover, D_{ij} is the distance between the sender and the receiver of the message. After calculating the waiting time according to the above mentioned equations, a vehicle will forward the event packet after the time expires. The vehicles with shorter retransmission times will broadcast sooner and cancel the timers of the others. Furthermore, after receiving a message the vehicles start beaconing a packet which holds information about the events' information that the vehicle has stored. When the other nodes get this packet and find an event information that they hold, but the sender of the beacon does not, they will broadcast this information in order to inform the uninformed node. Essentially, this is the store-carry-forward mechanism of the SRD protocol. As mentioned, it is used to recover the dissemination when the network is sparse or intermittently connected. Because of that, the dissemination equations are giving priority to the vehicles in the opposite directions to disseminate the data. Although proposing a scheme for lowering the number of beacons, this protocol will still consume a lot of overhead packets because of the periodic beacons. In fact, this is one of its main drawbacks. Also, its operation assumes just the highway environment which prevents it from urban scenario operation.

2.1.2.2 Data dissemination in highway scenarios using car-to-car communication

In [1] the authors propose a data dissemination protocol for highway VANETs called ATENA. When the vehicles receive an event packet for a first time they calculate their waiting time before the forwarding of the packet occurs. The nodes with a shortest waiting time broadcast sooner than the others and cancel their timers. The processing of the packet occurs as shown in Algorithm 2.1. As can be seen, once a receiver vehicle gets the event packet, it calculates its distance to the previous sender of the packet. In the first hop dissemination the sender of the packet will be the origin or the Source vehicle. Then, the default waiting delay is calculated as shown in the mentioned algorithm. If the receiver vehicle is inside the preferred zone, a random delay between 0s and 0.01s is added to the default delay. On the other hand, if the receiver vehicle is not it the preferred zone, a random delay between 0.02s and 0.05s is added to the default delay. Then, the vehicle schedules its retransmission after this delay expires. Meanwhile, if the vehicle receives the same message from another vehicle, that means that the other vehicle has calculated smaller delay and

Algorithm 2.1 ATENA ALGORITHM

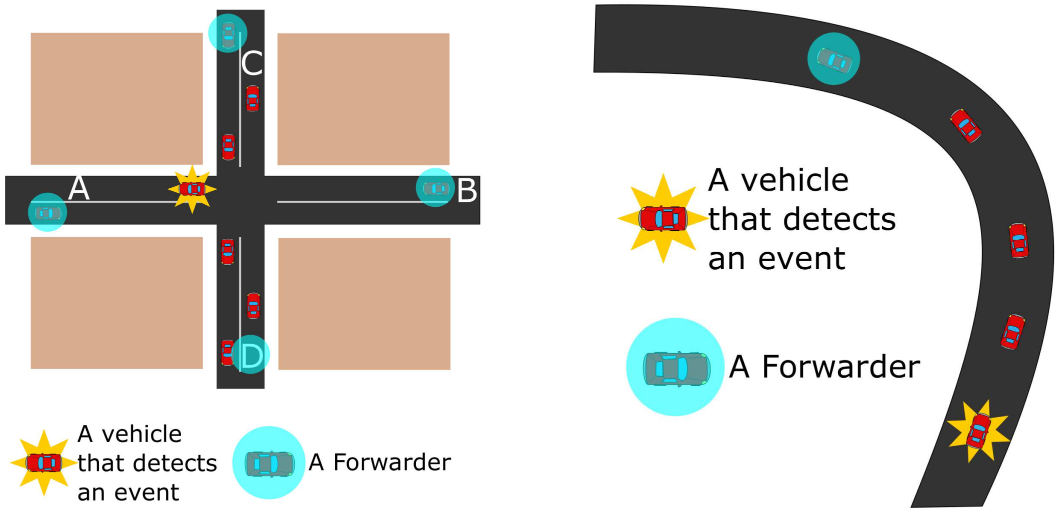
Inputs:
$Source$ - The vehicle that starts the dissemination
(s_x, s_y) - Coordinates of the sender vehicle
(r_x, r_y) - Coordinates of the receiver vehicle
if Message received for a first time **then**
  $distToSender = \sqrt{(s_x - r_x)^2 + (s_y - r_y)^2}$;
  $defaultDelay = 0.01 \times (\frac{distToSender}{communicationRadius})$;
  if Inside zone of preference **then**
    $Delay = defaultDelay + random(0, 0.01)$; {Waiting Time for priority 1}
  else
    $Delay = defaultDelay + random(0.02, 0.05)$; {Waiting Time for priority 2}
  end if
  $r.ScheduleMessage(Delay)$; {The vehicle r schedules the transmission.}
else
  if Scheduled message **then**
    if $Dist(r, Source) < Dist(s, Source)$ **then**
      Cancel the scheduled message
    end if
  end if
  Discards the received message
end if

disseminated the packet. In this case, the receiver vehicle compares its distance to the source and the distance of the vehicle that sent the duplicate packet to the source. If the distance of the vehicle that sent the duplicate packet to the source is greater, than the receiver vehicle cancels its timer and does not broadcast the message. At the end of the paper, the authors show the results of the simulation experiments they did. According to those, the proposed protocols shows satisfactory delivery ratio, while consuming more packets than the other compared protocols.

2.1.3 Data Dissemination Protocols for Urban and Highway Scenarios

2.1.3.1 An efficient road-based directional broadcast protocol for urban VANETs

In [42] the authors are proposing an algorithm that operates in both urban and highway scenarios. *Efficient Road-based Directional broadcast protocol for urban scenarios or ERD*, is the name of the protocol that they propose. Each vehicle emits beacons and updates a neighbors table constantly. Using this neighbors table, each node chooses a forwarding node that will further rebroadcast the message in a case of an event which has taken place. The election is done by evaluating the road IDs, the distance and the relevant position of the neighbors. The relevant position of the neighbors to the sender vehicle is calculated by using the coordinates of both vehicles. Finally, the table should be summed up with one vehicle driving on every different road inside the current node transmission range. Also, the chosen vehicle is the one that has the greatest distance from the one that performs the election. Nodes going forward and backward of the sender are assigned as forwarders too, because they will help to spread the data in the front and in the back of the sender vehicle. Furthermore, the algorithm has a special mode of operation when the neighbors are at an intersection or on a curvy road. This logic is justified by the fact that the nodes currently residing on intersection have a greater transmission potential then the other vehicles, because they can spread the signal to more than one street without encountering obstacles like walls, buildings, etc. An example of the intersection mode of operation of the protocol is shown in Figure 2.2a. As can be seen, once the sender vehicle is near an intersection it selects the furthers vehicles in each street segment connected by the intersection as forwarding vehicles. The street directions are determined by the mentioned relevant position of neighboring vehicles. Moreover, ERD also considers the single direction curvy roads as shown in Figure 2.2b. By using the neighbors relevant positions and their angle of movement, the sender can determine if it should operate according to the single direction road mode. In this case, the sender is not choosing a different forwarder in all of the moving directions. Instead, only the furthest node is selected to forward the packet. Furthermore, when the protocol operates on a highway, the sender of the message is also selecting just the furthest nodes that have not received the message before to act as forwarding vehicles.



(a) ERD's intersection mode of operation

(b) ERD's curvy road mode of operation

Figure 2.2: ERD - Operational Examples

2.1.3.2 A scalable data dissemination protocol for both highway and urban vehicular environments

The authors in [33] propose a scheme called *Adaptive multi-directional data dissemination (AMD)*, which divides the transmission area around the sender in virtual sectors according to the geographical area where the vehicle is. The protocol is supposed to work in both urban and highway scenarios. Hence, while operating at an intersection there will be four sectors, and while operating on a straight road or on a highway the transmission area will be divided onto two virtual sectors. For the purpose of maintaining a neighborhood table, the nodes periodically send beacon messages. With them they update the other vehicles with operational information about each other. Later on, all of the vehicles are assigned a retransmission timer based on their distance. The most distant one will have the shortest and the node that is closest to the sender will have the longest retransmission delay. Also, in each of the sectors the most distant vehicles will have similar timers, representing the first tier nodes. Then, the ones closer than them will be the second tier and so on. With this, the risk of a chosen forwarding node not retransmitting the data is minimized. More details about the sectors and the tiers definitions can be found in the mentioned paper. The following equations are used to calculate the forwarding waiting time:

$$T_{S_{ij}} = st \times ([\frac{S_{ij}+1}{ts_d}] - 1) + AD_{ij} \tag{2.7}$$

$$AD_{ij} = d \times (S_{ij} \quad mod \quad ts_d) \tag{2.8}$$

In Equation 2.7 $T_{S_{ij}}$ is the total waiting time. st is the maximum waiting time which should be composed of the medium access delay, the transmission delay, and the propagation delay. S_{ij} is the spiral sector number where the receiver is. In general, the higher priority is given to the furthest nodes in each different directional sector. Other details can be found in the mentioned paper. ts_d is the number of vehicles that are allowed to retransmit in a given time slot. With the usage of this parameter the authors aim to control the density of the vehicles transmitting in a single time slot. One of the benefits of using it is reducing of the collision messages. The calculation of the value of AD_{ij} is shown in Equation 2.8. It represents an additional delay that is added to the forwarding waiting timer. Its purpose is to further tackle the collisions occurrence during the data dissemination. The parameter d in that equation is another delay which is smaller than the st maximum waiting time in order not to overlap with it. The protocol operates in a similar fashion for highway scenarios. One modification is the classification of the vehicles into sectors. While operating on a highway, the sender divides the vehicles into two sectors because of the simple highway topology. Moreover, one of the disadvantages of this protocol is that it uses many redundant beacon messages.

2.1.3.3 Drive: An efficient and robust data dissemination protocol for highway and urban vehicular ad hoc networks

In [46], a V2V data dissemination protocol called DRIVE is proposed. The main goal of the work is to reduce the number of forwarding messages while maintaining a satisfactory delivery ratio. The modes of operation include urban and highway scenarios. Once the data is sent from the sender, the receivers check whether they are inside a *Sweet Spot*. The *Sweet Spot* represents a sub-area of the whole transmission range of the sender. There are four sub-areas, where the first one is around 90 degrees and the others are around 180, 270 and 360 degrees of the sender. A threshold of $+-$ 12.5 degrees is applied to these angles. If the receiver is currently inside the Sweet Spots it automatically rebroadcasts the data. If there are no vehicles inside the Sweet Spots, other nodes are assigned a retransmission. Their synchronization is solved by using timers. When a node is closer to these four spots, directly proportional, it is assigned a shorter timer. Inversely proportional, if the node is far from the chosen spots, their retransmission timer is greater. Once the first node rebroadcasts, and the others receive this duplicate message, their retransmission timer is canceled. An example of the sweet spots positioning is shown in Figure 2.3. For example, in the

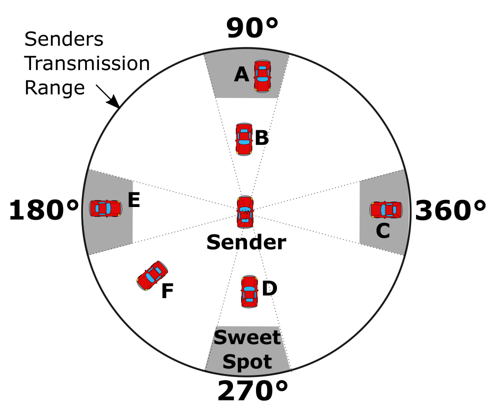


Figure 2.3: DRIVE's Sweet Spots

Algorithm 2.2 DRIVE Waiting Time calculation Algorithm

Inputs:
(x_s, y_s) - Coordinates of the sender vehicle
(x_r, y_r) - Coordinates of the receiver vehicle
$angle = atan2(y_s - y_r, x_s - x_r)$
$distToSender = \sqrt{(x_s - x_r)^2 + (y_s - y_r)^2}$;
$defaultDelay = 0.01 \times (\frac{distToSender}{CommunicationRadius})$
if $((angle \geq 67.5° and\, angle \leq 112.5°) \,||\, (angle \geq 157.5° and\, angle \leq 202.5°) \,||\, (angle \geq 247.5° and\, angle \leq 292.5°) \,||\, (angle \leq 22.5° and\, angle \geq 237.5°))$ **then**
    $Delay = defaultDelay + random(0, 0.01)$; {Waiting time when the vehicle is inside the Sweet Spots}
else
    $Delay = defaultDelay + random(0.02, 0.05)$; {Waiting time when the vehicle is outside of the Sweet Spots}
end if

same figure the vehicles A, C and E will be assigned shorter retransmission timers. On the other hand, B, D and F should retransmit later. Therefore, their timers are canceled either by A, C or E. The actual waiting time calculation algorithm is shown in Algorithm 2.2. The protocol operates with the same mechanism on highways too. The protocol also includes a store-carry and forward mechanism to address the issue when the VANET is intermittently connected and the dissemination cannot be continued till the end of the dissemination zone. Moreover, the main drawback of this protocol is that it is suitable mostly for regular street composition like the grid topology, but not for the irregular ones , as fork or curvy streets topology.

2.1.3.4 TrAD: Traffic Adaptive Data Dissemination Protocol for Both Urban and Highway VANETs

Another work called *Traffic Adaptive Data Dissemination Protocol for Both Urban and Highway VANETs (TrAD)* is presented in [39]. It aims to minimize the retransmitted packets, but at the same time to chose a node that will store the data and rebroadcast it after some time in another area that is not covered by the current transmission. This mechanism is known as Store-Carry-Forward (SCF). SCF simply elects a node that has a potential to escape from the current zone and rebroadcast the packet elsewhere. In order to reduce the number of rebroadcasts this protocol requires periodical beaconing and updating a neighborhood table with operational information about each other. Furthermore, the sender of the information groups its neighbors onto ten degrees directional clusters. For the vehicles in each cluster the sender calculates a value based on a predefined formula. The vehicle with a highest score continues the broadcast in each of the sectors. The mentioned formula firstly includes the potential additional coverage of the forwarder node, which counts the number of neighbors of the neighbors. Secondly, the air distance between the nodes is calculated. As a third parameter in the formula, the authors include the channel usage of the local node, which means whether the current transmission channel of the node is used or not. The advantage of this protocol would be its competence for irregular road topologies and for scenarios where the sender is at an intersection. However, the drawback of this work would be the number of false positives that it could generate while operating on wider roads.

2.2 Hovering Information/Floating Content in VANETs and MANETs

In this section we are going to classify and discuss some of the existing works on keeping an event alive. As mentioned in Chapter 1 of this thesis, the availability of an event over time in a bounded area is an issue which has been addressed under different topics in the VANETs literature. Because the VANETs are a sub-group of the MANETs, and those two have many common characteristics, in this section we are also going to discuss some of the protocols for the MANETs. It can be also noted that the operational basis of the existing Hovering Information and Floating Content protocols for VANETs is very similar to the one of the MANETs' protocols. In order to present them better, in this thesis we are classifying some of the existing literature in this area into three different subsections. In the first one we are discussing some of the works which have indirectly addressed the keeping of the event alive and as a one part of the whole solution. Then, we are presenting the works where the authors have referred to the problem as a Floating Content. Finally, the Hovering Information protocols will be presented in the last subsection. Also, in the remainder of this thesis we are going to refer to the availability over time topic as a Hovering Information.

2.2.1 Hovering Information/Floating Content as a segment of other protocols

2.2.1.1 Abiding geocast: time - stable geocast for ad hoc networks

In [24] the authors present a work named Abiding Geocast. In general, it is a routing protocol for VANETs that has a goal to efficiently deliver data from one place to its destination. In order to do that, it makes use of an unicast communication. Once the information is delivered to the destination region the communication switches to broadcast and the data is being delivered to all nodes in the region. However, in order to keep the data within that region and make it available to the new nodes that will enter there, the authors of this paper are describing three different approaches. For the first one they assume a server is present in the destination region. Therefore, once the information is being delivered in the region the server will keep it and broadcast it periodically or by request from the nodes that are passing by. The second approach does not assume a central server in the region. Instead, once the data is delivered into the region one of the nodes is elected to act as a server until it goes away from the region. Then, it will pass the information to another vehicle, and so on. The nodes can be elected for this role if they are more likely to spend more time in the region than the others. This is done by evaluating their position and moving speed. A node that is closer to the center of the region and has low speed has more probability to stay longer in the region than the others. Following this logic the protocol is electing the nodes that will store and make the information available to the others. Finally, in the third approach the authors do not assume the central server either. In this case, once the data is being delivered in the region, it is broadcasted within it and the information is being stored by all of that will receive it. Then, using periodic beacon messages, each node is monitoring its one-hop neighbor vehicle. When an uninformed neighbor is detected, the information is passed to it. The same procedure is repeated for the specified duration of the data longevity.

2.2.1.2 Information-centric opportunistic data dissemination in vehicular ad hoc networks

M. A. Leal et al. in [19] have initially proposed a data dissemination protocol for VANETs, but have addressed and proposed a solution for how to maintain the disseminated event alive within the region. In order to tackle the broadcast storm problem caused by the increased number of retransmission packets generated when Flooding protocol [11] is used, they propose a probabilistic protocol. A vehicle that will receive a data packet will retransmit it with a certain probability based on the distance of the receiver from the event and the density of the neighboring vehicles. The event coordinates are extracted from the received packet and the current coordinates of the vehicle are determined with using the GPS. Therefore, the distance from the event is calculated. A vehicle that is far away from the event has higher likelihood to retransmit the packet. The next parameter, the neighborhood density, is determined by exchanging periodic beacons. With receiving the beacons, every vehicle builds a list and knows its first hop neighbors. If the number of neighboring vehicles is less than a pre-specified threshold the likelihood of retransmission is higher. Finally, the combination of these two values provides the final rebroadcasting probability. Furthermore, in order to keep the event alive over time, the authors of this paper are proposing two different schemes. The first one is called a *periodical mode* and all of the vehicles are initially in this mode. All of them will choose a random time and broadcast the data packet once the timer is reached. However, if multiple vehicles trigger the broadcast at almost the same time and the vehicles density is high, many broadcast storms may arise. To solve this problem, once the vehicle with the earliest timer broadcasts it will cancel the timers of the others. Moreover, the authors do not specify any thresholds for this timers since they would depend on the vehicles arrival rate which may vary. Moreover, if the number of neighbors is low the vehicles switch to the second mode of operation i.e. *Store and Forward*. Once in this mode, a vehicle will store the data and rebroadcast it at a later time if a suitable node is encountered. That means that the information should not be expired and the encountered node should be within area of interest or maybe outside of the area of interest, but moving towards the interest zone.

2.2.2 Floating Content protocols

2.2.2.1 When does content float? Characterizing availability of anchored information in opportunistic content sharing

E. Hyytiä et al. in [13] give an overview and an analytical model for the Floating content topic for MANETs in general. They define a *anchor center*, which is the place where the event has happened and is represented by its coordinates. The area around the anchor center, which is relevant for the particular information and where the content should be available, is called *anchor zone* and is defined by a specific radius r. Therefore, once the content is created it is defined with its anchor center, the anchor radius, and the availability radius a, which is the last point by which the content could be replicated. Those radii are shown in Figure 2.4. The black nodes in the figure represent the nodes that are replicating the information, and the empty ones are those which are not replicating the data. The replication likelihood is determined by using a decreasing probabilistic function and as shown in Equation 2.9. As can be noticed in Figure 2.4, all of the nodes inside the anchor zone will replicate the available content, which is not the case for all of the nodes inside the availability region or outside of it.

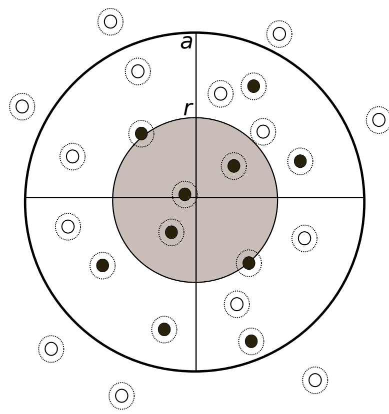


Figure 2.4: An anchor zone of an item

Using periodic beacon messages the nodes holding the information become aware of their uninformed neighbors. Afterwards, they broadcast the information and transfer it to the uninformed nodes. The probability of replication is defined by the following function:

$$p = \begin{cases} 1, & \text{if} \quad h \le r \\ R(h), & Otherwise \end{cases} \tag{2.9}$$

where h is the distance of the informed node from the anchor center and r is the anchor zone radius. $R(h)$ is a decreasing probabilistic step function which provides the broadcast probability outside the anchor zone. Its purpose is to help maintain the information availability in a sparse and intermittently connected network where the content may travel from the outside zone back within the boundaries. However, a concrete probabilistic function has not been defined in this paper.

Since this paper is about MANETs, the authors assume that the nodes have limited buffer capacity and because of that they define a deletion function too. This function is opposite of the replication one. Therefore, the nodes inside the anchor zone will delete the information with a probability of 0, and the nodes inside the availability region will use the distance based probabilistic step function to determine whether they should delete certain information or not. However, the probability for deletion is 1 when a node is outside of the availability region.

Furthermore, this paper presents detailed analytical models for the nodes movement. This model is done with the assumption that a Manhattan road network with its straight roads and regular intersections are used. Moreover, the authors also assume a Random Waypoint model where the nodes movement is unpredictable. These analytical models are supported by simulation experiments.

2.2.2.2 Floating content: Information sharing in urban areas

The authors in [29] present a *Floating Content* work for urban environments. The communication among the devices is assumed to be facilitated by the bluetooth technology. Similarly as in the previously explained work in [13], the coordinates where an item or information is created are called the *Anchor Center*. The area around the *Anchor Center*, defined as *Anchor Zone*, is the area where the content is replicated and is supposed to be maintained alive. The *Availability Zone* is the zone between the *Anchor Zone* and the specified *Availability Radius*. The content in this zone will not be replicated for sure, but with a certain decreasing probabilistic function. Furthermore, this zone serves as a bridge for the content to travel from one area of the

Anchor Zone to another, if the nodes inside are intermittently connected. Moreover, the floating content protocol is described in four stages. In the first one the nodes periodically send beacon messages to discover their peers. The second stage is the one where the node which discovered a new peer sends a list of available content items that it has stored in a form of a vector. In the third stage the receiver neighbor checks what kind of content the sender can offer and requests the ones for which it is interested. The authors also propose replication policies by which the requested content items will be transferred. The mentioned policies include:

- *FIFO (First In Firts Out.)* FIFO is a policy where the items that were created first will be transferred first.
- *RND (Random.)* Using the RND policy the sender will randomly transfer the items regardless of their creation time or anything else.
- *SAF (Smallest Area First.)* For the SAF policy the sender node considers the size of the anchor zone of the item A_m. The contents with a smaller zone will have the transmission priority. The anchor zone's size is defined by:

$$A_m = a_m, \tag{2.10}$$

  where a_m is the availability radius of the message.
- *SVF (Smallest Volume First.)* According to this policy the transfer of packets will start with the ones whose volume is smaller than the other packets. It is a combination of SAF and the size of the item. The floating content volume is calculated as:

$$V_m = A_m \times s(I_m), \tag{2.11}$$

where A_m is the anchor zone size and $s(I_m)$ is the size of the message body of an item I_m.

- *STF (Smallest Total resource consumption First.)* According to the STF replication policy the items that consume less resources will be transferred first. The calculation of the total resource usage of an item is calculated as:

$$A_m \times s(I_m) \times T_m, \tag{2.12}$$

where A_m is the anchor zone size, $s(I_m)$ is the size of the message body of an item I_m and T_m is the TTL of the item.

Finally, once the requested messages and the replication policy are received, the transfer of the requested items will begin. The transfer is done until the messages are fully exchanged or the nodes are not within each other‘s transmission range. In the later case, the messages that are not completely transmitted are discarded. If the messages are fully transferred the protocol restarts from the beginning. That represents the fourth stage of the floating content protocol. The whole procedure is done only if the nodes are within the anchor zone or according to the probability function inside the availability region. The deletion function is the opposite of the replication one. Later in the paper, the authors present a *Non-spatial Black-box* analytical model for the nodes movement and a simulation experiments analysis where they vary the anchor zone size, node‘s density, replication polices, etc.

2.2.3 Hovering Information protocols

2.2.3.1 Hovering Information - Self-Organizing Information that Finds its Own Storage

In [10] A.A.V. Castro et al. present their work on Hovering Information. It is a book chapter and they are defining the state of the art of the Hovering Information concept. At first, they go through the motivation and some applications for this kind of protocols. Later on, they define the Hovering Information concept with defining the messages packets‘ fields, coordinates, distances, areas, etc. Similarly as in the above explained Floating content concept, the Hovering information is characterized with an *Anchor Center* which is the coordinates of the point where the content item was created and an *Anchor Zone*, which is defined by an anchor zone radius. However, in this case the anchor zone is divided in two sub-areas i.e. *Safe Zone* and *Risk Zone*, which was not a case in the Floating Content works. The Safe zone is defined with a smaller radius than the Risk Zone. Replication of information does not occur in the Safe Zone, which means that a piece of information can safely stay at a node that is inside the Safe Zone. On the other hand, once a node is within the Risk Zone it should actively seek for other nodes to replicate the information. Later on, the authors specify two replication algorithms, Broadcast-based and Attractor-based algorithm. Their detailed operation will be explained later in this section. A zone equivalent to the *Availability Zone* in the Floating Content works, here is named as *Relevant Zone*. This zone is assumed to serve for the purposes of bridging the intermittently connected areas in the Anchor Zone. It is the zone where the hovering information seeks survivability, but the replication will not occur for sure. This is done in order to avoid the flooding of the data. Finally, the space outside of the *Relevant Zone* is called *Irrelevant Zone* and a piece of information in this zone can disappear without seeking replication. All of the above discussed zones are illustrated in Figure 2.5.

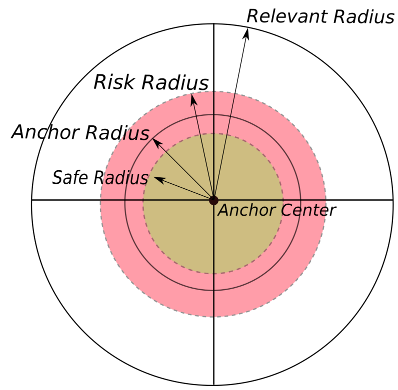
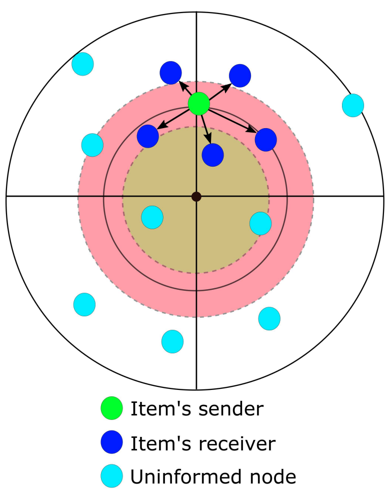
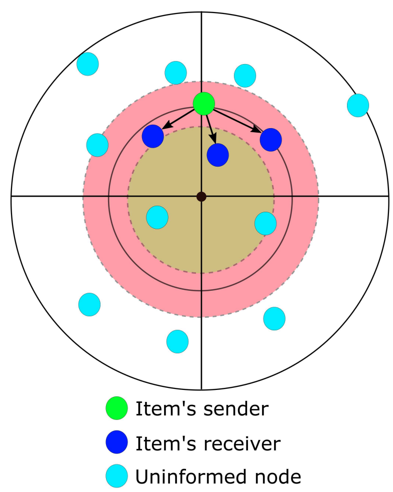


Figure 2.5: A hovering zone of an item

As mention above, in this work the authors specify two replication algorithms used when a piece of hovering information is within the Risk Zone and is seeking for a replication. The first proposed algorithm is the Broadcast-based algorithm. It works in a way that when the node that is in the Risk Zone discovers its neighbors and it replicates the content to all of them, regardless of their position. An illustration of the Broadcast-based algorithm can be seen in Figure 2.6a.



(a) Broadcast-based replication algorithm



(b) Attractor point replication algorithm (k = 3)

Figure 2.6: Broadcast-based and Attractor Point algorithms

On the other hand, the second proposed algorithm, Attractor-based algorithm will replicate the hovering information just to a pre-specified k number of neighbors, which are the closest to the Anchor center. An example can be seen in Figure 2.6b, for a k value of 3. Furthermore, the value of k can vary according to the nodes density, type of hovering information, size of the Anchor Zone, etc.

Finally, after describing the two replication algorithms, the authors propose two caching techniques which will help the nodes to decide which content to delete from their memory once the buffer is full. The first caching technique is a *Location-based Caching*. A node with a full memory will delete a content which is less relevant according to the following formula:

$$relevance = \alpha \times area + \beta \times proximity, \tag{2.13}$$

where α and β are weighting coefficients between 0 and 1 and $\alpha + \beta = 1$. In this case, the authors specify $alpha = 0.8$ and $\beta = 0.2$. The value of $area$ is the normalized estimation of the overlapping area of the current node's communication range and the item's Anchor Zone. $Proximity$ is the distance between the current node and the item's Anchor Center. A relevance value is computed for all of the stored items before receiving a new replica and once the buffer of the node is full. Then, the least relevant replica is deleted. The second caching technique is the *Generation-based Caching*. The generation of a replica is a number which represents how many times the item was previously replicated. For example, after an item is created its generation number is set to 0. The first node or the first group of nodes that will receive this replica will change its generation number to 1, and so on. Therefore, the generation number serves as an indicator of how many times an item has been replicated. Having a full buffer, a node will delete a replica with a greatest generation number. The likelihood that another node within the Anchor Zone has the same replica is higher if its generation number is greater.

2.2.3.2 Information Hovering in Vehicular Ad-Hoc Networks

The authors in [50] present a Hovering Information protocol for VANETs. The general operation of the proposed protocol is similar as in the previously explained Floating Content and Hovering Information protocols. The vehicles exchange periodic beacon messages. With them they discover their neighbors and have a list of them together with their interest or subscription in a certain content. If a node finds an uninformed neighbor in its neighbors‘ list for a content that it has previously stored, this node will broadcast the information. However, this iteration over the neighbors‘ list occurs according to the predefined scanning interval which in the case of this paper is 1 second. Moreover, the protocol that is proposed in this paper operates by assumption that all of the nodes have GPS and can determine their position. Furthermore, as shown in Figure 2.4, the region around the item center or Anchor Center is defined with an Anchor Zone radius and an Availability zone with Availability radius. Also, in this paper the Anchor Zone is called Hovering zone. When a node which is inside the Hovering Zone encounters another uninformed vehicle it will replicate the content with a probability of 1. If an informed vehicle within the Availability Zone encounters another uninformed node it will replicate the content according to a decreasing probabilistic function. In this paper the authors specify two probabilistic functions for this purpose. The first one is a decreasing probabilistic step function:

$$
p = \begin{cases} 0.80, & \text{if} \quad d \leq (r/4) \\ 0.60, & \text{if} \quad (r/4) < d \leq (r/2) \\ 0.40, & \text{if} \quad (r/2) < d <\leq (r \times 3/4) \\ 0.20, & \text{if} \quad (r \times 3/4) < d \leq (r) \\ 0, & \text{if} \quad d > (r), \end{cases} \tag{2.14}
$$

where d is the distance of the receiver vehicle from the Hovering Zone and r is the vehicle‘s transmission range.

The second proposed probabilistic function is a Gaussian-like function:

$$
p = e^{-d^2/2(2r)^2} \tag{2.15}
$$

Later on in the paper the authors present results of simulation experiments done for two variations of their protocol and using the above shown equations 2.14 and 2.15. Also, they have compared these variations with a blind flooding protocol where the vehicles inside the availability zone will replicate the item content regardless of the receivers‘ distance from the Hovering area.

2.2.4 Comparison of the discussed protocols

The main goal of the above explained Hovering Information and Floating Content protocols, as well as some parts of the routing and data dissemination protocols, is very similar. All of them are proposing solutions that will keep an event or content alive and maintain its availability over some time in the specified region. However, in order to distinguish better between their features, some of their differences or common features are highlighted in this section of the thesis. For this purpose we have created a table shown in Table 2.1. Because of the space limitations we have used abbreviations for the description of the protocols‘ features shown in the first row of the table. A check mark in the *DDP (Data Dissemination Protocol)* field indicates that the protocol is of that kind. *DRP (Data Routing Protocol)* is the second type of protocol in the table. These two fields will distinguish the papers explained in the section 2.2.1 of this paper. *FCP (Floating Content Protocol)* is the field for the protocols of section 2.2.2 of this paper. *HIP (Hovering Information Protocol)* field will have a check mark if the mentioned protocol appears under the Hovering Information name. The next field is *Positioning System*. All of the protocols discussed here function by using some kind of positioning system at the node‘s side. In some cases that is GPS or other trilateration methods for estimating the position of the nodes. The field *Uses Beacons* indicates whether the protocol operation is based on a constant and periodic exchange of short beacon messages. All of the discussed protocols do use beacons to facilitate their operation. The next two fields of the first row of the table are *For VANETs* and *For MANETs*. These two differentiate between the protocols designed for MANETs or VANETs. However, in some cases the authors of those protocols are not explicitly saying what kind of networks their work is intended for. In some of these cases we were trying to infer that from the simulations parameters of those papers. For example, if the speed of the nodes is above 10 meters per second that means that those nodes are some kind of vehicles. Therefore, that paper‘s contribution can address the rapid topology change challenge which is a case for in the VANETs. The same goes for the differentiation of the next two fields *Urban Scenario* and *Highway Scenario*.

Table 2.1: Comparison of protocols aiming to keep an event alive

Feature / Protocol Citation	[24]	[19]	[13]	[29]	[10]	[50]
DDP	✗	✓	✗	✗	✗	✗
DRP	✓	✗	✗	✗	✗	✗
FCP	✗	✗	✓	✓	✗	✗
HIP	✗	✗	✗	✗	✓	✓
Positioning System	✓	✓	✓	✓	✓	✓
Uses Beacons	✓	✓	✓	✓	✓	✓
For VANETs	✓	✓	✓	✓	✗	✓
For MANETs	✗	✗	✓	✓	✓	✗
Urban Scenario	✓	✗	✓	✓	✓	✓
Highway Scenario	✓	✓	✓	✗	✗	✓

Chapter 3

Proposed data dissemination and information hovering protocols

In this chapter we are going to present the details of the main contributions of this thesis. In section 3.1 we are going to discuss the *Delay Tolerant and Predictive Data Dissemination Protocol (DTP-DDP) for urban and highway VANETs.* In section 3.2 we are going to present the *Efficient Encounter-based Event Dissemination Protocol (E-BED) for Urban and Highway VANETs*, which is a modification of the protocol discussed in section 3.1. In order to provide an understandable flow, we are going to explain the whole protocol operation briefly again and focus on the modified parts. Finally, in section 3.3 we are going to present the details of the *Comprehensive and efficient Hovering Information Protocol (CHIP) for Urban and Highway VANETs.*

Moreover, in order to communicate with each other, we assume that all of the vehicles in the proposed protocols are in compliance with the DSRC technology, together with the WAVE communication standards. Later on, in order to successfully gather data for the proper protocol operation, we assume that a GPS (Global Positioning System) with embedded maps is available on each of the nodes. Some common terms used to clarify the operational details of the proposed protocols are:

- *Detector*: a vehicle that detects an event and starts the data dissemination.
- *Forwarder*: a vehicle that received the event packet and retransmits it shortly after to inform the other vehicles. In our protocols, only few nodes will be chosen as forwarders, based on their utility score.

3.1 Delay Tolerant and Predictive Data Dissemination Protocol (DTP-DDP) for urban and highway vehicular ad hoc networks (VANETs)

This section describes the operation of the proposed protocol. Its main goal is to reduce the number of rebroadcast messages, while achieving a satisfactory delivery ratio. Generally, that is done by reducing the number of vehicles that will further retransmit the information message, therefore choosing the ones that are supposed to be the most efficient. One of the main advantages of our approach is that the protocol itself is adaptive to the network density and can be used in both, urban and highway scenarios.

Moreover, after the detector of the event broadcasts the packet, it waits for the responses of the nodes that received this packet. After receiving the replies, the detector will select the most eligible vehicles to act as forwarders. Also, after the first hop, the forwarders of the information are collecting replies and selecting the next forwarders. The communication example, together with the packet's fields is shown in Figure 3.1. Moreover, the protocol operation could be split into three different states.

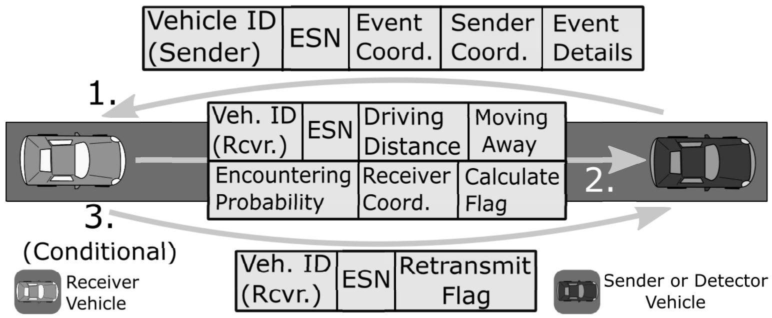


Figure 3.1: DTP-DDP - Communication Scenario Example

State I: Chronologically, the protocol operation starts with an event detection. Once the event is detected, the vehicle that registered the event broadcasts a message about it to the vehicles nearby. The vehicle with the yellow star in Figure 3.2 illustrates a detection of an event. The green circle line on the same figure is the radio coverage. The detector vehicle in this state will broadcast a packet with the following fields:

- *Vehicle ID.* Is unique identifier of the sender vehicle. Could be plate or engine number.

- *ESN.* Event Sequence Number. A random number generated at the moment of the event, used to distinguish different events.

- *Event Coordinates and Sender Coordinates.* Event and Sender coordinates are the same in the case of first hop dissemination. Later on, the sender coordinates are the coordinates of the forwarder node.

- *Event Details.* Can be event type, speed of the vehicle, etc.

This is the message number one in Figure 3.1. An Example scenario can be seen in Figure 3.2.

State II: At state two, the receiver of the event packet (Packet number one in Figure 3.1) firstly checks if the received message is a duplicate. The duplicates

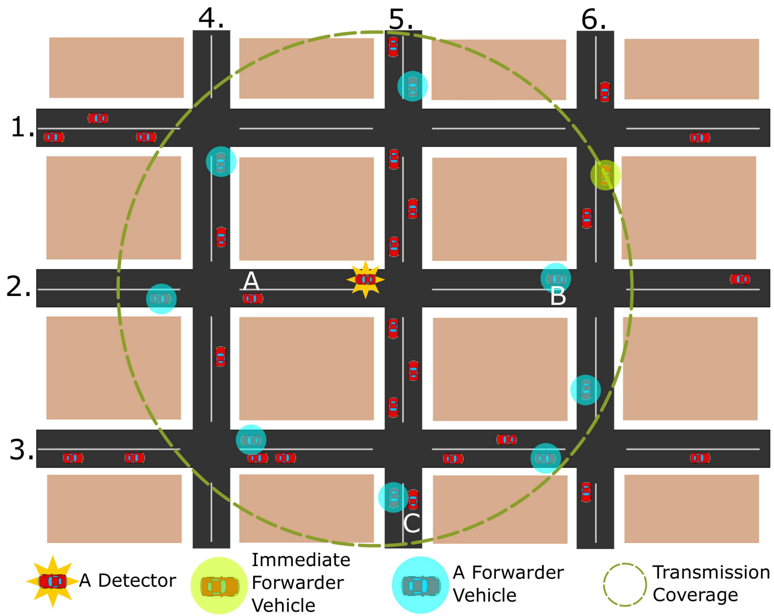


Figure 3.2: DTP-DDP - Urban Scenario Example

are simply discarded and the other messages are processed further. A non-duplicate packet will be checked if it was received with a receiving power of less than 12 percent of the receiving power threshold. This information about the receiving power and the sensitivity of the radio are fetched by the current communication device. These 12 percent mean that the vehicle is at the edge of the receiving boundary, which shows that it is either far away from the sender or there are other obstacles causing signal degradation. In this case, the receiver does not send any reply to the sender, because, most likely the reply packet will not be usable at that point. Later, the eventual response from the sender will not be able to reach this vehicle as well in case it is the one chosen for retransmission. According to our simulation experiments, a 12 percent threshold is enough to ensure that both endpoints will be capable of communicating for at least the next two messages that may occur. For that purpose we have done variations from 0% to 20%, and decided for current threshold. A lower value was causing high number of cases where vehicles that started the communication, were not able to finish it. On the other hand, the higher threshold was eliminating vehicles unnecessarily, even if they were able to finish the communication, and also was increasing the number of the rebroadcasting vehicles considered to be at the edge of the transmission range. Doing this check, the algorithm minimizes the number of false positives and false negatives. Thus, if the receiving power is less than the threshold, the vehicle that received the packet automatically rebroadcasts the event information. Later on, in the simulation results this step proves itself as really helpful for increasing the delivery ratio of the protocol. That situation can be justified by the fact that in most of the cases these are vehicles far from the sender, so their additional coverage is really high with minimum number of duplicate packets for the other nodes. However, because of the dynamic nature of VANETs, and also because of the different kind of obstacles, there might be cases where even beside the threshold check, the nodes drop the packet, being outside of their radio range.

On the other hand, if the receiving power is high enough, the receiver of the packet does the following three calculations and sends the results back to the sender.

- *Parameter I: Driving Distance.* The first parameter that the receiver of the information calculates is the driving distance to the event. Given the end point, which in this case would be the event/forwarder coordinates, the GPS is able to determine this variable.

- *Parameter II: Encountering Probability.* The second parameter calculated is the probability of the receiver encountering the event on its way. Here, the GPS provides the outgoing lanes that are connected to the current one. Then, the algorithm checks if one of them is the sender's‘ street name fetched by using the sender's coordinates as an input to the embedded maps. If the street name is not found the algorithm continues searching through the second tier of street names. After the third tier, the algorithm stops iterating. In our experiments, this practice has worked properly, and the third tier of outgoing streets is enough to determine the encountering probability considering the DSRC transmission range which is around 300m. Even if the protocol continues the search on the further street tiers, the encountering probability will be very low and it will not affect the final result. For example, in Figure 3.2 the encountering probability of vehicle 'A' to the event is $\frac{1}{1}$, since 'A' is already on the same street and moving towards the event. Vehicle's 'B' encountering probability is $\frac{1}{4}$, because the sender's street segment is one of the first tier outgoing streets of 'B'. Atthe same time, there are 4 possible street segments in the first tier of outgoing lanes. In this case we assume the U-turns are possible too. Vehicle's 'C' encountering probability is $\frac{1}{4\times4}$, because on its way to the event, 'C' should pass two junctions where each of them has four different options.

- *Parameter III: Moving Away Flag.* Finally, the third calculated parameter is whether the receiver vehicle is moving towards the event or not.

Besides the parameters, the receiver vehicle includes the following information into the reply message:

- *Vehicle ID.* The ID of the receiver vehicle.
- *ESN (Event Sequence Number.)* The same ESN as in the initial message. If there are multiple events in the same area, the vehicles can distinguish the messages according to this number.
- *Receiver's Coordinates.* The coordinates of the receiver vehicle.
- *Calculate Flag.* A flag set to 1 which is indicating the detector/forwarder that this is a reply message and that it should use it to select the best forwarder of

the event information.

Once these parameters and values are determined, all of the necessary information is ready to be sent either to the event detector or the forwarder node. In Figure 3.2, these conditions and values are checked and determined by the nodes inside the transmission range. However, there is just one vehicle, the green tinted one, that will satisfy the first condition of this state, since it is at the edge of the transmission area, and will rebroadcast the data instantly. State II is algorithmically shown in Algorithm 3.1.

Algorithm 3.1 ON RECEIVED EVENT

```
if ReceivedPower < Sensitivity + Sensitivity * 0.12 then
    Rebroadcasttheeventimmediately;
else

    Local Variables:
    myStreet = getMyStreet(); {Receiver‘s street}
    myAngle = getMyAngle(); {Movement angle of the receiver}
    Dist = GetMyDist(); {Driving distance between the nodes}

    list outgoingStreets = getStreets(myStreet); {Get the 1st, 2nd and 3rd Tier of outgoing streets connected to
    the current one}
    bool found = false;
    float encProb; {A variable to hold the encountering probability value.}

    for all street ∈ outgoingStreets do
        if !found then
            if SenderStreet == street then
                encProb = 1/previousOutgoingStreetsOptions; {Determining the Encountering Probability}
                found = true; {End the Iteration}
            end if
        end if
    end for

    Monitor vehicle‘s coordinates at time t-1 and t.
    int Distance1 = getDistance(senderCoords, t − 1); {Air Distance from the vehicle to the event at time t-1}
    int Distance2 = getDistance(senderCoords, t); {Air Distance from the vehicle to the event at time t}
    bool MovingAway = true;

    if Distance1 > Distance2 then
        MovingAway = false;
    end if
end if

Send(Dist, encProb, MovingTowards); {Sending the calculated parameters to the sender}
```

State III: The third step of the protocol is represented by the sender which receives the replies from the vehicles that received the event information and replied with above explained parameters. This step is avoided in the case of low receiving power, which was described earlier. Once the sender broadcasts the event information, it waits for some time to receive the replies. For example, in Figure 3.2, the yellow stared vehicle or the sender, waits for the replies of all of the vehicles inside the transmission range (except the green tinted node which will rebroadcast automatically). When the replies are gathered, the sender builds a list where it filters the nodes according to the values that were received. This crucial part of the algorithm consists of the following logic: the vehicles are being grouped by their street and the moving away flag of the node. For example, in Figure 3.2, the nodes A and B are on street "2", but 'A' is moving towards the event and 'B' is moving away. With this step, we wanted to achieve a situation where we have at least two nodes on a street, both of them moving in different directions, to rebroadcast the data. Also, in order to rank the vehicles, the following utility formula is calculated using the received parameters from the replies:

$$U(x) = \alpha \frac{Distance}{MaxDistance} + \beta(1 - EncProb) + \gamma MovingTowards \tag{3.1}$$

where $U(x)$ is the value based on which the nodes will be eliminated. $Distance$ is the actual driving distance from the node to the event. $MaxDistance$ is the driving distance of the farthest node that replied and it is used to adjust the distance parameter into the interval between 0 and 1. $EncProb$ is the probability that the vehicle which received the data will encounter the event, and $MovingTowards$ is a flag value which gives an info of whether the node is moving towards the received event or not. α, β and γ are a weighting coefficients which in this work are 0.7, 0.2 and 0.1 respectively. The algorithmic representation of this third state can be seen in

Algorithm 3.2. Also, the yellow stared vehicle in Figure 3.2 is the one that executes this algorithm.

Algorithm 3.2 ON RECEIVED REPLY

Wait for 1.5s to receive all of the replies. Put them in a list
for all $p \in V$ {Iterate over the received packets. "p" is packet and "V" is the list of all of the packets}

$$Utility[p] = \alpha \frac{Distance[p]}{MaxDistance} + \beta(1 - EncProb[p]) + \gamma MovingAway[p]$$

List[entry] = NodeID[p],StreetName[p],Utility[p];
end for
for all $entry \in List$ {Iterate over the list}
if $StreetName[p] == StreetName[p-1]$ **then**
    if $MovingAway[p] == MovingAway[p-1]$ **then**
        if $Utility[p] > Utility[p-1]$ **then**
            $DeleteUtility[p-1]$;
        else
            $DeleteUtility[p]$;
        end if
    end if
end if
end for

Let's now discuss the purpose and the impact of each of the parameters that we have mentioned and how they affect the efficiency of the protocol. Firstly, we decided to use the driving distance rather than a normal straight line distance, since it gives more information about the time needed to drive to the event. When using a straight line distance, in some cases a short distance may give false positives or false negatives about the actual distance and time needed to drive from the receiver vehicle to the sender of the information. This type of distance also gives a possibility to limit the dissemination area. For example, in our protocol, once the expected driving time from the receiver vehicle to the event is greater than 5 minutes, the additional rebroadcasting stops. We can refer to this as a region of interest. The α weight in the formula is 0.7. According to our simulation experiments the distance is the most important parameter while executing the broadcast suppression technique since it highly affects the additional coverage and reduces the number of nodes needed to rebroadcast the data and to cover the region of interest. It also reduces the dissemination delay. Secondly, the *EncouteringProb* parameter is the one by which we wanted to achieve a scenario where the vehicles that will most likely encounter the event will be excluded from retransmission in order to lower the number of duplicate packets and spread the information to the outside area of the event. As seen in Equation 3.1, the encountering probability is subtracted from 1 because in our case a lower likelihood should add more weight to the overall result, meaning the vehicle is going outside of the region. The third parameter $MovingAway$, has the same purpose as the second one, but it helps to further achieve the same desired results. With it, we filter the nodes according to the likelihood to move to the inside or outside area of the sender's transmission range. The weight of 0.1 was given to this parameter, because very often it does not depict the real topology. Normally, in protocols where no central vehicle is used, and where the receivers decide on their own for the rebroadcast action, the last two parameters that we use will probably not be needed, because the moving direction and encountering probability will not affect spreading of the data more efficiently. That is because of the fact that the retransmission occurs instantly and once the data is received the eventual rebroadcast is immediate. But, as we mentioned, in our work the central vehicle is waiting for some time till it receives the replies. In dynamic topologies such as the VANETs, this waiting time could cause drastic topology change and inaccurate results. For example, the nodes that initially were far from the sender, after the waiting time, could come closer to it. With the mentioned parameters we do a prediction of the next topology state or the state where the decision for which vehicle to rebroadcast is made. After the sorting and elimination of the redundant vehicles, hopefully, the algorithm will end with nodes far from the event going to the outside areas of the region of interest. Moreover, the mentioned coefficient numbers were chosen after a set of simulation experiments. It was stated that the *Distance* is the value that mostly affects the retransmission potential. However, in order to predict the above mentioned *next state* the *Encountering Probability* and *Moving Away* parameters are of great use. Their varying to greater values makes the protocol to chose nodes going to the outside of the region, but closer to the sender. Otherwise, their lower values are making their impact of the decision insignificant.

Finally, the third state of the algorithm ends with the response from the sender to the vehicles that should retransmit the data. When the decision is made the sender sends a message with the list of eligible nodes and a flag indicating the vehicles in the list to further spread the data. Once this message is received, the chosen nodes immediately do the broadcast. The full protocol operation is chronologically shown in the timed flow diagram in Figure 3.3.

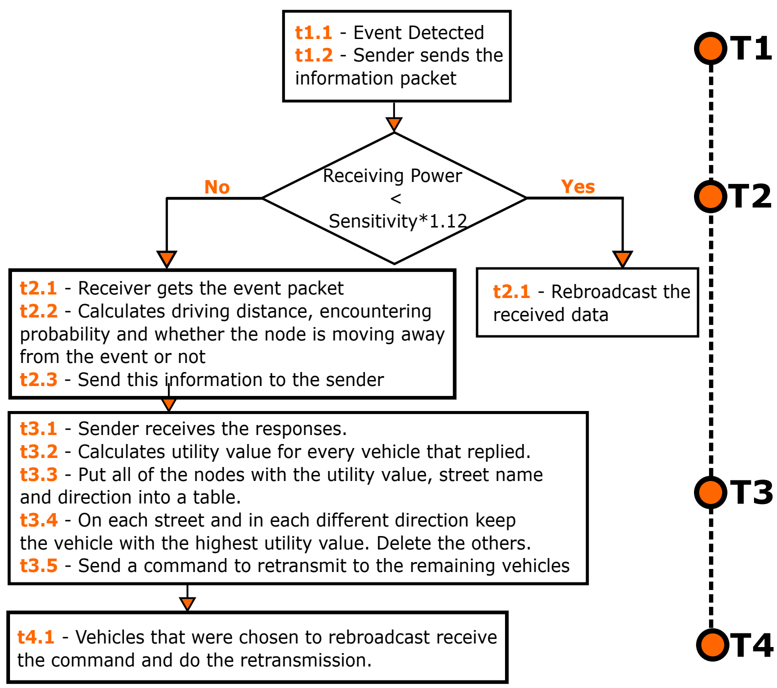


Figure 3.3: DTP-DDP - Timing Diagram

3.1.1 Section Summary

In this section of the thesis, we proposed a novel and efficient data dissemination protocol which the main goal was to minimize the number of retransmitted packets while sustaining a satisfactory delivery ratio. By utilizing GPS, the proposed protocol is able to collect the necessary information and disseminate the event data further. Once the data is broadcast, the algorithm chooses a maximum of one vehicle in each different street and direction of the street to retransmit the data. However, in order to do that, the protocol requires additional delay so that the sender of the data can gather the replies from other nodes in the transmission range. There is also an "edge mechanism" where the node that received the data checks the signal strength. If it is lower than a threshold, which means that most likely the reply and response communication could not be done, the receiver will rebroadcast the data automatically. In terms of distance, this threshold means that the receiver is at the edge of the transmission range. However, signal degradation caused by obstacles can be the reason for the weak singnal strengthtoo.

3.2 Efficient Encounter-based Event Dissemination Protocol (E-BED) for Urban and Highway Vehicular Ad Hoc Networks

E-BED's goal is to disseminate certain data within a bounded region with a minimum number of retransmission packets, while meeting the delivery ratio and delay constraints for urban and highway VANETs. Also, we were aiming E-BED to be an improvement over its predecessor DTP-DDP in terms of retransmission packets and delay. The results shown in Chapter 4 of this thesis proved that we have successfully done that.

As mentioned in the introduction of this section, the E-BED is a modification of DTP-DDP discussed in Chapter 3.1 of this thesis. Because of that, in this section we are going to provide a brief explanation of the protocol operation with a detailed discussion of the modifications that were done. Also, for E-BED we propose a different highway mode mechanism which is basically a highway adapted utility formula. More details about the detailed protocol's operation can be found in the Chapter 3.1 or in the published paper [27].

The three way communication remains the same as in DTP-DDP. In Figure 3.1 we have illustrated a communication example together with the packets' fields. However, in this case we have modified the highway mode of operation too and because of that the packets' fields shown in 3.1 are slightly different for the highway mode of operation. Hence, we are going to split the E-BED's explanation in two separate sections.

3.2.1 Urban Scenario

E-BED's urban mode of operation can be explained by separating it into three states.

State I: The initial state when the event is detected or the state when the forwarding node gets the command for rebroadcast. The packet's fields remain the same as in DTP-DDP and are shown in Figure 3.1. An Example scenario can be seen in Figure 3.4.

State II: The neighbors of the sender vehicle already received the packet and are aware of the event. If their distance to the current sender is greater than a certain threshold (A distance of 170m. Will be explained and justified later in this chapter), they reply to the detector/forwarder vehicle. The reply message is the same as in DTP-DDP. The main parameters that affect the next forwarder selection are:

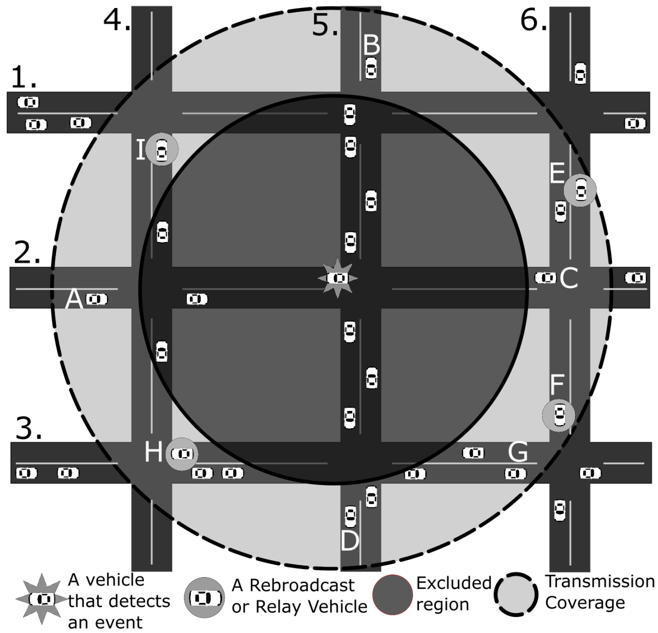


Figure 3.4: E-BED - Urban Scenario Example

- *Driving Distance.*
- *Encountering Probability.*
- *Moving Away flag.*

Detailed explanation of these parameters and the other reply packet's fields could be found in the DTP-DDP section or in the published papers [26, 27]. In Figure 3.1 this state is represented by the number 2 arrow. Also, in Figure 3.4, this state is being done by all of the nodes outside of the dark and inside the light tinted area. The dark part of the circle is the distance threshold. The nodes inside are considered to be too close to the sender and with a small broadcast effect even if some of them become forwarder. Hence, they are not replying, which minimizes the number of replies and directly affects the network saturation and the message collision probability.

State III: The sender has received the replies of the receivers whose distance is greater than the threshold mentioned in Stage II (Figure 3.4, light tinted area). In E-BED, the waiting time for the sender to get the replies is 50ms counted after the last received reply. According to our simulation analysis shown in Figure 3.5d, this waiting time is enough to ensure that most of the reply packets are delivered to the sender, while not sacrificing too much delay. Lowering this threshold may lead to unstable performance. Once the timer reaches 50ms, the sender performs the Algorithm 3.3. However, if the sender does not receive any reply it will periodically repeat the broadcast for a certain time. Also, if a reply is received after the waiting time it will be considered under a new selection process. Moreover, the decision of which nodes will further rebroadcast the data is made by ranking them according to the utility Equation 3.1 which is the same as in the case of DTP-DDP. Nevertheless, this equation is as given by:

$$U(x) = \alpha \frac{Distance}{MaxDistance} + \beta(1 - EncProb) + \gamma MovingTowards \tag{3.2}$$

The parameters explanation and justification, as well as the coefficients' values could be found in the Chapter 3.1 or in [26, 27]. Just for an example, in Figure 3.4, the encountering probability of the vehicle A to the event will be $\frac{1}{3}$, since the intersection on the way has three possible outgoing streets, and the sender‘s street is one of them. Also, the $EncounteringProbability$ and the $MoveingAway$ values are still part of the equation, since the communication among the detector/forwarder and the receivers remains the same as in DTP-DDP. Hence, it might take some time till the detector/forwarder receives all replies and selects the best forwarder. Therefore, these two parameters are used to predict if the vehicles have moved even further after the replies collection.

Algorithm 3.3 Selection Algorithm (Urban Scenario)

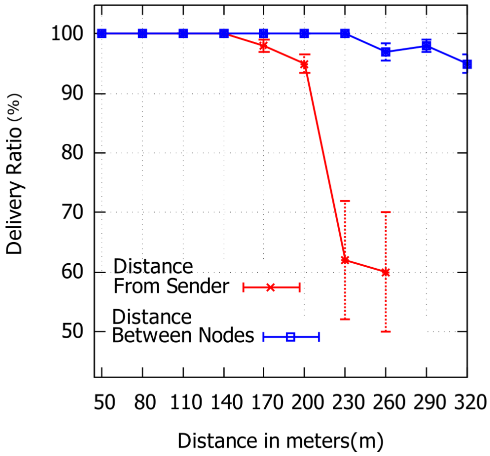
for all $p \in V$ {Iterate over the received packets. "V" is the list of all of the packets}

$$Utility[p] = \alpha \frac{Dist[p]}{MaxDist} + \beta(1 - EncProb[p]) + \gamma MovingAway[p]$$

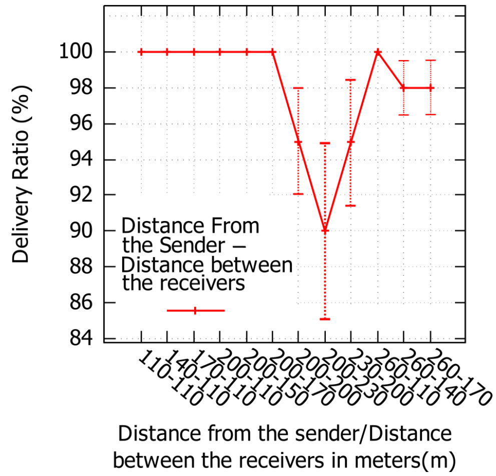
$List[entry] = NodeID[p], StreetName[p], Direction[p], NodeCoord[p], Utility[p];$
end for
Sort $List$ by $StreetName$
for all entry $e \in List$ {Iterate over the list}
if $StreetName$[e] $==$ $StreetName$[e$-$1] **then**
  if $MovingAway$[e] $==$ $MovingAway$[e$-$1] **then**
    if $Utility$[e]$>$$Utility$[e$-$1] **then**
      $DeleteUtility$[e$-$1];
    else
      $DeleteUtility$[e];
    end if
  end if
end if
end for
for all $entry\ e \in List$
$Distance1 = SQRT((Coord.X$[e] $-$ $Coord.X$[e$-$1]$)^2 + (Coord.Y$[e] $-$ $Coord.Y$[e$-$1]$))^2$ {Distance between the nodes}
if $Distance1$<200 **then**
  $Distance2 = SQRT((Coord.X$[e] $- SenderCoord.X)^2 + (Coord.Y$[e] $- SenderCoord.Y))^2$
  $Distance3 = SQRT((Coord.X$[e-1]$- SenderCoord.X)^2 + (Coord.Y$[e-1]$- SenderCoord.Y))^2$ {Distances from the sender}
  if $Distance2$<$Distance3$ **then**
    Erase node at the index e.
  else
    Erase node at the index e-1.
  end if
end if
end for

In general, the goal of the formula is to chose forwarding nodes far from the previous sender, and that at the moment of receiving the forwarding command are even further away than at the moment they have received the event data.

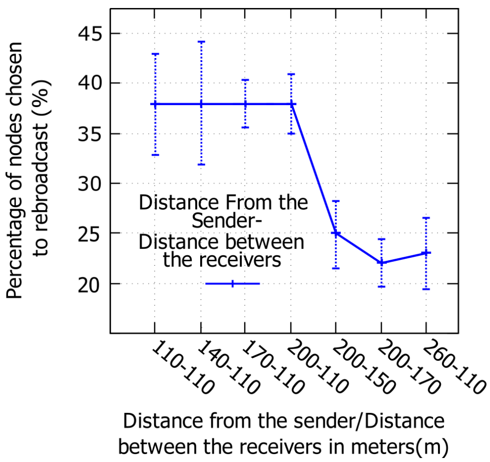
After calculating the utility value, the protocol picks one node with highest utility value on each street and in each different direction of the street. Unused nodes' data is being deleted. The street name of the nodes is determined by using their coordinates and the embedded maps. Having a forwarder node on different streets overcomes the signal degradation caused by major obstacles, and with that the effect of a single broadcast is greater. However, it is a very common situation that two or more nodes are on a different street, but still really close. This is a case in the DTP-DDP's operation. Then, the impact of one of their rebroadcasts is negligible and it can even



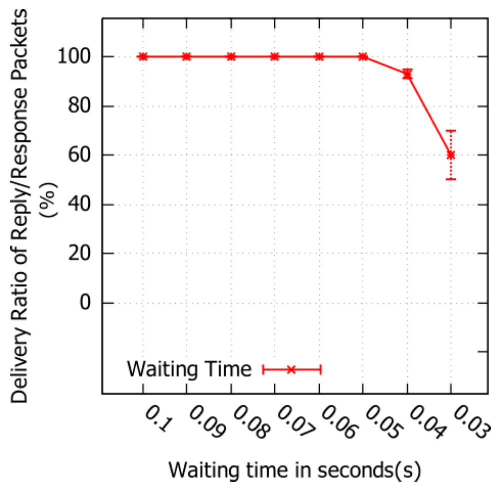
(a) Distance thresholds results



(b) Distance thresholds combinations



(c) Total number of rebroadcast packets for the distance thresholds with highest delivery ratio



(d) Delay thresholds results

Figure 3.5: E-BED - Thresholds results

cause packet collisions. For example, in Figure 3.4, after the explained steps all of the nodes with a letter sign beside them will be forwarders. That is why we have further excluded some of the nodes by adding a *distance between nodes* threshold. Its purpose is to solve the above mentioned issue. With it we exclude from forwarding the one of two selected nodes that are close to each other. The deleted node is the one that is closer to the sender. With that, the number of retransmissions is minimized without affecting the delivery ratio of the protocol. Consequently, the number of duplicate packets and collisions is decreased too. After this elimination, in Figure 3.4 forwarders will be the nodes in the circles or *I, E, F, H*. In our simulations, this threshold is set to 200m. To get this value we have done a set of simulation experiments. As can be seen in Figure 3.5a and 3.5b this threshold is the largest one that provides the maximum delivery ratio. Figure 3.5a shows the results of the experiments for the both thresholds applied independently. However, once the thresholds are applied together the results are not the same as in the independent tests. Hence, we have done another set of analysis to find the best combination of thresholds that provides the maximum delivery ratio. As can be seen in Figure 3.5b, other combinations provide the same result. In order to find the best one, we have done additional experiments with those combinations that provide the highest delivery ratio. In this case we have measured the total number of rebroadcast packets. These observations were done in different network densities and that is why instead of the actual number of forwarders we are showing the percentage, which is the ratio between the number of forwarders and the total number of nodes on the map. As can be seen in Figure 3.5c, 170-200, where 170m is the distance from the sender, and 200m is the inter-vehicular distance, is the combination that provides best results in terms of retransmission packets and delivery ratio.

Finally, when all of these steps are performed or as in Algorithm 3.3, the chosen nodes will receive a command from the sender to rebroadcast the received data.

3.2.2 Highway Scenario

The network topology in highway scenarios is different than the urban topologies. That is why the above discussed utility equation can be optimized for the highway operation of the protocol. A few modifications were made and with them E-BED could efficiently operate on highways too. Vehicles can switch to a highway mode of operation by checking the speed limit of the road where they are.

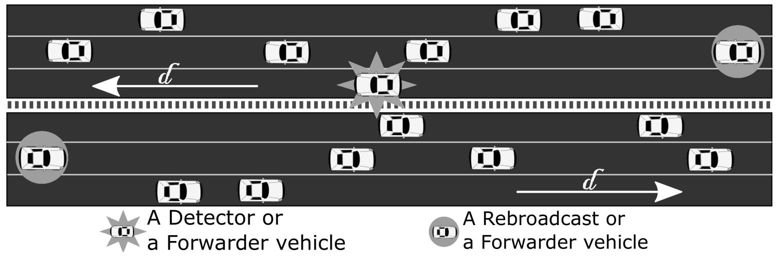


Figure 3.6: E-BED - Highway Scenario Example

The communication between the vehicles remains the same. However, some of the fields in the reply message of the receivers have to be changed. *Driving distance* is changed to *Euclidean distance* and the *Encountering Probability* is avoided in this case. Instead, the direction of movement of the receiver is added to the packet. The forwarders are chosen in the following way. By using the *Direction of movement* and the *Moving Away* flag, the sender distinguishes between the vehicles in the front and in the back. For example, if a receiver node is moving in the same direction as the sender and in the same time it is moving away from the sender, or a receiver node is moving in a different direction from the sender and it is moving towards the sender, that means that this node is the front of the sender. Furthermore, the sender chooses just one most distant vehicle in both of the sides. An example of this can be seen in Figure 3.6. In this way, the dissemination will be done with the minimum number of forwarders.

3.2.3 Section Summary

In this section, we proposed a data dissemination protocol, E-BED. The decision of which nodes will further disseminate the data is performed by the detector or the forwarders of the event. The necessary data is collected by exploiting a GPS with an embedded map. The E-BED's algorithm is able to extract the most efficient forwarders by using a utility equation. In a dynamic network environment, such as VANETs, this is considered to be a challenging task. The proposed E-BED alleviates the high network utilization issue, mainly by reducing the additional number of rebroadcast packets used to disseminate the events in a bounded region.

3.3 Comprehensive and efficient Hovering Information Protocol (CHIP) for Urban and Highway Vehicular Ad Hoc Networks (VANETs)

The following specific terms will be used to clarify CHIP's operational details:

- *Hovering Zone's Center:* The coordinates of the place where the event has happened.

- *Hovering Zone's Radius:* The length of the radius from the Hovering Zone's Center till the last point by which the event should be disseminated.

- *Hovering Zone:* The zone defined by the Hovering Zone's Center and Hovering Zone's Radius.

- *Detector*: The same vehicle as in the case of the proposed data dissemination protocols. It detects an event and initiates the data dissemination. After an event has been triggered and detected, the detector might leave the *Hovering Zone's Center* or not. CHIP considers both cases.

- *Forwarder*: The same vehicle as in the case of the proposed data dissemination protocols. It is a vehicle that received the event packet and retransmits it shortly after to inform the other vehicles. In CHIP, only a few nodes will be chosen as forwarders, based on their utility value.

- *Initiator*: the vehicle that restarts the dissemination at a later time when the detector leaves the *Hovering Zone's Center*.

The main goal of the CHIP's protocol is to keep an event alive within its *Hovering Zone* for a certain period of time. To this end, we have addressed this challenge in two different scenarios: (i) the detector remains at the event place after the event; and (ii) the detector leaves the event location after detection. In the first case, the detector remains at the place after detecting the event i.e. vehicles' crash, advertisements (A stationary unit broadcasting advertisements could be considered as a vehicle remaining at the *Hovering Zone's Center* after the event detection), etc. In the second case, the detector leaves the *Hovering Zone's Center* after the event occurrence, e.g., detection of slippery roads or other road conditions. Therefore, CHIP is comprised of two main set of algorithms that address both cases.

The first part is a hovering optimized data dissemination algorithm for urban and highway scenarios. They aim to spread the data packet through the *Hovering Zone* and inform the new incoming vehicles about the event as soon as they enter the zone. One of two different dissemination algorithms is triggered based on the scenario. The vehicles will choose the urban or highway mode algorithm based on their current position. In *Case I*, the detector vehicle remains at the event place and it restarts the data dissemination periodically, depending on the *Hovering Zone's Radius* and the region's allowed speed. For example, in our simulation experiments the *Hovering Zone's Radius* for the urban scenario is set to 1km. The maximum speed in cities is usually 60km/h which leads to a time distance of 60s for a vehicle traveling in a straight line from the *Hovering Zone's* edge to the event. Also, in order to guarantee that the vehicles will be informed ahead of time we lowered the repetition period by 10%, which gives a repetition period of 54s. The same calculation scheme applies for a highway scenario too. However, the maximum speed on a highway is higher which leads to a more frequent repetition interval.

The second algorithmic part is the one that selects the next data dissemination initiator vehicle, since the detector will leave the *Hovering Zone's Center* after it detects the event. Two different selection algorithms are proposed to specifically address the urban and highway topologies. The vehicles can choose the mode of operation by checking their current location. Also, the repetition period calculation scheme remains the same. Moreover, in *Case I* the detector vehicle is calculating this period and broadcasts the event information every time the timer expires. In *Case II* the vehicles that previously received the event will add the repetition period to the previous dissemination initiation time. Once this time frame expires the vehicles will execute the selection algorithm and the most successful candidate will initiate the dissemination again. As in the first example, if the previous dissemination happened at 13:00:00, the next one will be scheduled for 13:00:54. Also, the next dissemination will start according to the vehicles' utility scores. The one with the highest score will start the dissemination first. Once the other vehicles receive this packet they will cancel their dissemination initiations.

In general, for *Case I* the vehicles will make use just of the hovering optimized data dissemination algorithms, because the detector remains at the event place and is able to restart the dissemination periodically. For *Case II*, the vehicles will do the dissemination and the initiator selection algorithms one after the other. The information in the event packet is the only necessary information for the operation of these two cases.

The next subsections provide a detailed description of the proposed protocol.

3.3.1 Hovering optimized data dissemination algorithms

Once an event is detected, the detector creates an event packet with the following fields:

- *Event Sequence Number (ESN).* A random number which uniquely identifies the specific event. In a case of multiple events in the same *Hovering Zone* this number will be used to differentiate them.

- *Event Coordinates.* The actual coordinates of the event or the *Hovering Zone's Center.*

- *Sender's Coordinates.* The coordinates of the previous forwarder of the event packet. For the first hop data packet the sender's and the event coordinates will be the same.

- *PDT (Previous Dissemination Time).* Is the local time of the previous disseminationused to calculate the next dissemination initiation.

- *Time to Live (TTL).* Is the time frame during which the event should be kept alive in the *Hovering Zone.*

- *Event Details.* Various details about the event. Might be the event local time, event type, its severity, etc.

3.3.1.1 Urban Mode

After creating it, the detector broadcasts the event packet. The vehicles that receive the event information start the dissemination algorithm. To choose the best forwarders, every vehicle that received the event packet calculates its utility score [0,1] by considering three factors:

- Factor I: *Distance*
- Factor II: *Junction*
- Factor III: *Movement Prediction*

After calculating their final utility values the vehicles schedule the retransmission of the event packet according to their own utility scores. Vehicles with a greater score schedule the retransmission sooner. The other nodes which scheduled their retransmission for a later time will cancel it once they receive the event packet from the vehicle that had better utility value and had broadcasted the packet before them.

Detailed description and the purpose of the factors is provided below. All numerical values necessary for calculating the different factors are retrieved by using the vehicles' GPS and their embedded maps.

Factor I: Provides a value which represents the distance between the sender and the receiver of the data packet. A vehicle that is far from the previous forwarder is a better choice for the next forwarder than another node that is closer. This is justified by the fact that the transmission effect of the furthest vehicles is greater than the closer ones. Also, it affects the total number of packets used to disseminate the data through the *Hovering Zone*. With choosing forwarders that are far from the previous ones, the whole *Hovering Zone* will be covered with fewer (smaller) number of packets. Higher euclidean distance from the previous forwarder provides higher value for the distance factor in the final equation. It is calculated as:

$$Distance\ Factor = \frac{Euclidean\ Distance\ to\ Forwarder}{Maximum\ Transmission\ Range}, \tag{3.3}$$

where *Euclidean Distance to Forwarder* is the euclidean distance between the forwarder and the receiver of the packet, and *Maximum Transmission Range* is the maximum, obstacle free, transmission range of the DSRC radio.

Factor II: Buildings and other obstacles cause a huge signal degradation in urban scenarios. To maximize the efficiency of a single transmission the forwarder should be close to a junction. Being close to an intersection will make the signal propagation more effective in the directions of the streets connected by the given junction. Therefore, more vehicles could be informed while smaller number of forwarders. Closer distance to the intersection will make the *Junction Factor* to have higher impact on the final equation value.

Moreover, CHIP evaluates one more parameter that affects the *Junction Factor* value. That is the closest junction rank. CHIP will rank the closest intersection to the receiver vehicle by the number of lanes that it connects. A node that is close to a junction which gathers more lanes has higher likelihood of transmitting the packet to more vehicles, since the capacity of the street infrastructure is always according to the vehicular traffic at the place.

Factor II is calculated as follows:

$$Junction\ Factor = \frac{1}{2} \times (1 - \frac{Distance\ to\ Junction}{Length\ of the\ street}) + \frac{1}{2} \times (1 - \frac{1}{JunctionRank}), \quad (3.4)$$

where *Distance to Junction* is the euclidean distance from the vehicle to the nearest junction, no matter if the given junction is in the front or in the back of the node. The *Length of the street* is the length of the street segment where the vehicle is driving at the moment. *Junction Rank* is the exact number of lanes that the closest intersection connects. The multiplication by $\frac{1}{2}$ is because the importance of the junction closeness and its rank is equal. If a highly ranked junction is far from the vehicle then the broadcast effect is lower than if the vehicle is close to that junction. Also, the value of the *Factor II* should be between 0 and 1. In Figure 3.7 the *Junction Rank* of vehicle C and D is 12 and 8 respectively.

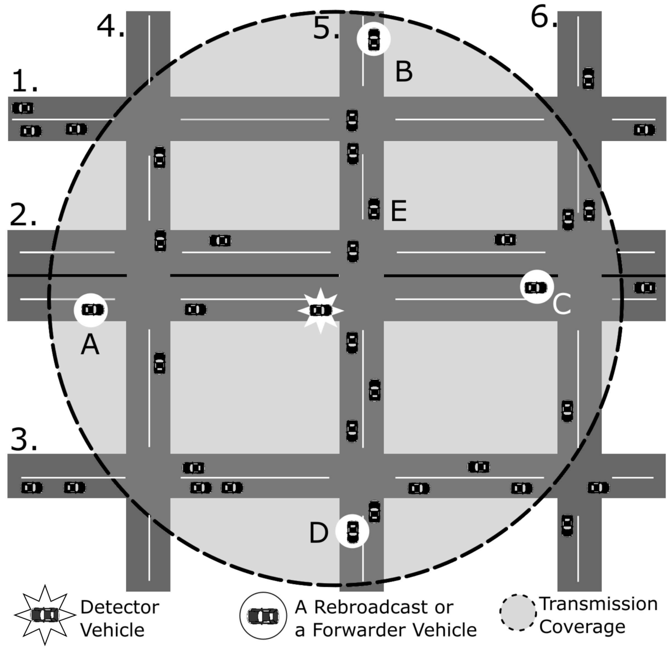


Figure 3.7: CHIP - Urban Scenario Example

Factor III: The purpose of the *Movement Prediction Factor (MPF)* is to estimate the likelihood of the receiver vehicle not to pass through the *Hovering Zone's Center*. As mentioned above, the CHIP's dissemination works in a way that the vehicles with a greater utility score will retransmit the event packet sooner than the others and cancel their later retransmissions. However, in a sparse and intermittently connected VANETs, the broadcast of the forwarder vehicle might not reach any other nodes. In order to maximize the effect of the CHIP's dissemination, once the forwarder broadcasts the packet it schedules other retransmissions periodically until the next dissemination start by the detector or initiator node. However, if this forwarder receives a duplicate of the same message after its broadcast that means that the event packet reached another node which forwards the data too. Therefore, there is no need for this forwarder to retransmit the same packet again. In this case, it cancels the scheduled periodical retransmissions. To determine the best retransmission period we have done a set of experiments and measured how many new vehicles in the area are informed during the current dissemination. Also, we have measured the total number of retransmitted packets for the same dissemination. The goal is to achieve the best delivery ratio rate with a smaller number of packets sent. The ratio of the newly informed vehicles ratio, and the transmitted packets is shown in Figure 3.8.

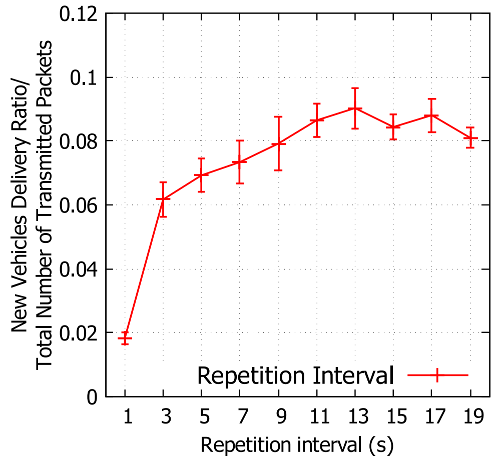


Figure 3.8: E-BED - Repetition Interval efficiency ratio

As can be seen, the interval of 13s to repeat the event packet if no other vehicle forwards it, is the one which provides the best efficiency. That means that the newly informed vehicles ratio is satisfactory while still preserving the network bandwidth.

Moreover, if the sparse or intermittently connected VANET is a case, a better choice for a forwarder will be a vehicle that is not likely to pass through the *Hovering Zone's Center*, because the detector vehicle is there and it covers the transmission range around it. Therefore, a node that tends to move to the edges of the *Hovering Zone* is an ideal candidate. Also, once the event is disseminated till the end of the zone, the forwarders that are close to the edges will not receive any duplicate packets. That is because the other vehicles inside the zone should have already received the packet before, and the nodes that are outside of the *Hovering Zone* will just receive that packet and will not continue the dissemination. In this case, if the forwarders close to the edge are still in the zone after the retransmission period they will broadcast the packet again. Thereafter, more vehicles that are outside of the *Hovering Zone* will become aware of the event and if they enter the zone later, they would be already informed ahead of time. Moreover, this feature can also help to connect the intermittently connected partitions of the *Hovering Zone* as the vehicles that periodically broadcast the packet would serve as bridges. To calculate the probability of not going through the *Hovering Zone's Center* and to get value for the *Factor IV* the vehicles use the following equation:

$$\begin{array}{l} Movement \\ Predication \\ Factor \end{array} = \frac{1}{2} \times (1 - Encountering\ Probability) + \frac{1}{2} \times Moving\ Away\ Flag\,, \tag{3.5}$$

where the *Encountering Probability* is the likelihood of the receiver vehicle experiencing the event. To determine its encountering probability a node fetches its current the event's street segments by using the coordinates and its embedded maps. After that, it gets the outgoing lanes of its current street segment and checks whether one of them is the *Hovering Zone's Center's* one. If that is the case the iteration stops. Otherwise, it continues until the origin street is found. However, in our implementation if the origin's street segment is not found till the third set of outgoing lanes the iteration stops. Three sets of outgoing lanes are usually enough to determine the encountering probability. Even if the algorithm iterates further and the street segment is found, it will return negligible probability. For example, in Figure 3.7 the encountering likelihood of vehicle A to the event is $\frac{1}{4}$, since the junction where vehicle A is going to has four different outgoing lanes to be chosen from. Here we assume that U-turns are possible and that the vehicle might change its lane. One of these outgoing lanes is the origin's one and that is why the iteration stops here. In the same figure, the encountering probability of the vehicle E to the event is $\frac{1}{4\times4\times4}$, since in order for node E to reach the event it has to pick one of the four possible outgoing streets on the three different junctions on its way to the event's street segment.

Furthermore, the *Moving Away Flag* will be set to 1 if the node is moving away from the *Hovering Zone's Center* or to 0 if it is going towards it. This flag can be determined by monitoring the vehicle's coordinates over the time. If the distance between the vehicle's coordinates and the event coordinates is increasing over time, that means that the vehicle is going away from the event. The *Moving Away Flag* of vehicle A and C in Figure 3.7 will be set to 1 and 0 respectively.

These two parameters are providing the *Movement Prediction Factor*. They are multiplied by $\frac{1}{2}$, because as per our experience their importance for determining the future movement of the vehicles is equal. Also, the value of the factor should be in the range [0,1].

Finally, the values of the three factors are combined into one single formula shown in Equation 3.6. According to our research, the three factors should have equal impact on the final value and that is why all of them are multiplied by $\frac{1}{3}$. For example, if the *Distance Factor* is weighted more, than the equation will tend to provide higher utility values to the nodes that are far, despite their junction closeness, rank or future movement.

$$U(x) = \frac{1}{3} \times \begin{matrix} Distance \\ Factor \end{matrix} + \frac{1}{3} \times \begin{matrix} Junction \\ Factor \end{matrix} + \frac{1}{3} \times \begin{matrix} Movement \\ Prediction \\ Factor \end{matrix} \tag{3.6}$$

Ideally, the utility value will extract as forwarders for the vehicles that are far from the previous sender, close to an intersection which connects many lanes, and going to the edges of the *Hovering Zone.*

3.3.1.2 Highway Mode

The utility equation for the *Highway Mode* of the protocol is composed of two factors which overlap with the ones for *Urban Mode* of the dissemination protocol:

- Factor I: *Distance*
- Factor II: *Movement Prediction*

Factor I: The *Distance Factor* purpose and equation remain the same as in the CHIP's *Urban Mode*.

Factor II: The *Movement Prediction* factor is modified to address the specific scenario challenges. In highway scenarios the *Hovering Zone* is represented just by the two possible directions of the highway. In CHIP we aimed to chose as forwarders the vehicles that are going to the edges of the zones. Unlike in the *Urban Mode* of the dissemination, the forwarders will not schedule periodic retransmission of the event packet. Instead of that, every forwarder will rebroadcast the event information once it is at the *Hovering Zone's* edge. This feature will make the vehicles coming from the opposite direction to be informed about the event ahead of time. Therefore, the best forwarders will be the ones that are not moving towards the *Hovering Zone's Center*. In this case, because of the simple VANET topology for highways, the *Encountering Probability* parameter is not necessary to predict the vehicle's future movement. Hence, the *Movement Prediction* factor in this case will be determined solely by the *Moving Away Flag.* The final utility equation for the *Highway Mode* dissemination is given by:

$$U(x) = \frac{1}{2} \times Distance\ Factor + \frac{1}{2} \times Movement\ Prediction\ Factor \tag{3.7}$$

For example, in Figure 3.9 the vehicles A, B and C will forward the packet in one of the highway directions and D, E and F in the other one. Their distance to the previous forwarder is greater than the other vehicles and they are moving away from the event. C and F will first of all broadcast the event packet one more time when they are at the *Hovering Zone's* edge. B and E will follow up and finally the last rebroadcast wave at the *Hovering Zone's* edge will be from A and D.

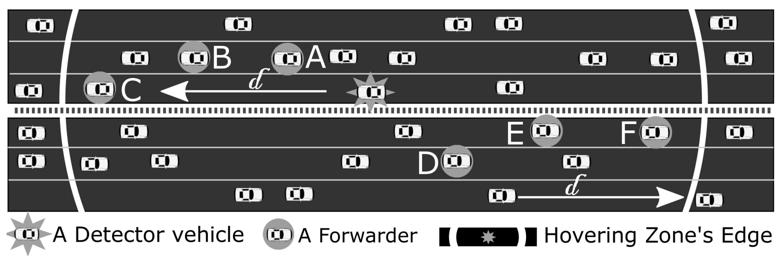


Figure 3.9: CHIP - Highway Scenario Example

3.3.2 Dissemination initiator selection algorithms

3.3.2.1 Urban Mode

The utility formula for the next vehicle to initiate the dissemination is determined by two factors:

- Factor I: *Distance*
- Factor II: *Junction*

Factor I: The best vehicle to initiate the next dissemination is the one that is closest to the *Hovering Zone's Center*. If that is the case, the other nodes that are closer to the event will receive the information sooner and with a higher probability than the others. Therefore, the *Distance* factor is given by:

$$Distance\ Factor = 1 - \frac{Euclidean\ Distance\ to\ the\ event}{Hovering\ Zone's\ Radius}, \tag{3.8}$$

where *Euclidean Distance to the event* is the air distance between the vehicle that calculates the utility score and the *Hovering Zone's Center*. *Hovering Zone's Radius* is the length of the predefined radius of the *Hovering Zone*.

Factor II: Despite the advantages of being close to the *Hovering Zone's Center*, it is highly beneficial for the next initiator to be close to an intersection which connects many lanes. That avoids the signal degradation caused by the buildings and spreads the information more efficiently. This factor is essentially the same as the *Junction Factor* in the CHIP's Urban Mode dissemination algorithm. More details about it can be found in section 3.3.1.1.

The final utility equation for the dissemination initiator selection is as follows:

$$U(x) = Distance\ Factor \times Junction\ Factor \tag{3.9}$$

Ideally, the next initiator vehicle should be as close as possible to the *Hovering Zone's Center* and to an intersection of a high rank. Also, it is important to mention that when the CHIP's dissemination algorithm is used together with the dissemination initiator scheme, the periodic retransmissions of the packet by the forwarders are avoided. When using the initiator algorithms a vehicle that is in a region that is not reachable by the other nodes' transmission range will broadcast the packet in any case and would inform the other vehicles in that region. Therefore, the periodic broadcast feature of the forwarders is avoided when these two schemes are used together.

3.3.2.2 Highway Mode

The same approach of the urban initiation algorithm goes for the highway scenario. The best dissemination initiator will be a vehicle that at the scheduled time is as close as possible to the *Hovering Zone's Center.* However, the *Junction* factor is excluded in this case. Therefore, the utility equation for the *Highway Mode* of the initiation algorithm will be represented just by the *Distance* factor.

$$U(x) = 1 - \frac{Euclidean\ Distance\ to\ the\ event}{Hovering\ Zone's\ Radius}, \tag{3.10}$$

where the *Euclidean Distance to the event* is the air distance between the vehicle that calculates its initiator score and the *Hovering Zone's Center.* The *Hovering Zone Radius* is the predefined length of the *Hovering Zone's Radius.*

3.3.3 Use Cases

3.3.3.1 Use Case 1: Non-Stationary detector

An example of a detector vehicle leaving the *Hovering Zone's Center* after the event is a slippery road detection. Let's assume the vehicle's EPS (Electric Power Steering) system detected the slipperiness of the street. Then, the vehicle creates a packet and broadcasts it, T1 in Figure 3.10. Other vehicles that receive this packet check whether their distance to the event is less than the *Hovering Zone's Radius.* If that is a case the algorithm moves to the *Yes* case at T2 in the timing diagram. Otherwise, if it is outside of the *Hovering Zone*, the vehicle will just consume the information and will not proceed with the further execution of CHIP. After passing this filter, the algorithm calculates the vehicle's forwarding utility value [0,1]. According to this value the vehicle schedules its forwarding broadcast. Greater utility value will provide sooner forward of the message. The time between T2 and T3 in the CHIP's time diagram is the gap between the forwarding broadcast schedule and the actual broadcast. Meanwhile, if the vehicle receives the same message from another node, that means that the utility value of that node was higher and it broadcasted the message sooner. Receiving the duplicate message will cancel the later forwarding of the packet by the vehicle with a lower utility score. In the other case, the vehicle with the higher utility score already broadcasted the packet. However, since the detector in this case is non-stationary and the initiation algorithm takes place, the periodic broadcasts by the forwarders at T2.4 will not be scheduled. Both of these cases lead to T4 part of the timing diagram. The time gap between T3 and T4 is the actual repetition time of the event. At T4 all the vehicles that received the event information during the dissemination session will perform the calculation of the initiation utility value. Same as in the dissemination algorithm, the vehicle with the highest value broadcasts sooner and stops the others' scheduled broadcasts. The process follows the same fashion from T2 to T5 until the TTL of the event packet is reached.

3.3.3.2 Use Case 2: Stationary detector

A good example for this use case would be an accident. The airbags open and the vehicle broadcasts the event packet, T1 in Figure 3.10. In this case the time diagram would exclude the actions at T2.5, T4 and T5. That means that only the dissemination algorithm will be executed. Once the receiver vehicles validate that their distance to the event is less than the *Hovering Zone's Radius* they calculate their forwarding utility value. Later on, they schedule the forwarding broadcast according to the utility score. Also, they schedule the periodic broadcasts according to the time interval explained above in this paper. When the timer for the forwarding broadcast expires the vehicle transmits the packet and continues with the periodic broadcasts. Meanwhile, if it receives a duplicate packet for the same event, that means that another vehicle with a higher utility value transmitted the packet and the scheduled broadcasts of the vehicle with the lower score will be canceled. The same process repeats and goes back from T3 to T2 until the specified TTL for the event.

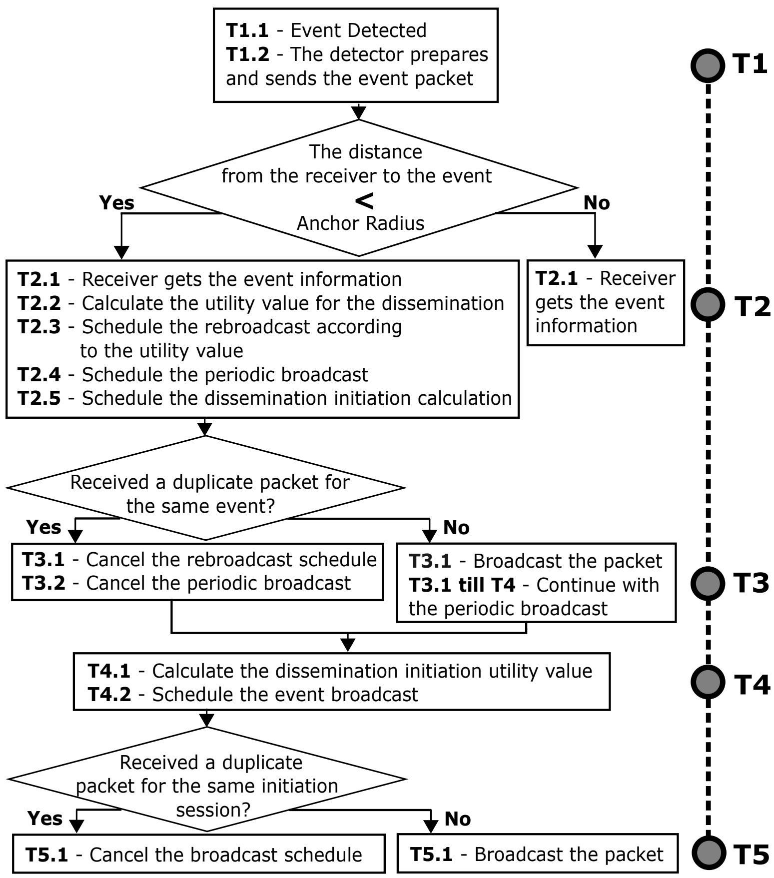


Figure 3.10: CHIP - Timing Diagram

3.3.4 Section Summary

In this section of the thesis, a *Hovering Information* protocol called CHIP was proposed for urban and highway scenarios. It addresses the hovering event challenge from a different perspective than the existing VANET protocols and, to the best of the author's knowledge, the proposed scheme is one of the first to drop the use of beacon messages. Instead, CHIP uses a data dissemination scheme coupled with a dissemination initiator procedure. The dissemination scheme spreads the information through a region of interest and the initiator selection mechanism picks another vehicle to restart the data dissemination algorithm at a later time when the vehicle that detected the event is not anymore present at the event location. In the simple case, i.e., when the vehicle stays at the event occurrence location, the vehicle that detected the event restarts the dissemination periodically. This paper also introduces a pattern for calculating the repetition period of the dissemination algorithm. This repetition period calculation is crucial to guarantee that most of the vehicles within the *Hovering Zone* will be informed about the event in advance.

Chapter 4

Performance Evaluation

In this chapter of the thesis we are going to present the results of the extensive simulation experiments that were done to evaluate the performance of the proposed protocols. Also, comparisons with other selected and relevant protocols were done to prove the effectiveness of our algorithms. The protocols were implemented with the OMNeT++ 4.6 network simulator [44] on an Ubuntu, Linux distribution. Also, in order to satisfy the WAVE standards within the VANET we have used the Veins 2.1 framework [35, 36]. In order to provide a realistic vehicular mobility we have used the Simulation of Urban Mobility (SUMO) 0.25.0 [18] software. The other simulation parameters specific for the data dissemination and for the information hovering protocols are shown in their separate sections.

As in this thesis we have proposed three different protocols, we are going to present their results in three different sections.

4.1 The proposed Data Dissemination protocols

The proposed protocols were tested on urban and highway scenarios. For the urban scenario we have used testing environments with 25, 50, 75, 100, 125 and 150 nodes on the map, which size is 1km^2, with 5x5 bidirectional grid lanes. On the highway scenario the density variation was performed in terms of vehicles per hour, which in our case was for 1000, 1200, 1400, 1600, 1800 and 2000 vehicles per hour that passed the highway of 10km. The highway model was bidirectional too. The simulations were repeated 10 times for each case. Therefore, we calculated the average and the confidence interval. For both urban and highway scenario, the protocols were tested using the following three metrics:

- ***Delivery Ratio:*** A simple delivery ratio calculated by evaluating the ratio between the number of vehicles present at the moment of event dissemination, and the number of vehicles that received the data.

- ***Total Number of Rebroadcast Packets:*** This metrics shows the total number of rebroadcast packets transmitted on the whole map. With that, we can see how many packets are needed to be transmitted, so the given delivery ratio is achieved. More efficient protocol would achieve a good delivery ratio with less rebroadcast packets.

- ***Delay:*** The delay metric represents an average time for the message to reach its receiver. Here we have measured the delay from the sender to all of the receivers, and calculated the average time. The delay parameter is important mostly for the emergency information dissemination. A protocol designed for that purpose should have a small delay.

Some of the simulation parameters for the proposed data dissemination protocols are shown in Table 4.1.

Table 4.1: Data Dissemination Protocols - Simulation Parameters

Parameters	Value
Simulated Area (Urban)	$1km^2$
Simulated Area (Highway)	10km
Simulated scenario (Urban)	Two way 5x5 grid
Simulated scenario (Highway)	Two way
Speed (Urban)	50km/h
Speed (Highway)	72km/h - 118km/h
Transmission Power	2.2mW
Frequency Band	5.9 GHz
Transmission Range	300m
Bit Rate	18Mbit/s
Packet size	2048 bytes
Confidence Interval	95%

4.1.1 Delay Tolerant and Predictive Data Dissemination Protocol (DTP-DDP) for urban and highway VANETs

In this section we are going to present the results for the first proposed protocol DTP-DDP. They will be classified into two different sections, for the urban and for the highway scenario. Moreover, we have compared the proposed protocol with the DRIVE protocol [46], and with a pure Flooding protocol [11].

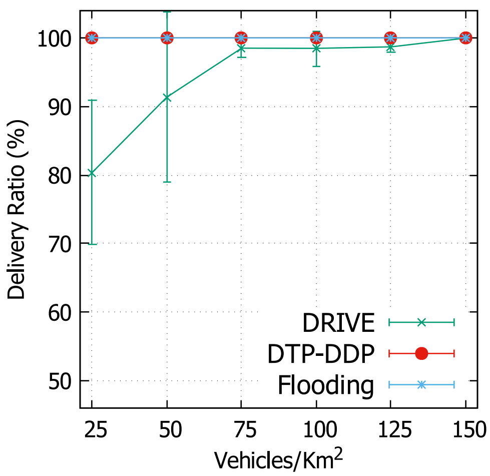
4.1.1.1 DTP-DDP Urban Scenario Simulation Results

This section provides the DTP-DDP simulation results for the urban grid scenario.

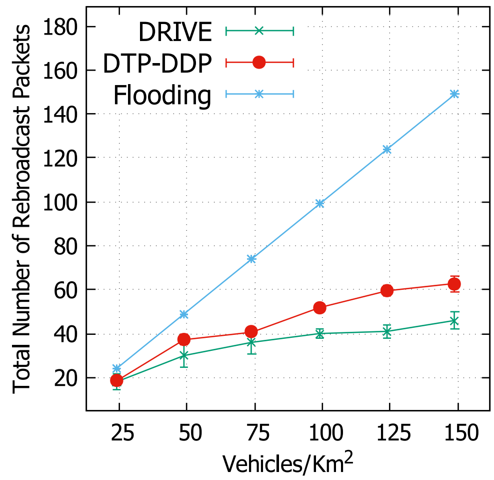
Figure 4.1a presents the delivery ratio results for the three data dissemination techniques DTP-DDP, DRIVE [46] and Flooding. As we can see the proposed DTP-DDP protocol has the same delivery ratio as Flooding. For 25 vehicles per km^2 it has 20% greater delivery ratio than the DRIVE protocol. Thus, DTP-DDP proves to be a suitable protocol for sparse network densities. These results can be justified by the fact that our protocol uses more rebroadcast messages than DRIVE. In the same time, it uses less retransmission packets than Flooding, but because it intelligently selects the most efficient forwarders it achieves similar delivery ratio as Flooding. Moreover, the trade off between this result and the number of retransmitted packets can be seen in the next graph.

The total number of rebroadcast packets generated are shown in Figure 4.1b. The proposed protocol shows similar results as the DRIVE protocol, although DRIVE performs slightly better in this category. However, the trade off mentioned previously is the reason for this result. Logically, the number of rebroadcast packets increases with the number of nodes present on the map. For example, for 150 vehicles the Flooding algorithm has 150 rebroadcast packets. However, the DTP-DDP and DRIVE have a result of around 55 retransmissions. In the case of DTP-DDP this is mostly a result of the utility score ranking equation which is selecting just the nodes with the highest scores to forward the data.

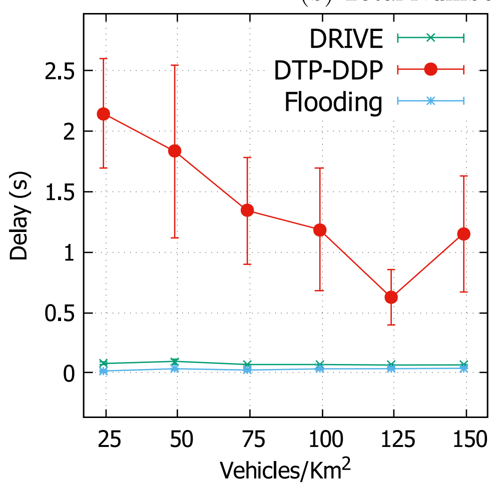
In Figure 4.1c, the average delay of the compared protocols is shown. DTP-DDP protocol has significantly greater delay than the other two schemes. That is because of the waiting time of 1.5 seconds that the sender counts while gathering the replies. However, if the dissemination area of 1km^2 is considered, DTP-DDP still satisfies the constraints for an emergency data dissemination protocol. It can be also noticed that with increasing of the network density the delay is decreasing. This is because when the network is dense more vehicles are getting informed by a single broadcast. Hence, the average delay is being decreased.



(a) Delivery Ratio (%)



(b) Total Number of Rebroadcast Packets



(c) Delay

Figure 4.1: DTP-DDP - Urban Scenario Simulation Results

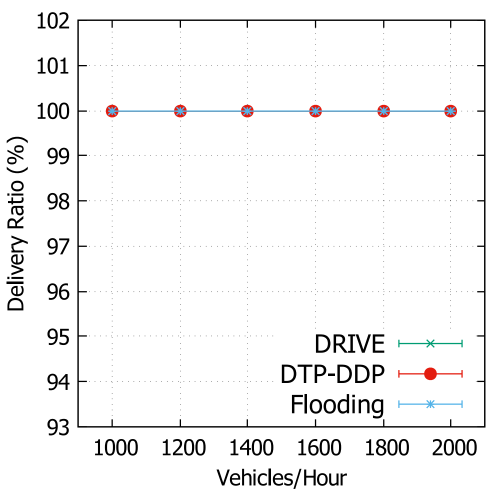
4.1.1.2 DTP-DDP Highway Scenario Simulation Results

Figure 4.2 shows the results gathered on the Highway map.

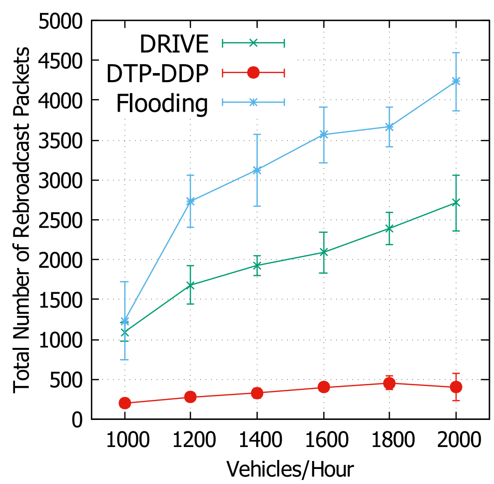
In Figure 4.2a the delivery ratio of the three protocols is presented. As seen all of them achieve a 100% delivery ratio, even in the worst case scenario of 1000 vehicles per hour. However, Flooding and DRIVE use much more retransmission packets to achieve this result. Moreover, DTP-DDP achieves this result as a consequence of its adaptive mechanism to select the next forwarders. On the other hand, DRIVE is selecting the most distant vehicles in both directions of the highway to forward the data. Because of that, it shows satisfactory delivery ratio results.

Figure 4.2b depicts the total number of rebroadcast packets needed to achieve the delivery ratio in Figure 4.2a. As seen here, the DTP-DDP outperforms the other two schemes. As described in the protocol section, once applied on a two-way street such as a highway, there will be just two vehicles in the front and in the back of the sender that will retransmit the data. For DRIVE this is not always the case and that is why its number of rebroadcast packets is higher than our protocol.

Furthermore, the delay graph is not provided in this section because it displays unfair results. That is because of the simulation environment nature of the algorithm. Because of the waiting time, and as the incoming vehicles keep entering the highway, there are new vehicles that will be elected for retransmission all of the time and with that the delay increases as the simulation proceeds. In real world the algorithm will terminate with reaching certain distance.



(a) Delivery Ratio (%)



(b) Total Number of Rebroadcast Packets

Figure 4.2: DTP-DDP - Highway Scenario Simulation Results

4.1.2 Efficient Encounter-based Event Dissemination Protocol (E-BED) for Urban and Highway VANETs

In this section we are going to present the simulation results for the second proposed data dissemination protocol E-BED. These results are further differentiated into two sections, for the urban and for the highway scenario. E-BED was compared to its predecessor DTP-DDP [26], Flooding, DRIVE [46], DBRS [16] and AID [7].

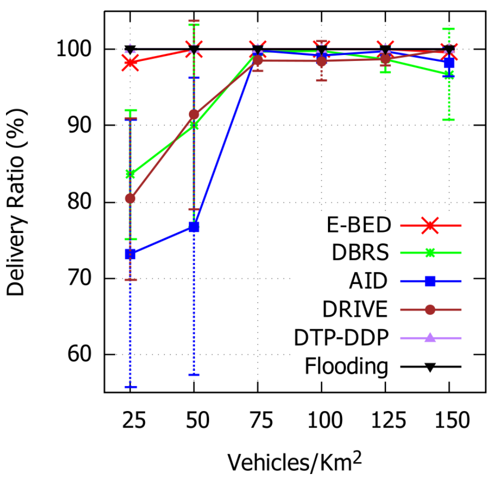
4.1.2.1 E-BED Urban Scenario Simulation Results

The *delivery ratio* of E-BED, shown in Figure 4.3a, is close to 100% even for the sparse network density. Our protocol has higher delivery ratio mainly because it chooses nodes on different streets to further propagate the data, and with that it overcomes the obstacles signal degradation issue. This is not a case for the other compared protocols, which is why they have lower delivery ratio.

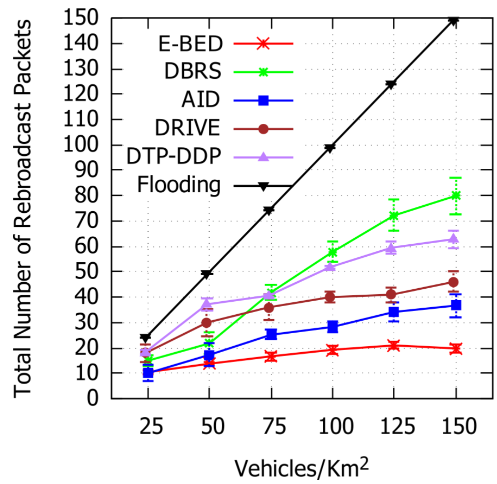
In terms of *TNRP* or total number of forwarders, E-BED outperforms the selected protocols. That shows that one of the main goals of this work, to minimize the number of retransmissions, was successfully achieved. Moreover, AID, DRIVE and DBRS, which have lower delivery ratio than E-BED, use more forwarders than the proposed protocol. Therefore, the network is not efficiently utilized. On the other side, we have proved that the thresholds used in E-BED have eliminated the unnecessary forwarders, while not affecting the delivery ratio of the protocol.

In figure 4.3c and 4.3d the *delay* of the compared protocols is shown. Flooding, DBRS and DRIVE protocols outperform E-BED. DTP-DDP has much higher delay than all of them, mainly because of the longer waiting times of the senders to get the replies. In sparse networks DRIVE activates store-carry and forward mechanism and that is why its delay is even greater than E-BED for the sparser network densities.

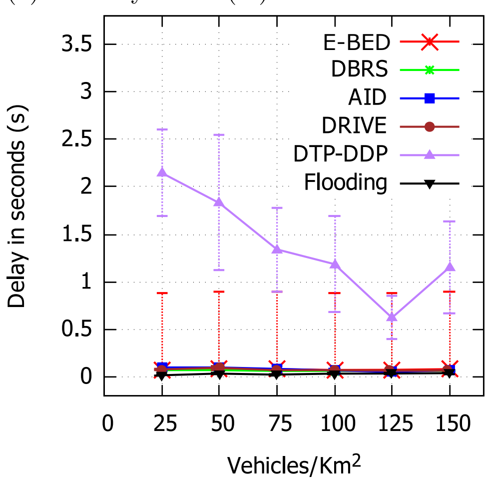
AID has waiting timer to count the duplicate packets received and that is the reason for its worst delay performance in sparse networks. The E-BED‘s reason for the higher delay is its nature of operation i.e. three way communication. However, it satisfies the delay constraints for an emergency data dissemination, while exhibiting excellent delivery ratio performance. In the future, we will further investigate how to minimize delay while sustaining high delivery ratio.



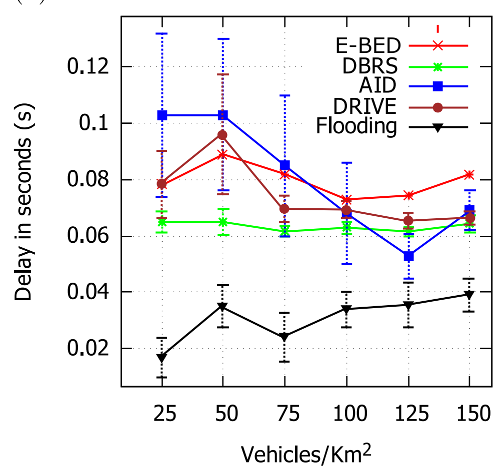
(a) Delivery Ratio (%)



(b) Total Number of Rebroadcast Packets



(c) Delay (s)



(d) Delay Zoomed (s)

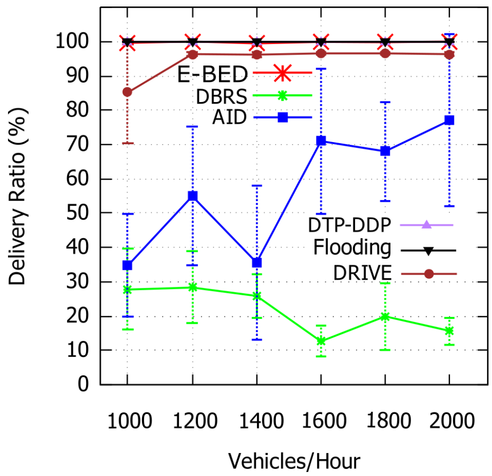
Figure 4.3: E-BED - Urban Scenario Simulation Results

4.1.2.2 E-BED Highway Scenario Simulation Results

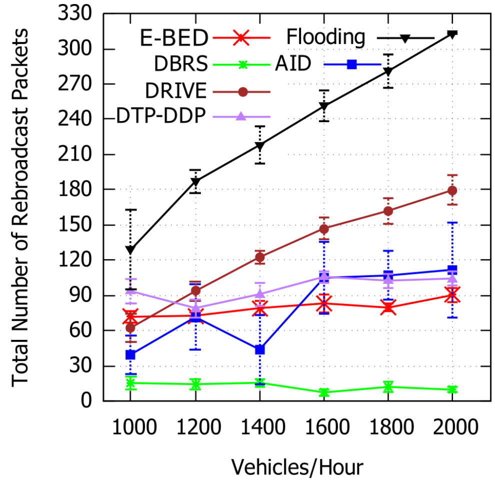
As shown in Figure 4.4a, the *delivery ratio* of the proposed highway mode of our protocol is stable and close to 100%. This is due to the E-BED' algorithm that specifically chooses the one furthest node in the front and in the back of the sender vehicle to further disseminate the data. Since the most distant nodes have the greatest broadcast effect, the delivery ratio of E-BED is higher than the selected protocols where the furthest node is not always the forwarder.

As can be seen in Figure 4.4b, the E-BED's *TNRP* used to cover the entire highway area is bellow the other protocols. This shows that the data dissemination technique of E-BED is significantly more efficient than the selected protocols. With considering this metric we prove that the goal to minimize the TNRP, while not affecting the *delivery ratio*, is achieved for the highway mode of operation too. The efficiency of E-BED comes from its mechanism to pick just one forwarder in the front and in the back of the sender. In Flooding, for example, every single node that receives the information rebroadcasts it one more time. In the same figure, DBRS and AID show better results, in terms of *TNRP*, than E-BED. However, the *delivery ratio* of DBRS and AID is much lower than E-BED.

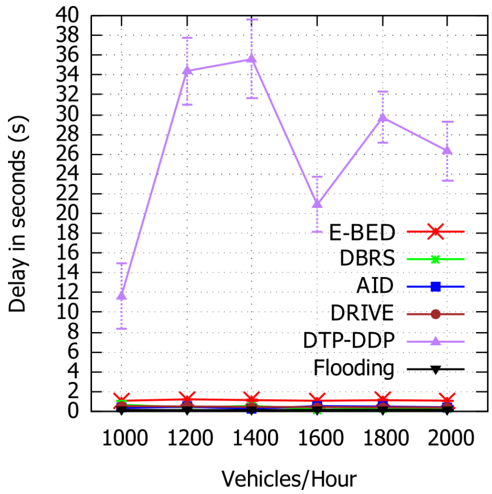
Figures 4.4c and 4.4d, show the results in terms of *delay*. E-BED has a great improvement over its ancestor DTP-DDP, mainly because of the lower waiting times used to collect the replies. Nevertheless, the other protocols have lower delay than E-BED. The main reason for this is the centralized node selection mechanism performed by the sender or the data, which includes the three way communication scheme. However, considering the 10km highway length for which the experiments were done, we can say that E-BED still meets the constraints for emergency data dissemination.



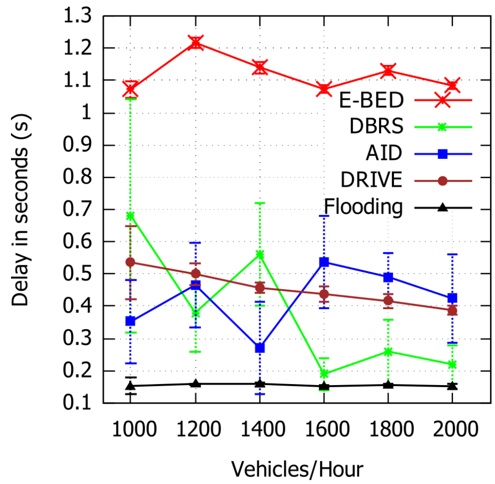
(a) Delivery Ratio (%)



(b) Total Number of Rebroadcast Packets



(c) Delay (s)



(d) Delay Zoomed (s)

Figure 4.4: E-BED - Highway Scenario Simulation Results

4.2 The proposed Hovering Information protocol - Comprehensive and efficient Hovering Information Protocol (CHIP) for Urban and Highway VANETs

In this section we are presenting the results of the proposed hovering information protocol and the other selected compared protocols. Firstly, the simulations were done with the assumption that the detector stays at the *Hovering Zone's Center* after the event or it is stationary, meaning that just the CHIP's hovering optimized dissemination algorithms were used. The second set of simulations were done with the detector vehicle leaving the *Hovering Zone's Center* after the event. In that case, both of the proposed sets of algorithms were used. For both cases, stationary and non-stationary detectors, the urban and the highway modes of the algorithms were tested too. To test CHIP in more realistic environment, the urban scenario results were gathered by using an actual map from Oshawa, ON, Canada, extracted from OpenStreetMaps website [28] and shown in Figure 4.5. The vehicular density included 5000, 7000, 9000, 11000, 13000, 15000 and 17000 vehicles per hour passing on the map. Furthermore, the highway mode of the proposed protocol was tested on a two directional highway, where each direction includes three different lanes. The vehicular density included 200, 400, 600, 800, 1000, 1200, 1400 and 1600 vehicles per hour passing in both directions of the highway. The other simulation details are shown in Table 4.2.

Table 4.2: Hovering Information Protocols - Simulation Parameters

Parameters	**Value**
Map Size (Urban / Highway)	13km^2 / 10km
Hovering Zone's Radius (Urban and Highway)	1km
Map type (Urban)	Oshawa's real map
Map type (Highway)	Two way 3 lanes each
Vehicles' Speed (Urban)	40km/h - 60km/h
Vehicles' Speed (Highway)	70km/h - 120km/h
Simulation Time (Urban & Highway)	900s
Simulation Warm Up Time (Urban / Highway)	150s / 300s
Transmission Range	300m
Packet Size	2048 bytes

Figure 4.5: CHIP - Urban Scenario Map - Oshawa, ON, Canada

With the simulations we collected results about the following metrics:

- *New Vehicles Delivery Ratio (NVDR)*. The average ratio between the number of new vehicles that entered the *Hovering Zone* since the previous dissemination initiation and received the event information, and the total number of new vehicles that entered the *Hovering Zone* since the previous dissemination initiation.
- *Time to Receive the Packet (TRP)*. The average time that is needed for a vehicle to receive the event information after it enters the *Hovering Zone*.
- *Total Number of Transmitted Packets (TNTP)*. The total number of transmitted packets during the simulation time.
- *Collisions*. The total number of collisions that occurred during the simulation time.

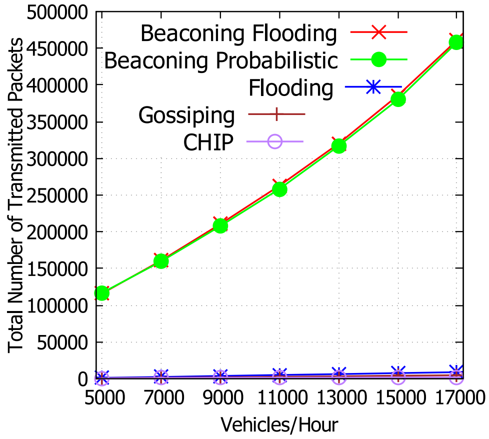
- *Relevant Delivery Ratio.* The average ratio between the total number of vehicles that have passed the street segment where the event is and received the event information prior to that, and the total number of vehicles that have passed the street segment where the event is.

4.2.1 Simulation Results - Stationary Detector

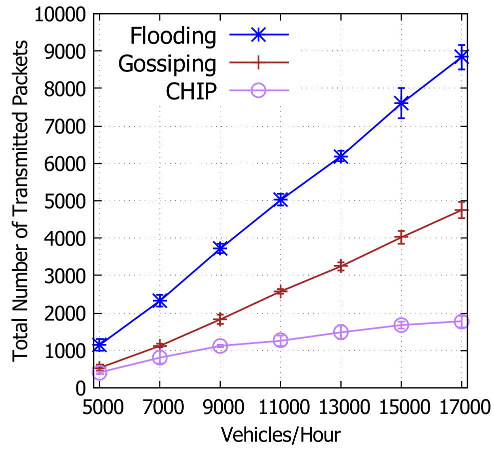
This section presents the simulation results where the detector stays at the *Hovering Zone's Center* after the event has occurred. In this case CHIP uses just the hovering optimized data dissemination algorithms.

4.2.1.1 Urban Scenario

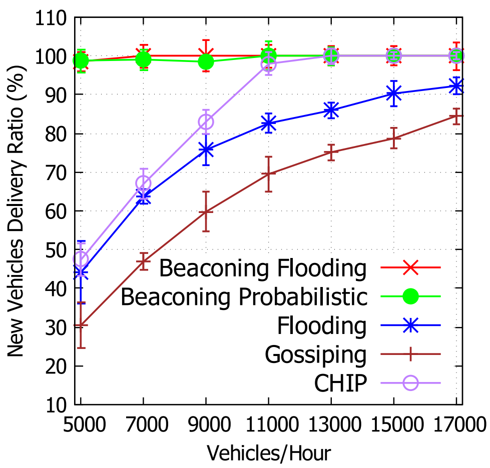
The TNTP for this scenario are shown in Figure 4.6a and 4.6b. Beaconing Flooding and Probabilistic hovering algorithms consume a tremendous number of packets. As a consequence, the number of collisions are higher than the other protocols. The reason for this are the periodic beacons that the vehicles operating with this protocols use. The pure Flooding dissemination algorithm uses fewer packets than the beaconing approaches, but still more than Gossiping and CHIP. That is because with Flooding every vehicle rebroadcasts the packet. Since the retransmission likelihood in Gossiping is 50%, it is noticeable that it uses twice as fewer packets than Flooding. In this category CHIP outperforms the other compared protocols mainly because in its case just few of the vehicles are forwarding the data. Due to the same reason, with increasing the vehicular density the CHIP's TNTP are increasing with much smaller difference than the ones of the compared protocols.



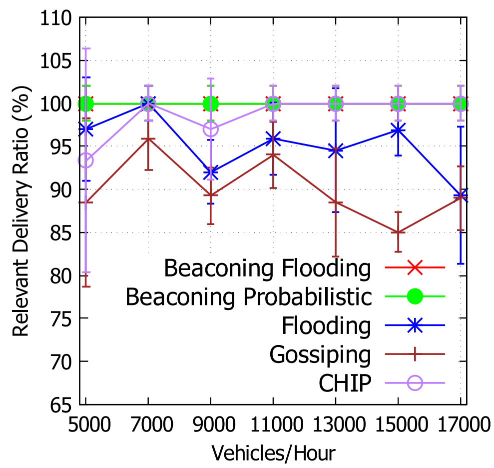
(a) Total Number of Transmitted Packets



(b) Total Number of Transmitted Packets (Zoomed)



(c) New Vehicles Delivery Ratio (%)

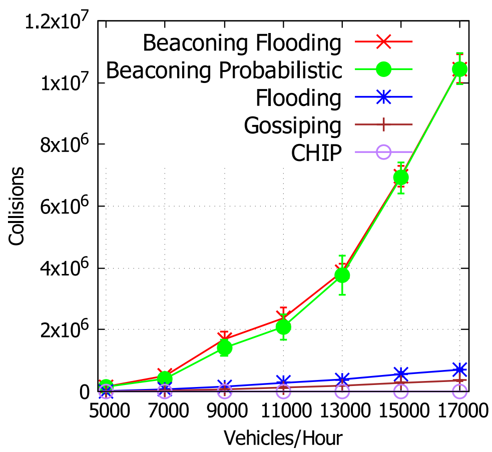


(d) Relevant Delivery Ratio (%)

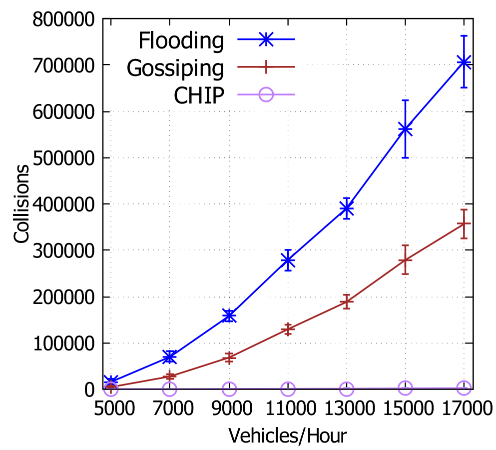
Figure 4.6: CHIP - Stationary detector - Urban Scenario Simulation Results

The NVDR results are shown in Figure 4.6c. As expected, the hovering approaches that use periodic beacons achieve constant results close to 100%. The reason for that is the often request beacon messages that the vehicles in this scheme broadcast (Every 1s). The proposed protocol maintains the same NVDR as the beaconing approaches for the denser scenarios. The utility formula picks the most effective forwarders which later periodically retransmit the packet. These features make it to perform better than the other algorithms in its category. However, for the sparser scenario

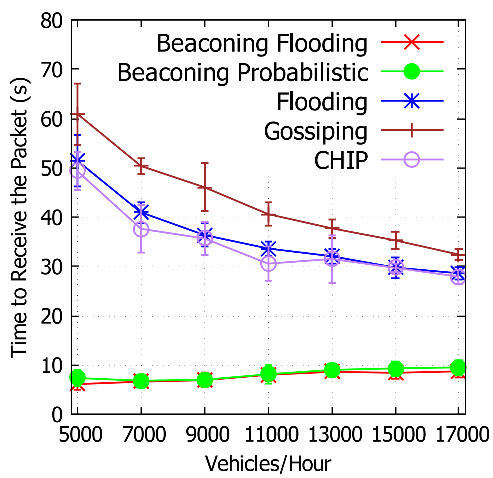
CHIP is outperformed by the beaconing approaches. The trade-off comes at the huge number of TNTP consumed by the beaconing approaches.



(a) Collisions



(b) Collisions (Zoomed)



(c) Time to Receive the Packet (s)

Figure 4.7: (Continued) CHIP - Stationary detector - Urban Scenario Simulation Results

Although the CHIP's NVDR for sparse densities is not at the same level as in the case of the beaconing approaches, in Figure 4.6d it can be seen that the CHIP's RDR is almost the same as the one of the beaconing approaches. This means that the final goal of successfully informing the vehicles that will really go through the event is achieved with much less TNTP than the other protocols. Despite their lower NVDR, Flooding and Gossiping show a satisfactory RDR too. This is because of the robust repetition interval calculation scheme which was discussed earlier in this paper.

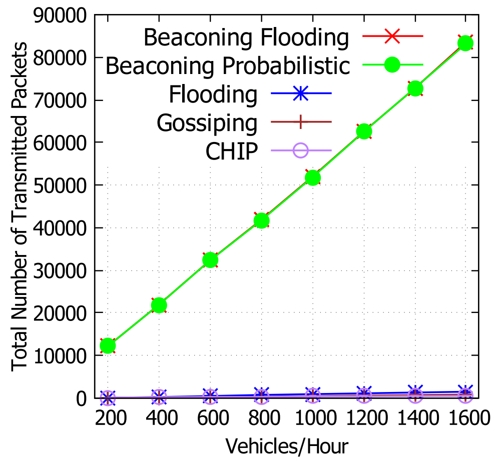
The number of collisions that occurred during the simulation time by each of the compared protocols is shown in Figure 4.7a and 4.7b. The increase of TNTP leads to increased number of collisions. More collisions mean that more of the network bandwidth is wasted. Therefore, the beaconing protocols result is an enormous number of collisions that increase almost exponentially with the VANET density. The other three dissemination protocols' collisions number is much lower, but as expected the Flooding maintains the higher number among them. It is followed by Gossiping and at the very bottom of the graph is the CHIP's line. As Gossiping has had twice as much TNTP than Flooding, in this case it results with a twice smaller number of collisions. Also, as explained above, the CHIP's TNTP are not increasing with a high factor even when the VANET density increases, which is a case for the other protocols. Therefore, the measured number of collisions stays close to zero.

Figure 4.7c shows the average TRP. The performance of the Beaconing Flooding and Probabilistic algorithms is better than the others. Because of the periodic beacons the vehicles that enter the *Hovering Zone* are being informed about the event very soon after they enter, i.e. 5-10 seconds. As can be noticed, the TRP of these protocols increases with the vehicles' density, which is not a case for CHIP, Flooding, and Gossiping. This is because of the enormous amount of collisions that occur during the operation of these protocols and cause dropping of the actual data packets. The high number of TNTP is the main cause for the increased number of collisions.

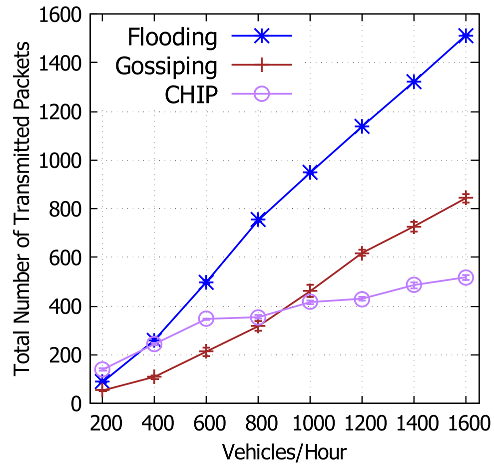
On the other hand, the other protocols average TRP varies from 30-60 seconds, where the CHIP's one does not exceed 50s. That is very important because of the following. The *Hovering Zone Radius* in our simulations was set to 1000m. Also, the maximum speed of the vehicles in urban environments is 60km/h. That means that a vehicle traveling in a straight line from the edge of the *Hovering Zone* to the event will need approximately 60s. Not exceeding 50s of TRP means that the vehicles in the zone will be informed about the event in advance and they can react accordingly. The TRP for Flooding and Gossiping is above CHIP's one because of the periodic broadcasts of the packet that the forwarders in CHIP do. With those, some of the new vehicles in the *Hovering Zone* are informed without waiting for the next dissemination session.

4.2.1.2 Highway Scenario

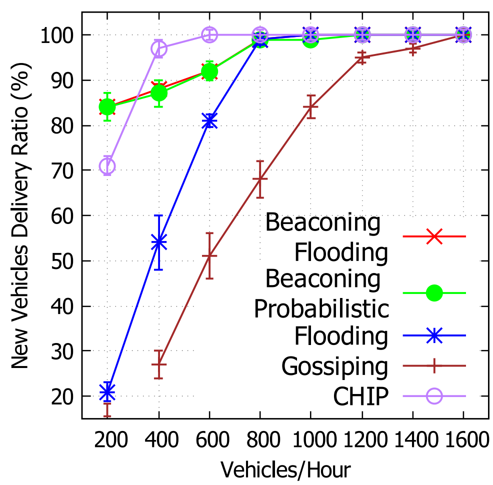
The TNTP are shown in Figure 4.8a and 4.8b. The periodic beacon messages in the beaconing approaches result with a high number of TNTP. Since most of the packets are as a result of the beacons and not the data packets, the difference between the Beaconing Flooding and the Beaconing Probabilistic protocol is negligible. CHIP, Gossiping and Flooding achieve much lower number of TNTP. In the same time Flooding produces most TNTP among those three. Since the Gossiping rebroadcast probability is 50%, its TNTP are twice less than Flooding. At the sparse VANET density CHIP has similar TNTP with Flooding Gossiping. However, a part of those packets in CHIP are used as a broadcasts at the *Hovering Zone's* edge by the forwarders, which informs earlier even more vehicles. That is not a case for Flooding and Gossiping. Also, similarly as for the urban scenario, while increasing the vehicular density, the CHIP' TNTP are not increasing with the same difference as in the case of the other compared protocols. The reason for this is its effective algorithm which even if there are many nodes, it chooses just the furthest ones to forward the data.



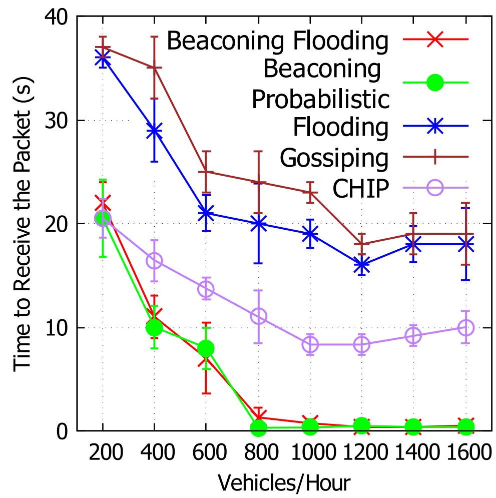
(a) Total Number of Transmitted Packets



(b) Total Number of Transmitted Packets (Zoomed)



(c) New Vehicles Delivery Ratio (%)



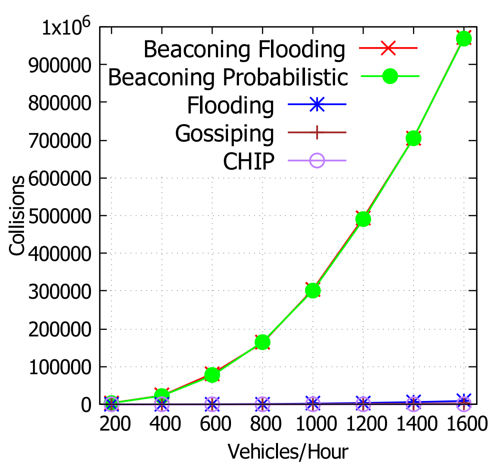
(d) Time to Receive the Packet (s)

Figure 4.8: CHIP - Stationary detector - Highway Scenario Simulation Results

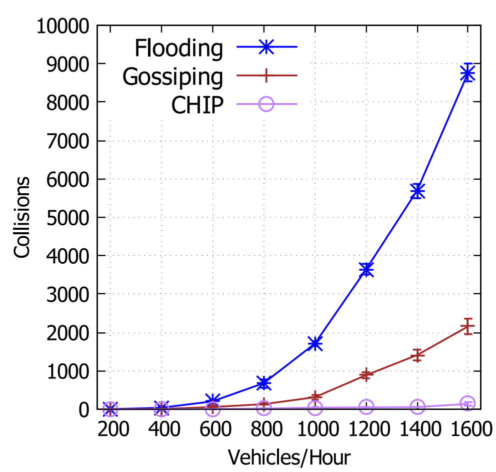
The NVDR is shown in Figure 4.8c. In this case CHIP maintains similar NVDR with the beaconing approaches, despite the much lower TNTP that it consumes. With this we prove the effectiveness of the proposed algorithm. Also, the CHIP's mechanism, where the forwarders broadcast the event information one more time once they are at the *Hovering Zone's* edge, helps to match its NVDR with the beaconing approaches. Moreover, Flooding and Gossiping do not show satisfactory performance for the sparse scenarios where the VANET is partitioned. They do not have any additional mechanisms for the forwarders to repeat the broadcast multiple times and that is why they cannot successfully address this challenge.

The RDR graph is not shown for the highway scenario. Because of the simple highway VANET topology, and the carefully chosen repetition interval of the detector vehicle, all of the protocols achieve a RDR close to 100%.

The TRP results are show in Figure 4.8d. The beaconing approaches have the shortest TRP because of the periodic beacon request messages. Flooding and Gossiping achieve TRP which is similar to the repetition interval in this case. As per the repetition time calculation scheme discussed in the above sections, the dissemination repetition time in this case would be 24s. Therefore, the TRP of Flooding and Gossiping are similar to this number. The CHIP's TRP is much lower than this because of the additional broadcast of the forwarders at the *Hovering Zone's* edge. With that, the vehicles that just entered and the ones that are about to enter are informed in advance and that decreases the average TRP.



(a) Collisions



(b) Collisions (Zoomed)

Figure 4.9: (Continued) CHIP - Stationary detector - Highway Scenario Simulation Results

The number of collisions that occurred during the simulation time are shown in Figure 4.9a and 4.9b. Similarly as for the urban scenario, the beaconing approaches have the highest number of collisions because of the frequent beacon messages. However, the difference between those two is not significant because most of the messages that they broadcast are beacons and not data packets. Therefore, the number of collisions is similar. Flooding, Gossiping and CHIP are having a smaller number of collisions. As it was expected, the Flooding protocol has produced more collisions than CHIP and Gossiping, where Gossiping has twice less than Flooding. CHIP's collisions are negligible which is shown at the bottom of the graph. Moreover, the number of collisions is tightly connected with the TNTP. Therefore, the explanation for these results is obvious.

In Figures 4.10 and 4.11 we are presenting the highway results of the simulation experiments while varying the Hovering Zone Radius and assuming the detector vehicle not leaving the event place.

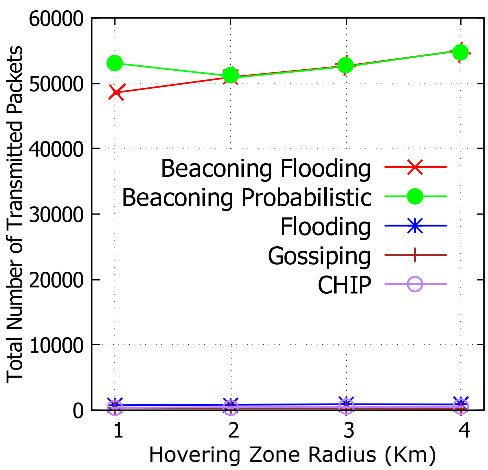
The TNTP are shown in Figure 4.10a and 4.10b. As could be seen, the TNTP of the beaconing approaches remain similar with increasing of the zone's radius. This is because despite the hovering zone radius increase all of the vehicles in the simulation scenario constantly send beacon messages, which are the major cause for the huge TNTP that those protocols have. On the other hand, Flooding, CHIP, and Gossiping have much smaller number of TNTP. The TNTP of Flooding and CHIP slightly increase with the hovering zone radius incrementation because they are spreading the information to a further point. However, CHIP maintains much lower rate of TNTP than Flooding. The Gossiping TNTP are dropping down because of the huge drop of the NVDR performance as shown in Figure 4.10c.

In Figure 4.10c the NVDR performance of the compared protocols is shown. All of the selected protocols except Gossiping are maintaining a satisfactory NVDR results, while increasing the hovering zone radius. In the case of the beaconing approaches this is a result of the constant beacons that they use. In the case of CHIP this is a result of the adaptive and efficient dissemination mechanism as well as the robust repetition interval calculation that was proposed. Flooding also has a satisfactory NVDR because of the efficient calculation scheme for the repetition time. However, Gossiping's performance drops because of the random forwarder choosing mechanism, which does not always select efficient forwarders. With increasing of the dissemination radius the chance of selecting non efficient forwarders is increasing. Hence, the NVDR of the Gossiping protocol is not satisfactory.

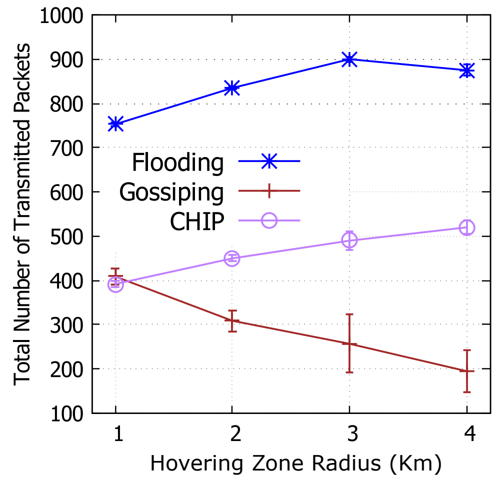
The TRP results are shown in Figure 4.10d. The beaconing approaches maintain the earliest TRP when compared to the other protocols. The major reason for that is the frequent beacon messages. However, the CHIP's TRP is still satisfactory and better than the Flooding and Gossiping. In the same time, CHIP is using less TNTP than all of them. Obviously, the TRP of the selected protocols is increasing with increasing the hovering zone radius. Except Gossiping, which TRP is increasing with a much higher rate than the others because of the NVDR performance drop, the other protocols TRP is increasing with a similar rate while increasing the dissemination radius.

The collisions that occurred during the simulation time and while increasing the hovering zone radius are shown in Figures 4.11a and 4.11b. The beaconing approaches produce a very large number of collisions because of their frequent and constant beaconing. They remain very similar with increasing of the hovering zone because regardless of the zone, all of the vehicles using these approaches send beacon messages all the time. On the other hand, Flooding, CHIP, and Gossiping maintain a much smaller number of collisions. The collisions that occurred with Flooding are increasing with increasing of the hovering radius because of the larger dissemination area. The

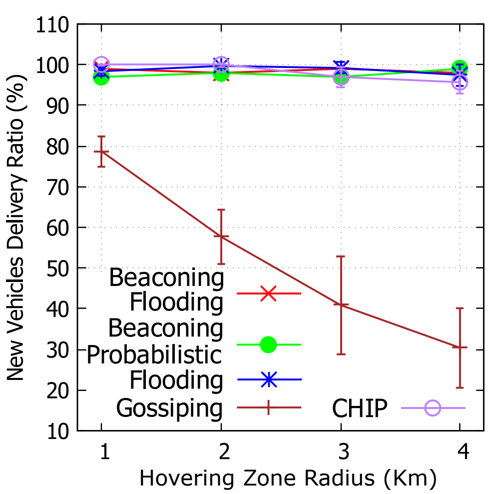
Gossiping's collisions are decreasing because of the NVDR performance drop that Gossiping faces with. Finally, the CHIP's collisions are lowest among all the other protocols. Also, they are not increasing with the increasing of the hovering zone. These two are a result of the mechanism that picks the most distant vehicles to be forwarders of the event information.



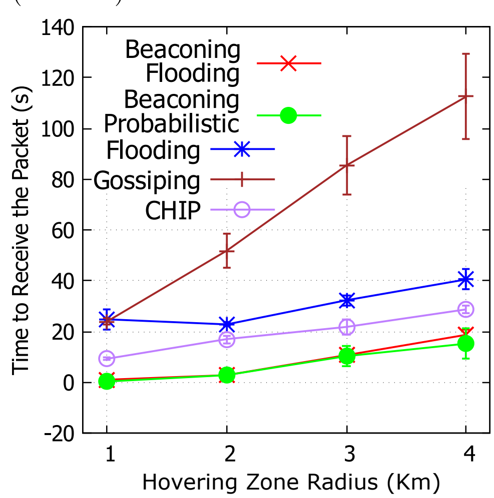
(a) Total Number of Transmitted Packets



(b) Total Number of Transmitted Packets (Zoomed)

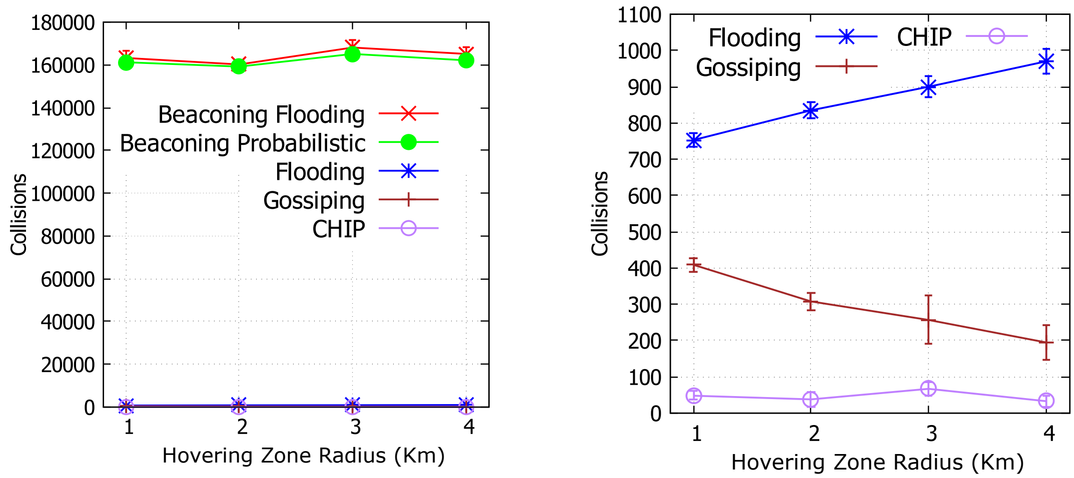


(c) New Vehicles Delivery Ratio (%)



(d) Time to Receive the Packet (s)

Figure 4.10: CHIP - Stationary detector - Hovering Radius Variations - Highway Scenario Simulation Results



(a) Collisions

(b) Collisions (Zoomed)

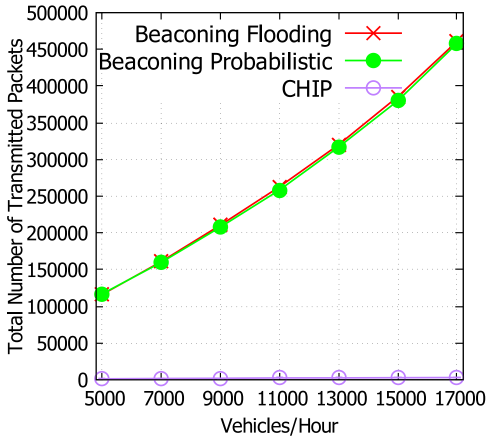
Figure 4.11: (Continued) CHIP - Stationary detector - Hovering Radius Variations - Highway Scenario Simulation Results

4.2.2 Simulation Results - Non-Stationary Detector

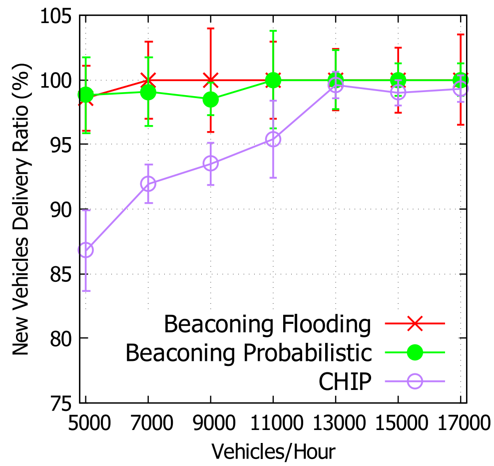
The results for this section are shown in Figure 4.12. However, the Flooding and Gossiping schemes are excluded from the comparison. They are dissemination protocols and they do not have a mechanism to select the next dissemination initiator when the detector leaves the *Hovering Zone's Center*. Therefore, in this case CHIP is compared just with the Beaconing Flooding and Beaconing Probabilistic hovering schemes. Moreover, the beaconing approaches do not have a specific scheme for operation in the case of non-stationary detector. Therefore, their results are very similar to the ones in Figure 4.7.

4.2.2.1 Urban Scenario

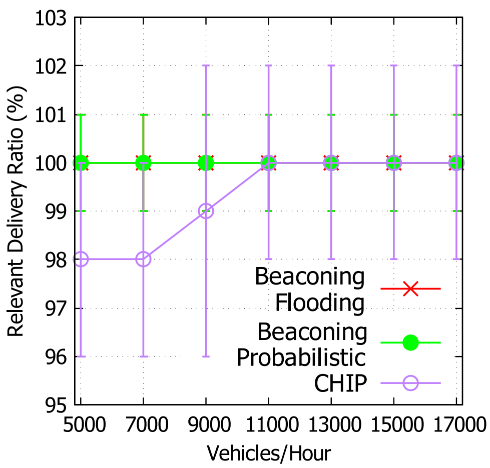
The TNTP are shown in Figure 4.12a. The beaconing approaches consume a tremendous number of TNTP because of their periodic beacons. On the other hand, the CHIP's number of TNTP is much lower. This is because of its dissemination and ini-



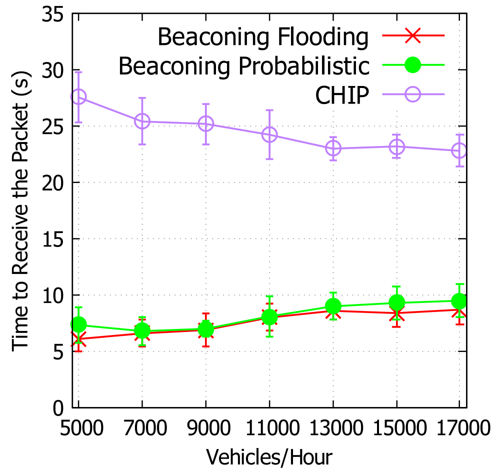
(a) Total Number of Transmitted Packets



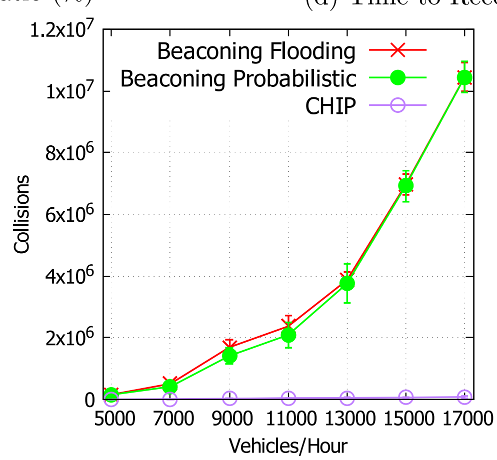
(b) New Vehicles Delivery Ratio (%)



(c) Relevant Delivery Ratio (%)



(d) Time to Receive the Packet (s)



(e) Collisions

Figure 4.12: CHIP - Non-Stationary detector - Urban Scenario Simulation Results

tiator algorithms which select just few crucial nodes to participate in the information spread process.

The NVDR results are presented in Figure 4.12b. In this case CHIP's NVDR is much better for the sparser VANETs when compared to the one in Figure 4.6c. The reason for this is the dissemination initiator selection algorithm where a vehicle that is in a region which is not reachable by the other vehicles transmission range, broadcasts the event packet when its utility equation based timer expires. Therefore, the nodes in this region become informed and that increases the average NVDR.

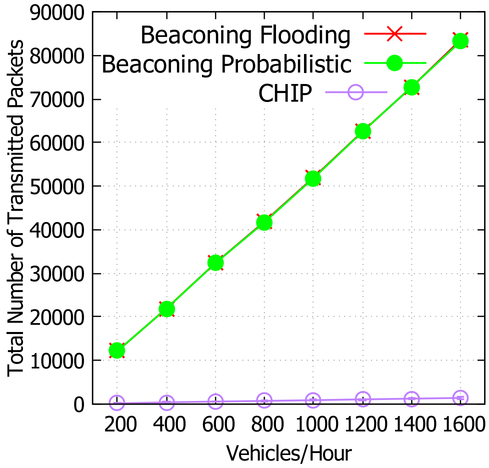
The RDR is shown in Figure 4.12c. As can be seen, the CHIP's performance is very close to the performance of the beaconing approaches. Almost all of the vehicles that pass the event street would be informed in advance if the CHIP protocol is used. Therefore, we prove that the enormous number of TNTP used by the beacons is not worth in this case and CHIP would be a better choice for a hovering protocol.

The situation where the initiator vehicle is in a region not reachable by the others' nodes transmission range positively affects the CHIP's TRP too. In this case the TRP is significantly better than in the case of a stationary detector.

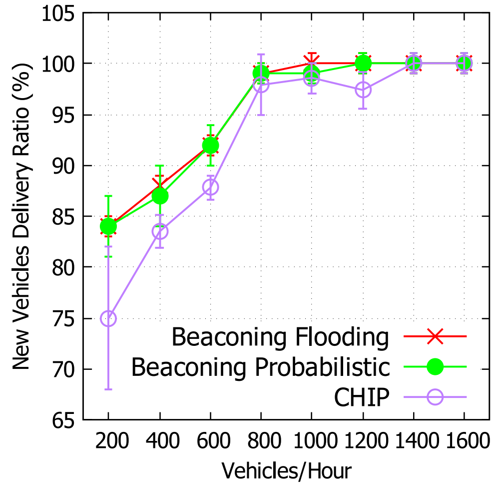
The collisions that occurred during the simulation time are shown in Figure 4.12e. Higher number of TNTP leads to more collisions. Therefore, the beaconing approaches result with a high number of collisions, whereas CHIP's ones are on a low level because of the low number of TNTP.

4.2.2.2 Highway Scenario

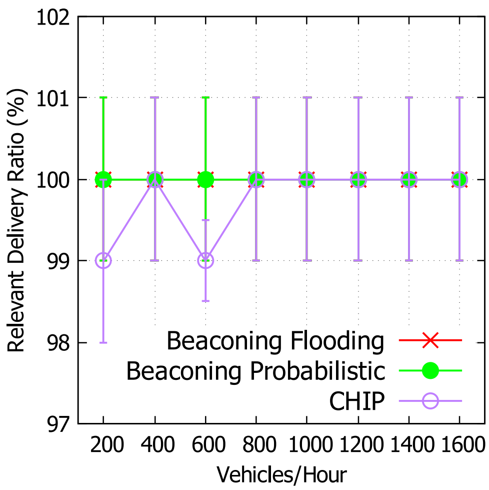
The TNTP are shown in Figure 4.13a. Because of the frequent beacon messages, the beaconing protocols consume too many packets to operate. Moreover, CHIP's algorithms select just some of the nodes to disseminate the data and to restart the dissemination. Because of that its TNTP are much lower than the ones of beaconing



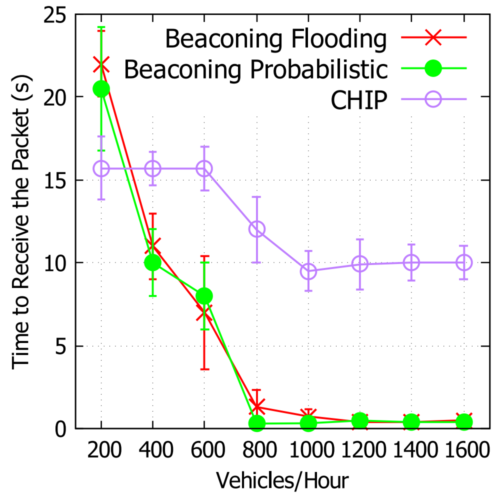
(a) Total Number of Transmitted Packets



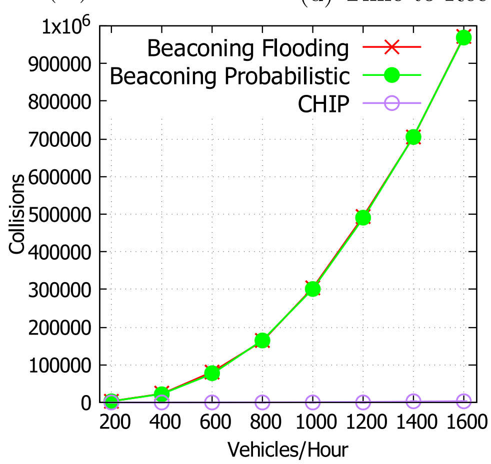
(b) New Vehicles Delivery Ratio (%)



(c) Relevant Delivery Ratio (%)



(d) Time to Receive the Packet (s)



(e) Collisions

Figure 4.13: CHIP - Non-Stationary detector - Highway Scenario Simulation Results

approaches.

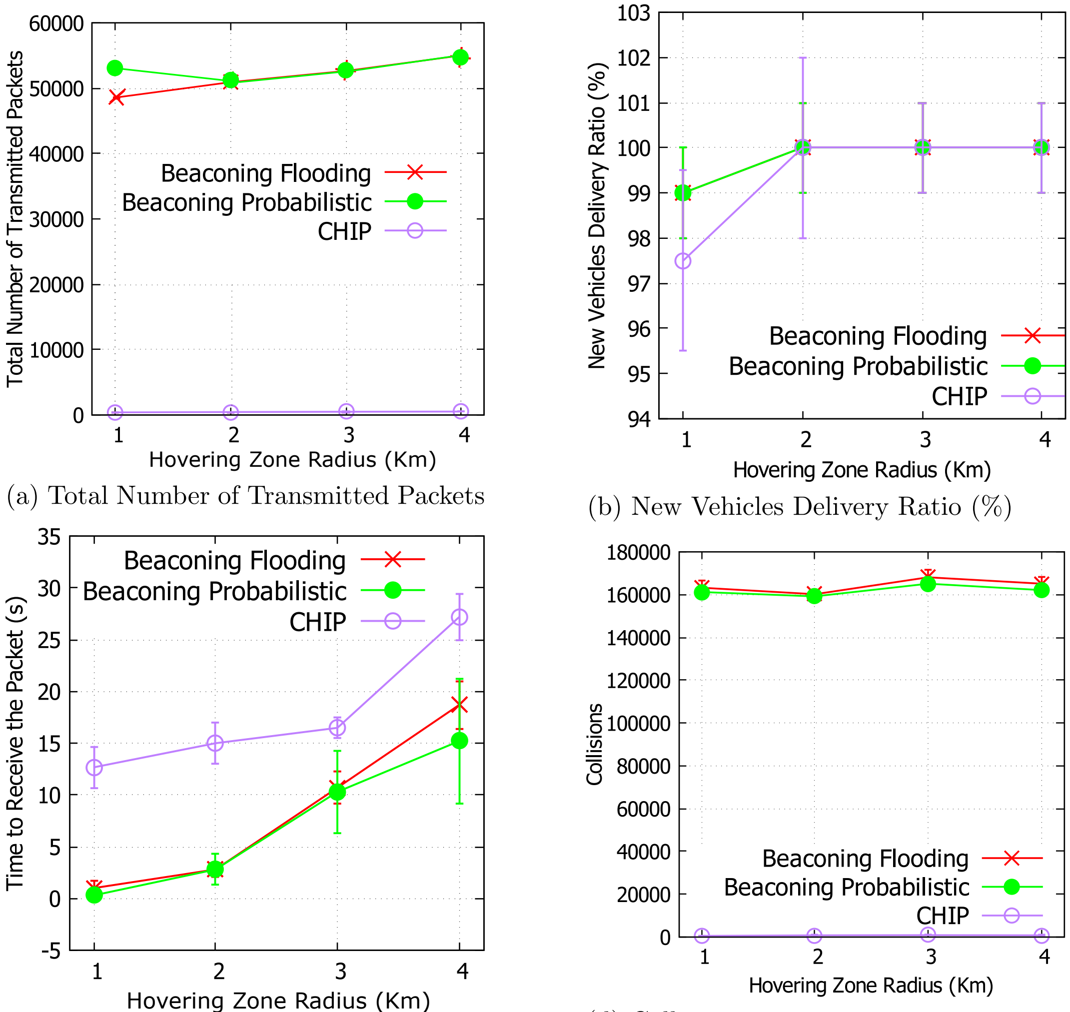
The NVDR results are shown in Figure 4.13b. All of the protocols have similar results. The beaconing protocols have a slightly better performance because of the frequent beacons which make the vehicles to have more updated topology view and with that they achieve better NVDR.

The RDR results are shown in Figure 4.13c. The beaconing approaches and CHIP achieve RDR close to 100%. For the beaconing approaches this is a result of the frequent beacon messages. CHIP's satisfactory results are a cause of the carefully chosen dissemination restart time, which guarantees that the nodes driving to the event are informed in advance. Also, the intelligently selected forwarders and their additional broadcast at the *Hovering Zone's* edge shows to be effective.

The TRP results are shown in Figure 4.13d. For the denser scenarios CHIP shows similar results as in the case of the stationary detector. However, the results for the sparser scenarios where CHIP operates with the initiator selection scheme are lower than in Figure 4.8d. A vehicle that is in a region not reachable by the dissemination of the others acts as an initiator of the dissemination. With that it informs the vehicles in that region sooner which affects the lowering of the average TRP.

The collisions for this scenario are shown in Figure 4.13e. They go directly proportionally with the TNTP. Because of this, the beaconing approaches have many collisions and wasted bandwidth. On the other hand, CHIP's collisions are at the bottom of the graph.

Another set of simulation experiments that we did in order to evaluate the performance of the proposed protocol and to compare it with other relevant protocols in the literature is the hovering zone radius variation while assuming a non-stationary detector of the event. In this case CHIP will operate with the dissemination initiator mechanism. The results from these experiments are shown in Figure 4.14. The



(a) Total Number of Transmitted Packets

(b) New Vehicles Delivery Ratio (%)

(c) Time to Receive the Packet (s)

(d) Collisions

Figure 4.14: CHIP - Non - Stationary detector - Hovering Radius Variations - Highway Scenario Simulation Results

Flooding and Gossiping protocols did not take part of the simulation experiments in this case because they are a pure dissemination protocols and do not have an initiator selection mechanism to restart the data dissemination at a later time. Because of this, CHIP is compared just to the beaconing approaches.

The TNTP are shown in Figure 4.14a. The beaconing approaches' TNTP number is much higher than the CHIP's one mainly because of the frequent beacon messages. Their TNTP are remaining similar with increasing the hovering zone radius because despite the radius size all of the vehicles send beacon messages and those are the main cause for the high TNTP number. CHIP's TNTP are slightly increasing with the increasing of the radius because of the larger zone that it should disseminate the information through.

The NVDR are shown in Figure 4.14b. All protocols maintain satisfactory NVDR performance. For the beaconing protocols this is because of the frequent beacons and for CHIP this is because of its efficient dissemination and initiation mechanism. Also, the repetition time calculation scheme proves to be robust and effective. Nevertheless, CHIP is using just a fraction of the beaconing protocols' TNTP.

The average TRP of the selected protocols is shown in Figure 4.14c. The beaconing protocols' average TRP is earlier than the CHIP's one as a result of the frequent beacons. However, the CHIP's TRP is satisfactory and proves that the vehicles moving to the event will be informed ahead of time.

The results for the amount of collisions that occurred are shown in Figure 4.14d. The beaconing approaches collisions number is much higher than the CHIP's one. This occurs as a result of the higher TNTP that the beaconing protocols use, which are mainly caused by the frequent beacon messages.

Chapter 5

Conclusions and Future Work

In this thesis we have proposed three different communication protocols for VANETs.

The first proposed protocol is a *Delay Tolerant and Predictive Data Dissemination Protocol (DTP-DDP) for Urban and Highway Vehicular Ad Hoc Networks (VANETs)* [26] and is discussed in Chapter 3.1. It operates in a way that the vehicle that broadcasts the event information waits for a certain time to collect replies from the vehicles that received the message. Later on, the vehicle that collected the replies calculates a utility value for each of them. This value is calculated based on the driving distance, the encountering probability to the event and a moving away flag which indicates whether the vehicle is moving in the direction of the event or not. On each different street and in each different direction the vehicle with the highest utility score is chosen to forward the message. A packet with a forwarding command for the selected vehicles is being broadcasted. Once those vehicles receive the command they retransmit the event data. However, *DTP-DDP* also implements an *edge mechanism* which means that once the vehicle receives the event packet from the detector or the forwarder with a low signal strength it is not sending any replies, but it broadcasts the message immediately. With this, the risk of losing the reply and response messages is avoided. Moreover, in the case of the first hop dissemination, it is the detector of the event that collects the replies and selects the next forwarders. After that, it is the forwarders that perform this process. Once the event is being spread in the predefined dissemination region the protocol operation is terminated.

The second proposed protocol is *Efficient Encounter-based Event Dissemination Protocol (E-BED) for Urban and Highway Vehicular Ad Hoc Networks* [27] and is discussed in details in Chapter 3.2 of this thesis. *E-BED* is an improvement of the previously proposed *DTP-DPP*. The general operation of *E-BED* is similar to its predecessor *DTP-DDP*. The vehicle that detected the event or the forwarder of the event packet waits for a certain time to collect reply messages from the receivers. However, in *E-BED* the waiting time has been lowered when compared to *DTP-DDP* in order to reduce the minimum end to end delay, but at the same time ensure that the replies are being received successfully. Because of that, the *edge mechanism* that *DTP-DDP* has is avoided in this case. Also, in *E-BED* not all of the receiver vehicles reply to the sender. We have done a set of experiments and set a minimum distance threshold that the vehicles should exceed in order to send their reply. The purpose of that is to reduce the number of reply messages being sent. In addition, the vehicles that are close to the previous sender do not have a significant broadcast effect. Furthermore, the collector of the replies calculates a utility score for each of the vehicles that replied. In each different street and in each different direction of the streets one vehicle with a highest score is selected to retransmit the data. However, in the case of *DTP-DDP* it is a common situation that two or more vehicles are on a different street but still really close to each other. Hence, one of their broadcasts is unnecessary. To avoid this situation, in *E-BED* we have introduced another distance threshold between the vehicles. Same as in the previous case, this threshold was set after an extensive simulation experiments and measurements have been done. After the previously mentioned selection operation, the vehicle that collected the replies measures the distance among the selected forwarders. If the distance between two of them is higher than the threshold, the vehicle that is closer to the event is excluded from the forwarders' list. Finally, a message with a command for retransmission is broadcasted. The vehicles included in this message will forward the event information immediately.

Finally, the third proposed work is *Comprehensive and efficient Hovering Information Protocol (CHIP) for Urban and Highway Vehicular Ad Hoc Networks (VANETs)*. To our best knowledge this work is first of its kind in the literature. Its main goal is to keep an event data alive in a certain region. In order to do that the other hovering information protocols use a beaconing approach, which means that in order to operate successfully they are constantly generating beacon messages. Although achieving a great packet delivery ratio, these protocols produce an enormous amount of redundant messages which waste the network bandwidth and saturate the network. *CHIP* uses a whole new approach to address the same issue. In general, it is composed of a data dissemination protocol which is run periodically as calculated by the proposed formula. Also, in the case when the detector of the event is not anymore at the event place the protocol performs an algorithm which will pick the next vehicle to restart the dissemination. Moreover, the dissemination and the next dissemination initiator selection algorithms do not use any additional response and reply message. The whole operation is performed just by using the same event packet that is being broadcasted. The more eligible forwarders of the data and the more eligible dissemination initiators broadcast before the other vehicles. When those receive the signal they cancel their transmission schedules.

Moreover, we have done a performance evaluation and compared each of the proposed works with other selected and relevant protocols from the literature. We have done that by the means of simulation experiments. More details about this could be found in the Chapter 4 of this thesis. Furthermore, *DTP-DDP* maintains the same packet delivery ratio as the compared protocols while generating less retransmission packets than those protocols. However, its end to end delay is higher than the other protocols. Because of the shorter waiting time for the replies, *E-BED* improves over *DTP-DDP* in terms of the delay. In its case, the delay is similar as the other compared protocols while achieving higher delivery ratio than those protocols and in the same time generating less packets than all of them, including its predecessor *DTP-DDP*. Finally, the *CHIP's* results show its superiority in terms of used packets over the selected protocols. It achieves very similar delivery ratio for the new vehicles that enter the hovering zone with a few hundred times fewer packets than those protocols. In *CHIP*, the average time to receive the event information after entering the hovering zone is higher than the beaconing approaches, but still short enough to ensure that the vehicles will be informed about the event before going through it.

In the future we are planning to extend the operational efficiency of *E-BED* and *CHIP* by considering the capability of some of the vehicles in the VANET to exchange data by using the cellular networks.

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