A Novel Data Dissemination Scheme in Vehicular Networks for Intelligent Transportation System Applications

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my readers.

I understand that my thesis may be made electronically available to the public.

--Fatemeh Rezaei

Abstract

Numerous local incidents occur on road networks daily many of which may lead to congestion and safety hazards. If vehicles can be provided with information about such incidents or traffic conditions in advance, the quality of driving in terms of time, distance, and safety can be improved significantly.

Vehicular Ad Hoc Networks (VANETs) have recently emerged as an effective tool for improving road safety through the propagation of warning messages among the vehicles in the network about potential obstacles on the road ahead.

This research has presented an effective warning data dissemination scheme which deploys relay strategy and concept of Region of Interest (RoI). A warning data message is characterized as spatio-temporal, implying that both the location and the time of an incident must be considered. Factors such as the type of warning message, the layout of the road network, the traffic density and the capacity of alternative roads are influential in determining the RoI in which the warning message needs to be propagated. In the developed scheme, the type of warning message is taken into account for the determination of the RoI so that the more severe the incident, the wider the RoI. In the selection of the relay point, the border relay area in which the relay point is placed, is adapted to the traffic density so that the higher the traffic density , the narrower the relay area. Traffic statistics are used to calculate the RoI, which is then enclosed in the warning message so that the message is not retransmitted beyond the RoI. Also, the responsibility for retransmitting the message is assigned to the relay node. The data is then

disseminated effectively so that vehicles in areas unrelated to the incident are not informed.

The primary objective of this research is to provide better understanding of the dissemination of warning data in the context of a vehicular network with the ultimate goal of increasing the possibility of using VANETs for safety applications.

Acknowledgments

In the name of Allah, the most beneficent, the most merciful

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It is my great pleasure to express my sincerest gratitude to my parents, the best and most kind-hearted individuals I have ever known. Although we are living far away from each other, my heart and thoughts are always with them. I will always remember and greatly appreciate their endless devotions, prayers, and inspiration throughout my life.

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Last, but certainly not least, I cannot ignore the inspiration I have received from my precious little girl, Golsa, who was born in the middle of my studies. Although my life

became very difficult, she has helped me to understand the true meaning of love and sacrifice. Golsa has enabled me to understand that the best, happiest, and sweetest moment for a mother can be achieved through her child's simple smile.

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Chapter 1

Introduction

Traffic information propagation in transportation networks using vehicular networking is investigated in this research. There are several applications proposed using vehicular-based networks in which various types of data with different degrees of importance, target regions, and delay tolerance may need to be transmitted. The focus of this research is on the dissemination of data related to vehicle safety applications, particularly real-time collision avoidance and warning. Data generated or received is related to any incident that causes a reduction of roadway capacity or an abnormal increase in demand including vehicle crashes, breakdowns, and work-zone lane closures. The purpose of data dissemination in transportation networks is to inform vehicles about dynamic road traffic condition so that a safe and efficient transportation system can be achieved.

This chapter begins with an introduction to traffic information propagation and its beneficial consequences. A comparison is made between conventional traffic information propagation system and the current proposed approaches. Afterwards, various network architectures, as underlying networks for data dissemination, are presented and their properties are discussed. The existing challenges related to the data dissemination are briefly presented. Finally, the research contributions as well as the outline of the remainder of the thesis are presented.

1. 1 Traffic Data Dissemination

Many people lose their lives and/or are injured due to accidents or unexpected events taking place on road networks. Besides traffic jams, these accidents generate a tremendous waste of time and fuel. Undoubtedly, if the vehicles are provided with timely and dynamic information related to road traffic conditions, any unexpected events or accidents, the safety and efficiency of the transportation system with respect to time, distance, fuel consumption, and environmentally destructive emissions can be improved. As an example depicted in Figure 1.1, when a car crash takes place, a warning message is generated by the affected vehicle and propagated to a certain area. Precautionary steps can be taken by the vehicles that are very close to the accident; consequently, further accidents may be prevented. Also, vehicles that are located further and are going to take the affected road segment as a part of their paths, can take alternative paths because they are informed about the accident and the congestion. Due to the beneficial consequence of traffic information propagation, there are growing interests and demands in the area of Intelligent Transportation Systems (ITS) for developing information dissemination applications.

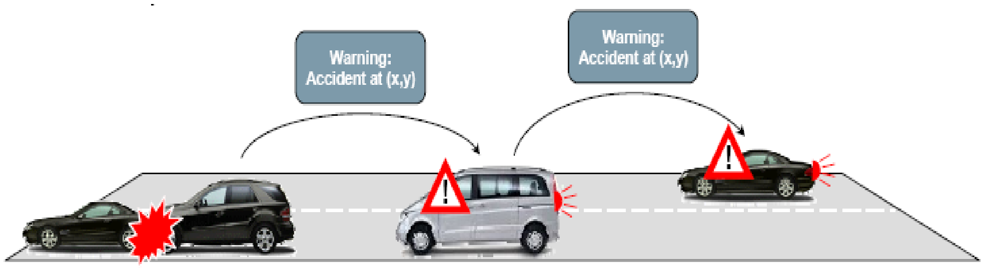


Figure 1.1: Warning Message Propagation through the Network

1. 1. 1 Conventional Traffic Information Propagation

Conventional Traffic Information Systems (TIS) are organized in a centralized way as shown in Figure 1.2 [1]. As shown in the figure, the sensor-based traffic-monitoring systems are placed directly at the roadside and they collect data about the current traffic conditions. The data is then transferred to a central Traffic Information Center (TIC), where the current road situation is analyzed. The analysis of the traffic condition is summarised into a message and forwarded to an FM radio broadcast station and a traffic message channel. Finally, a message is transmitted to the drivers via a radio data system. Alternatively, the traffic messages can be transferred on demand via a cellular mobile phone network [1].

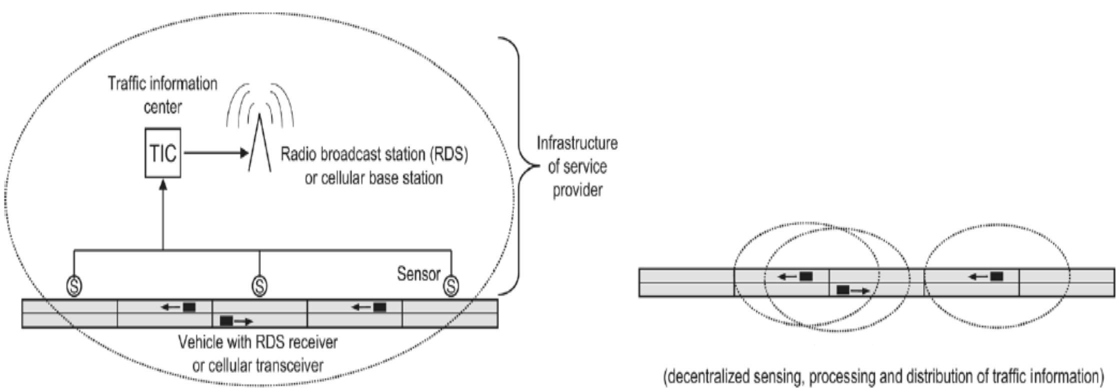


Figure 1.2: Conventional Form of Traffic Information System (Left) and Vehicular Network (Right) [1]

A centralized service for distributing traffic information has several undesirable characteristics as follows [1]:

- A large number of sensors are needed to be deployed since the service is limited to streets where sensors are placed. Therefore, large investments for communication infrastructure (e.g., sensors, central unit, wired and wireless connections) are needed.
- The recorded traffic density data is transmitted to a central unit for traffic analysis. This procedure causes a relatively high delay before the result is broadcasted to the drivers on the road.
- Since a central unit covers a relatively large area and due to the limited bandwidth for transmitting the traffic messages, only major road events are transmitted. Thus, constantly up-to-date and detailed information for the local area may not be available.
- In the case of cellular distribution of traffic information, service charges will apply to the users.

It can be concluded that collecting and/ or propagating data in a local environment, low information delivery latency, scalability, and low deployment and/or maintenance cost are the characteristic lacking in existing TIS developments and need to be taken into consideration for future developments with respect to functionality and performance improvement.

1. 1. 2 Vehicular Network Technology

For the reasons mentioned in the previous section, a completely different approach for monitoring the traffic situation and distributing the traffic messages to vehicles has been proposed. The proposed approach is a decentralized self-organizing traffic information system in which vehicles are equipped with sensing, computing, and communication capabilities and are able to communicate with one another on top of an ad-hoc network established among the equipped vehicles and some possible roadside units. This technology is referred to as vehicular network technology in which each equipped vehicle acts as a mobile sensor presented on the road with the capability of establishing a network. As shown in Figure 1.2, a comparison is made between the conventional form of traffic information systems and a vehicular network.

1. 1. 3 Vehicular Network Applications

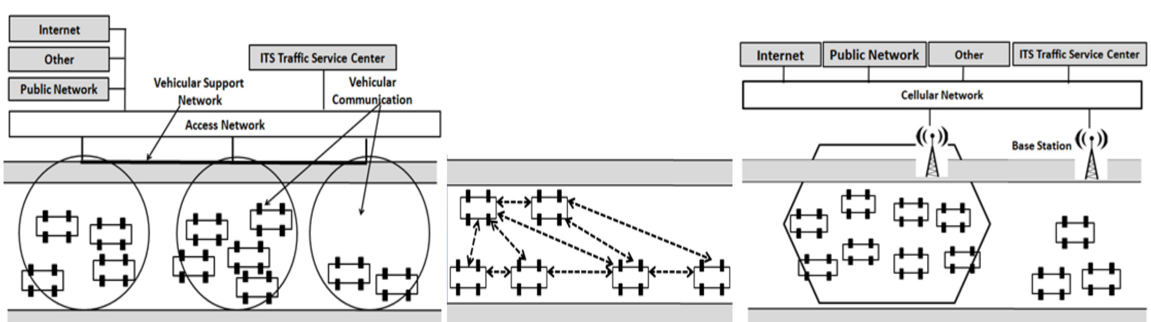
The expected applications based on vehicular networks are broad and can be divided into two categories explained as follows:

1) Applications in which their main concerns are safety and efficiency in transportation systems: These applications include emergency warning systems, lane-changing assistant, intersection coordination, traffic sign/signal violation warning, and road-condition warning. Applications of this category usually are delay sensitive and they can exploit the vehicle-to-vehicle communication due to its low message delivery latency in local propagation. These applications are in the interest of public sector [2]. Because the safety and efficiency are the main concerns in this group, there is a growing interest to pursue research in this area.

2) Comfort applications which include weather information, gas station, restaurant location, price information, and interactive communication such as Internet access or music downloads [1]: This category of applications is in the interest of the private business and automotive industry [2].

1. 2 Underlying Communication Network Architecture

There are several possible network architectures to organize and connect the communicating systems which are built in vehicles. Four alternative network architectures include [3]: 1) a pure wireless vehicle-to-vehicle ad-hoc network known as VANET or in other words, using direct vehicular communication; 2) a wired backbone with wireless last-hops or using dedicated infrastructure; 3) a hybrid architecture using vehicle-to-vehicle communications that does not rely on a fixed infrastructure, but can exploit it for improved performance and functionality when it is available; and 4) cellular systems. The pictorial illustrations of the networks except the hybrid architecture are shown in Figure 1.3 and relative comparisons made regarding some of the networks' properties are summarized in Table 1.1.



a) Communication Using Dedicated Infrastructure

b) Direct Vehicle to Vehicle Communication

c) Cellular Systems

Figure 1.3: Three Types of Network Architectures

As mentioned, traffic information can be distributed among vehicles deploying some dedicated road side units. The feasibility of vehicle-to-infrastructure communication is explained by [8], [9]. With respect to research carried out by [8], the possibilities and limitations for the use of scattered WLAN cells by devices in fast moving vehicles is discussed and an analysis of the performance that can be expected for the communication in such scenarios is presented. In this research, transmission characteristics are measured for sending and receiving high data volumes using UDP and TCP in vehicles moving at different speeds and passing one or more IEEE 802.11 access points at the roadside. Based on the observations, implications for higher-layer protocols and applications are discussed. With respect to research carried out by [9], the concern is whether 802.11-based wireless network can provide reasonable performance to network clients moving in cars at vehicular speed. The high level conclusion is that Wi-Fi networks are viable for a variety of applications, particularly ones that can tolerate intermittent connectivity.

Table 1.1: Relative Comparisons among Communicating Approaches

		Approaches		
Properties		Vehicular communication using dedicated infrastructures	Vehicular communication using cellular systems	Direct vehicular communication
Communication latency		Medium	High	Low
Link availability		Low	Low to Medium	Medium to High
Data rate		Medium to High	Low to Medium	High
System availability	Local	High	High	High
	Global	Low	Medium	High
Cost issue	Initial	High	High	Medium to High
	Operational	Medium	Medium to High	Null to low
Communication service area		Medium	Large	Small to Medium
Exploit geographic relevance of data		No	No	Yes
Support for traffic safety applications		Low to Medium	Low	High

Some of the advantages of infrastructure support include: low latency communication with vehicles in the covered area and extending connectivity / gateway to the Internet. However, this approach requires major changes to the existing highway infrastructure. In addition, it is difficult and expensive to deploy and maintain such communication infrastructures along the road, especially in the rural areas. To address these limitations and problems, recent research efforts have focused on avoiding the reliance on the infrastructure and designing a communication system, according to an Inter-Vehicle-Communication (IVC) network which does not need to have infrastructure support. Some projects using pure IVC include CarTALK 2000 [4], CarNet [5], NoW [6], and the car2car consortium [7].

1. 2. 1 Advantages of Inter Vehicle Communication

There are two key advantages to using IVC when compared with a cellular system. The two benefits of IVC are briefly explained as follows [1]:

1) Direct communication: Since vehicles communicate directly without any intermediate base stations, IVC is suitable for the distribution of time-critical data such as emergency notifications in the area of an accident due to its low delay. Furthermore, vehicles can communicate even in the remote areas that not covered by cellular systems. Yet, due to the established communication network among the vehicles, it is possible that the vehicles can communicate everywhere.
2) No service fees: IVC requires no communication infrastructure or service provider. Service charges are completely avoided.

1. 3 Existing Challenges

The discussion of the data dissemination among vehicles depends on the type of assumed network architecture. In the presence of infrastructures or road side units, two data dissemination approaches are assumed: push-based and pull-based. It should be mentioned that these two approaches are well explained and discussed in Chapter 2.

In the situations in which the infrastructure is absent or the VANETs architecture, two dissemination approaches can be considered: flooding and relaying. The flooding approach generally generates high message traffic. Therefore, the main challenge, encountered in this approach, is avoiding the broadcast storm problem [2]. If the relaying approach is used as a means of data dissemination in VANETs, there are also two challenges that may be encountered: 1) selecting relay points; and 2) ensuring reliability as selected nodes participate in packet retransmissions. The VANETs' intrinsic characteristics have led to the existing challenges in the data dissemination approaches. These characteristics include: 1) high mobility of vehicles resulting in dynamic and volatile network topology; 2) large scale of the established network during high traffic density periods; 3) high density of the established network; and 4) network fragmentation periods due to low market penetration rate and low traffic density periods. It is noted that to overcome these challenges encountered in data dissemination using VANETs, several approaches are proposed in various research efforts which are extensively discussed in Chapter 2.

If the vehicles are provided with updated information regarding road traffic conditions, they can make informed and intelligent decisions and thereby, take appropriate actions to avoid being trapped in heavy traffic jams. Informed and intelligent decisions can be referred to a situation in which vehicles do not choose deliberately the congested paths due to unexpected events and alternatively, can take available paths with less congestion level. If the region of data dissemination extends, more vehicles are informed and more vehicles are able to make better decisions. Although informing more vehicles is beneficial, it may not be wise from a communication perspective because informing more vehicles generates higher message traffic, longer delays, and data irrelevancy to the area that is reached by extending the region of propagation. It should be noted that delay has a very undesirable impact on the safety of data disseminations which require very low message latency. It can be concluded that there needs to be a certain area in which the data packet can be transmitted effectively. This research tries to focus on effective traffic information propagation in transportation networks.

1.4 Research Objectives

The primary objective of this research is to provide a better understanding of the data disseminations, VANETs architecture, and how the extension of the data dissemination can influence the costs involved. The specific objectives of this research are as follows:

- To investigate effect of data dissemination in vehicular ad hoc networks. To achieve this objective, two metrics, additional travel cost and communication cost, are defined to examine how extending the region of data dissemination can affect the paths taken by the vehicles and number of vehicles involved.
- To investigate the effective region for data dissemination which is called Region of Interest (RoI). The purpose of information propagation is to inform vehicles

about any unexpected events causing undesirable consequences on road networks. Clearly the information can be very beneficial for the vehicles driving at the vicinity of the undesirable events. Although extending the region of information propagation informs more vehicles, the gains of extending this region comes at the cost of an increase in the number of messages transmitted, and consequently the delay imposed on message propagation. Furthermore, irrelevancy of data to the areas that may be reached is another consequence that can affect determination of the RoI; and

- To propose an effective data dissemination scheme which offers a way to confine the data to the RoI.

1. 5 Thesis Outline

The remainder of the thesis is organized into four chapters. In Chapter 2, literature and research efforts related to data dissemination approaches in vehicular networks are reviewed. Also, the challenges faced, and proposed solutions are briefly explained. Chapter 3 begins with the system model and assumptions made. It continues with the metrics defined and investigates how extending the region of data propagation can affect the shortest paths taken by vehicles and the number of vehicles involved. Afterwards, it is strived to investigate the effective region for data dissemination and some factors that can affect determination of the RoI. Chapter 4 introduces the proposed scheme in which data dissemination is confined to the RoI. Finally, the summary of the thesis is presented in Chapter 5 along with explanations about future work with respect to this research.

Chapter 2

Background and Literature Review

This chapter begins with a brief description about Vehicular Ad hoc Networks (VANETs), their characteristics, similarities, and differences with Mobile Ad hoc Networks (MANETs) which they share a similar underlying philosophy. This chapter reviews different data dissemination approaches presented in a variety of studies and also issues associated with data dissemination in the vehicular networks. The encountered challenges and the proposed solutions by literatures with respect to the issues associated will be extensively discussed.

2. 1 Vehicular Ad hoc Networks (VANETs)

VANETs are self organizing networks established among vehicles equipped with communication facilities. The equipped vehicles are network nodes so that each node can act as the source of data, destination for data and a network router. In the envisioned applications, the equipped vehicles are able to communicate over the 5.9 GHz frequency band via a Dedicated Short-Range Communication (DSRC) based device. DSRC with a range of up to 1000 m allows high-speed communications between vehicles for ITS related applications. Potential DSRC-based applications for public safety and traffic management consist of intersection collision avoidance, warning messages, and approaching emergency vehicle warning.

In 2002, American Society for Testing and Materials (ASTM) approved and published the first new DSRC standard; ASTM E2213-02, for the physical and data link layer in OSI model of network architecture. The standard extends IEEE 802.11a into the high-speed vehicle environment. Basing 5 GHz DSRC on IEEE 802.11a allows expedited development of devices from available chip sets and promotes the interoperability of DSRC devices in wireless LAN environments [10].

2. 1. 1 VANETs versus MANETs

VANETs and MANETs have some similar characteristics such as short-range transmission range, low bandwidth, omni-directional broadcast (at most times), and low storage capacity. In spite of these similarities, they have some different characteristics. The characteristics of MANETs are presented below:

- Most MANET networks are defined in support of special purpose operations and are short-lived such as disaster relief, search-and-rescue, law enforcement, and multi-media classrooms [20].
- MANETs involve a small number of nodes compared with VANETs.
- Nodes have arbitrary movements.

- Transient periods of loss of connectivity can be experienced particularly under sparse traffic conditions.
- Power is a crucial issue.

The characteristics of VANETs are presented below:

- Applications developed for VANETs have very specific and well-defined goals such as providing intelligent and safe transport systems which give good incentives for continuing research in this area.
- VANETs involve a large number of vehicles specifically during high traffic density period.
- VANETs consist of highly mobile nodes moving in the predefined road network. It should be noted that this predefined network topology provides the possibility of predicting vehicular position. Also, there is a possibility of disconnection between vehicles moving along different but adjacent roads due to obstruction [2].
- Most safety applications related to VANETs try to disseminate traffic relevant information to all reachable nodes to a certain geographical area rather than inquiry for a specific route or specific services [2].
- The network topology is dynamic due to high mobility of vehicles. Because of relative fast movement of vehicles, links in network topology are highly volatile.
- Network fragmentation periods can be experienced due to low market penetration rate and during low traffic density periods.
- There is no concern about power.

2. 2 Classification of Data Dissemination Approaches

The data dissemination approaches proposed in the vehicular networking context can be classified into two main categories: 1) Vehicle to Infrastructures data dissemination (V2I) and vice versa (I2V); and 2) Vehicle to Vehicle (V2V) data dissemination. Each of these categories are briefly explained in the following subsections:

2. 2. 1 V2I and I2V Data Disseminations

Push-based and pull-based approaches are considered for V2I (or I2V) data dissemination. In the push-based approach, the generated data is broadcasted to everyone. The drawback of this form of dissemination is that everybody may not be interested to the same data. Therefore is more suitable for applications supporting local and public-interest data such as data related to unexpected events or accidents causing congestion and safety hazards. It also generates low contentions and collisions for packet propagation. However in the second approach (pull-based), vehicles are enabled to query information about specific targets and responses to their queries are routed toward them. As it can be inferred, the pull-based dissemination is useful for acquiring unpopular and individual-specific data. It generates a lot of cross traffics including contentions and collisions.

Reference [11] is a research effort which considers information source (data center) to disseminate data to many vehicles on the roads. It is noted that periodically pouring data on the road is necessary since vehicles receiving the data may move away quickly, and vehicles coming later still need the data.

The data center can be a computer with a wireless interface, a wireless access point, or an infostation [12]. A data center may have a list of data items to disseminate, referred to as the dissemination Data Set (D-Set). The data center periodically broadcasts the D-Set so that each data item is broadcasted once in each cycle. The disseminated data are relayed by moving vehicles and are poured to the desired area. The data delivery information such as source id, source location, packet generation time, propagation direction is specified by the data center and placed in the packet header. It is believed that the disseminated data are often spatial or/and temporal sensitive. For example, the traffic jam at downtown is not likely to be the interest of the drivers who are 30 miles away and will also be less helpful two hours later. Thus, a data item is attached with two more attributes: 1) the dissemination zone (D-Zone); and 2) the expiration time. The vehicles outside this D-Zone will discard the data to save bandwidth. The vehicles use periodic beacon messages to report their moving velocity, direction, and location, so each vehicle (including the data center) can obtain the information about their one-hop neighbours and construct a neighbour list. To avoid overloading the channel with too many beacons, a vehicle can adjust its beacon interval based on its moving velocity. The details of the scheme proposed in reference [11], Data Pouring (DP), are described below.

Basically, the DP scheme uses the partially predictable vehicle mobility which is limited by the road layout. Instead of spreading data throughout the network, it broadcasts the data to one or several roads, called Axis roads (A-Roads). The A-Roads are selected from those main roads going through the data center, and they normally have a higher vehicle traffic density than other roads. The DP scheme also delivers data to the vehicles moving on the roads that intersect with the A-Road, called Crossing roads (C-Roads). However, it does not proactively push data to the C-Roads. Since the vehicles on the C-Roads moving toward the A-Roads will eventually reach a point intersecting with A-Roads, they will obtain the data. Therefore, the D-Zone of a data item only includes the A-Road where this data item is propagated. Figure 2.1 shows the basic idea of the DP scheme.

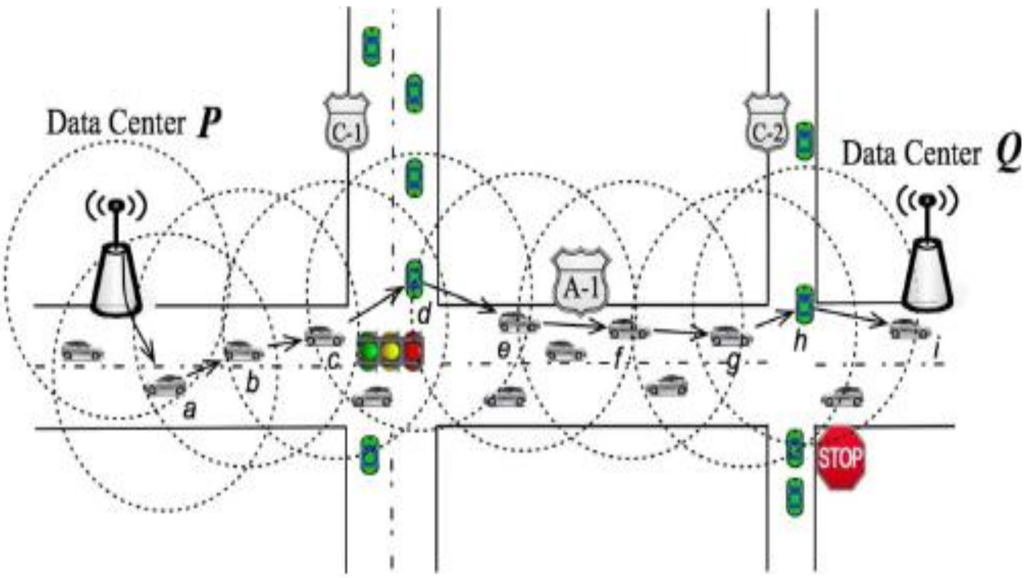


Figure 2.1: Data Pouring (DP) Scheme [11]

In the DP scheme, the data center specifies the road to propagate data based on D-Zone and adds this information to the packet header. Then, it designates a passing-by vehicle to broadcast the data (for example, vehicle “a” in Figure 2.1). To propagate the data to the desired road, the data item needs to be consecutively broadcast along the road by other vehicles such as a → b → c → d → e → f → g → h, shown in Figure 2.1. To deal with the broadcast storm problem, each designated broadcasting vehicle selects one vehicle that is farther away in the data propagation direction from its neighbour list and designates the selected neighbour as the next broadcast node by adding it to the packet header. After receiving the data, the designated vehicle (the forwarder) rebroadcasts the data. In this way, the data are poured to vehicles on the A-Roads. A forwarder delivers the data to all potential receivers within its one hop range and designates one vehicle as the next forwarder to broadcast the data father along the propagation direction. To further improve the performance of the DP, Data Pouring with Intersection Buffering (DP-IB) is proposed in which it is tried to reduce the amount of data poured from the source by buffering and rebroadcasting data at the intersection deploying a device called IBers [11].

Reference [13] is a research effort which focuses on the decentralized discovery of parking places. The proposed model consists of communication between vehicles and fixed infrastructures named as “parking automat” and also between vehicles. The details of this research work are explained in the section which aggregation method is described as means of avoiding broadcast storm problem.

Parking automat is a German world for road side parking fee payment terminals. Parking automats are able to sense their occupation status at any point in time and broadcast this information encapsulated in a data packet. The minimum broadcast interval needed to exchange information with nearly all passing vehicles for reports can be estimated. Considering a communication range of 300 m, a vehicle passing the parking automat with approximately 40 km/h on a straight lane is able to communicate with the parking automat for approximately 54 seconds. Because of the validity period of a report, which can be greater than 200 seconds and the fact that vehicles rebroadcast received information, a parking automat must not necessarily exchange its information with every passing vehicle. The information about a parking place observed by one parking automat is sent to the nearby vehicles and then will be disseminated among the vehicles. Disseminated information sent by a parking automat has the following attributes:

- ID: Each parking place possesses a unique identifier.
- POO: The point of origin is the position of the broadcasting parking automat.
- TOO: The time of origin is the initial broadcasting time of a report.
- The capacity and occupancy of parking place

2. 2. 2 V2V Data Dissemination

Flooding and relaying are two approaches that can be considered for vehicle to vehicle data dissemination. The basic idea in the first approach is that generated or received data is broadcasted to all neighbours. In other words, every node participates in dissemination. As it can be inferred it is suitable for delay sensitive applications and also for sparsely connected or fragmented networks. Flooding in general generates high message overhead and consequent broadcast storm problem. The problem can be more severe when the node density is high in urban area and extremely dense during rush hours or traffic jams. Therefore, there are several solutions proposed in order to avoid broadcast storm problem. It should be mentioned that these solutions are discussed in details in Section 2. In the second approach, relaying, instead of disseminating the message to all neighbours, a relay node is selected. The relay node is responsible to forward the packet further and so on. As it is clear contention is less in compared with the first approach and it is scalable for dense networks. This is due to the less of number of the nodes participating in forwarding message and consequently generated overhead is less. However, selecting relay node and ensure reliability are two challenges that need to be addressed and are discussed later.

2. 3 Flooding and Proposed Techniques to Avoid Broadcast Storm Problem

Flooding is one of the approaches that can be used for data dissemination in a pure vehicular ad hoc network which does not have any infrastructure support for communication. Because of the shared wireless medium, blindly flooding the data packets leads to frequent contention and collisions among neighbouring nodes. This problem is sometimes referred as broadcast storm problem. This problem also exists in the MANET environments which less number of nodes are involved [14, 15]. However, high density and fast movement of vehicles add to its severity in the vehicular networking context. This section presents the proposed broadcast storm mitigation techniques reviewed in the literature which focuses on this issue.

There are two main approaches that are considered in the literature: 1) Simple forwarding restricted by the timer and number of hops; 2) Map based/geographic forwarding exploiting the map or geographic information such as directed flooding and aggregation. The details are described below.

2. 3. 1 Timer-Based (Simple Forwarding)

A role-based multi-cast protocol is proposed in [16, 25] that suppresses broadcast redundancy by assigning shorter waiting time prior to rebroadcasting to more distant receivers. It should be noted that the primary objective of this study is to achieve maximum reachability in a sparsely connected network. The details of the research is provided in the following:

Each vehicle maintains the set *N* of neighbours. It constantly updates *N* according to the notification from the data link layer. Also, each vehicle associates the set S with the warning message. Every time the system receives the message from a sender, it adds the sender' identity to *S*. On the first reception of the message, *S* is initialized with the corresponding sender identity and the system switches into one of the two states: WaitToResend or WaitForNeighbour.

If $N \backslash S \neq 0$, then the system has neighbours other than the sender of the previously received message and it enters the WaitToResend mode. It is assumed that the message header contains the position of its sender. By knowing its own position, the system determines a waiting time *WT* depending on the distance *d* to the sender such that the waiting time is shorter for more distant receivers as shown below [16]:

$$WT(d) = -\frac{MaxWT}{Range} \cdot \widehat{d} + MaxWT\ , \quad \hat{d} = \min\{d, Range\} \tag{1}$$

where *MaxWT*: maximum waiting time and *Range*: transmission range

Clearly an immediate resending would cause traffic on the channel. Hence, it is tried to avoid peak load by forcing the receivers to wait. As shown in the equation, nodes at the border of the reception area take part in forwarding the message quickly. While the system awaits the moment to resend, it still updates the sets *N* and *S*. If on any of these updates the condition $N \backslash S \neq 0$ does not hold anymore, it forwards the message after the calculated waiting time is over.

If $N \backslash S = 0$, then there are no new receivers nearby and the system switches into WaitForNeighbour mode. In this state, the system waits until an update of N occurs such that $N \backslash S \neq 0$. Then, the system forwards the message [16].

The vehicles use omnidirectional antennas implying that a sender can transmit to multiple hosts simultaneously. It is measured approximately 600 m as the maximum distance for receiving data. The maximum waiting time until a vehicle forwards a packet is 40 ms. The dissemination of the message is controlled by the maximum hops it can take and is limited to 20 hops. The supported applications are distributing a warning message about an accident in road traffic. A straight road 10 km long with two lanes in each direction is modeled and the accident happens in the middle of the simulated stretch. Two different road types are considered: a divided highway and a highway without divider. For the road model of the divided highway, the multicast region covers the area behind the accident on the side of the highway where the accident happens shown in Figure 2.2. On the undivided highway, the vehicle having an accident can affect both driving directions. Hence, all vehicles approaching the position of the accident are part of the multicast region. Both scenarios are shown in the Figure 2.2. It is assumed that the traffic is relatively dense but is still free flowing.

The primary objective of this algorithm is to overcome the problem of fragmentation in sparsely connected networks. Therefore, it considers low market penetration rate and consequently the network is fragmented. To study the effect of market penetration rate the percentage of equipped vehicles is incremented from 1% up to 10 %. The transition to full market share with the values of 15, 20, 25, 50, and 100 % deployment are also considered [16].

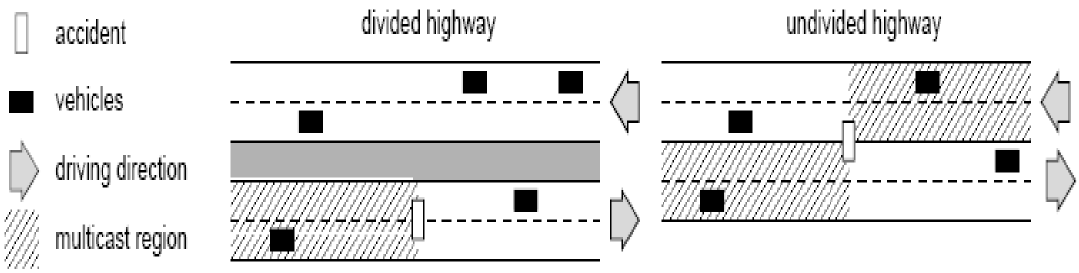


Figure 2.2: Sample Scenarios for Different Road Types [6]

Three probabilistic and timer-based broadcast techniques are proposed by the authors in [2]. These techniques are used at network layer which are listed and described in the following: 1) weighted p-persistence, 2) slotted 1-persistence, and 3) slotted p-persistence schemes.

1) Weighted p-persistence broadcasting: Upon receiving a packet from node *i*, node *j* checks the packet ID and rebroadcasts with probability p_{ij} if it receives the packet for the first time; otherwise, it discards the packet. Denoting the relative distance between nodes *i* and *j* by D_{ij} and the average transmission range by *R*, the forwarding probability, p_{ij}, can be calculated on a per packet basis using the following simple expression:

$$p_{ij} = \frac{D_{ij}}{R} \tag{2}$$

Note that if node *j* receives duplicate packets from multiple sources within the waiting period of *WAIT_TIME* before retransmission, it selects the smallest p_{ij} value as its reforwarding probability. This is because each node should use the relative distance to the nearest broadcaster in order to ensure that nodes that are farther away transmit with higher probability. If node j decides not to rebroadcast, it should buffer the message for an additional *WAIT_TIME* + δ ms, where δ is the one-hop transmission and propagation delay, which is typically less than *WAIT_TIME*. In order to prevent message die o ut and guarantee 100 percent reachability, node j should rebroadcast the message with probability 1 after *WAIT_TIME* + δ ms, if it does not hear the retransmission from its neighbours (Figure 2.3 (a)).

2) Slotted 1-persistence broadcasting: Upon receiving a packet, a node checks the packet ID and rebroadcasts with probability 1 at the assigned time slot T_{sij} if it receives the packet for the first time and has not received any duplicates before its assigned time slot; otherwise, it discards the packet. Given the relative distance between nodes i and j, D_{ij}, the average transmission range, R, and the predetermined number of slots Ns, T_{sij} can be calculated as $T_{Sij} = S_{ij} \times \tau$. In this equation, τ is the estimated one-hop delay, which includes the medium access delay and propagation delay, and S_{ij} is the assigned slot number, which can be expressed as [2]

$$S_{ij} = N_s \left(1 - \left\lceil \frac{\min(D_{ij}, R)}{R} \right\rceil \right) \tag{3}$$

The time slot approach follows the same logic as the weighted p-persistence scheme, but instead of calculating the reforwarding probability, each node uses the GPS information to calculate the waiting time to retransmit. For example, in Figure 2.3 (b) the broadcast coverage is spatially divided into four regions, and a shorter waiting time will be assigned to the nodes located in the farthest region. Hence, when a node receives duplicate packets from more than one sender, it takes on the smallest *Dij* value. Similar to the p-persistence scheme, this approach requires transmission range information in order to agree on a certain value of slot size or number of slots.

3) Slotted p-persistence broadcasting: Upon receiving a packet, a node checks the packet *ID* and rebroadcasts with the pre-determined probability p at the assigned time slot T_{sij}, as expressed by Equation 3 mentioned above, if it receives the packet for the first time and has not received any duplicates before its assigned time slot; otherwise, it discards the packet.

Each node in this scheme should also buffer the message for a certain period of time (e.g., $[Ns - 1] \times WAIT\_TIME + \delta$ ms) and retransmits with probability 1 if nobody in the neighbourhood rebroadcasts in order to prevent the message's dying out. Figure 3.3 (c) illustrates the concept of slotted p-persistence with four slots. Similar to the p-persistence case, the performance of this scheme also depends on the value chosen for the reforwarding probability p.

2. 3. 2 Hop Limited (Simple Forwarding)

The basic idea of this approach is to avoid broadcast storm problem by simply limiting the number of hops the message gets propagated. However, determining the number of hops can be challenging. By applying this strategy, data packets do not get transmitted beyond the number of hops specified in the data packet. Reference [17] is a research work that deploys this strategy and the query disseminations are limited by the number of hops. The research discusses design issues relevant to a system for targeted ad delivery mechanisms for vehicles. This system is comprised of digital billboards, a push model architecture for disseminating advertisements to vehicles, and AdTorrent, an integrated system for searching, ranking and swarming-based content delivery of localized advertisements relevant to the user. Every node that runs the application collects the advertisements and indexes the data based on certain metadata which could be keywords, location and other information associated with the data. Upon a user indicating interest, a localized (hop-limited) query is broadcast. Each node upon receiving the query, goes through its local index and replies with the document identifier (TorrentID) and piece list relevant to that document. AdTorrent ranks the results and then obtains the content using swarming.

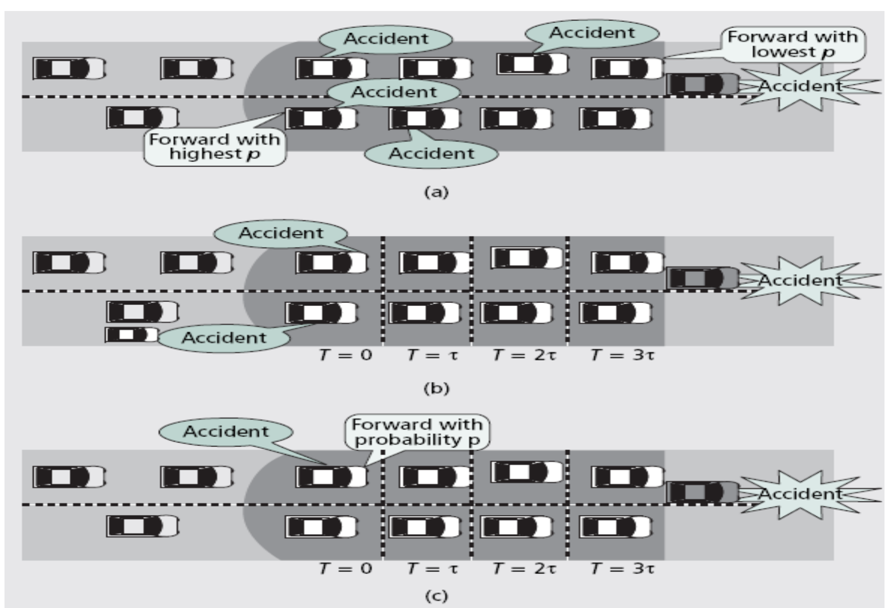


Figure 2.3: a) Weighted p-persistence, b) Slotted 1-persistence, and c) Slotted p-persistence [2]

As discussed in this research work, AdTorrent searches for relevant ad-content using a hop-limited query broadcast. Since setting a large hop-limit queries more nodes, a larger hop-limit improves the probability of finding the desired content and will likely increase the number of sources from which the content may be downloaded. However, gain in the quality of search results comes at the cost of significant increase in the messages sent per query in the network. In other words, there is an inherent trade-off between the reliability/effectiveness of the search and the flooding overhead. Thus, the hop limit in the query flood is a key design issue. Therefore, an analytical model is presented in this research to estimate the performance impact of key design parameters such as the scope of the query flooding (determined by the number of hops) on the query hit ratio in epidemic query dissemination. The analytical model defined as overall hit rate (across all searches) is as following [17]:

$$P(B,k) = \sum_{i=0}^{N} \frac{\lambda_i}{\lambda} [1 - (1 - p_{local}\ (i,B,k))M^{(k)}] \tag{4}$$

The cache size *B* and the hop limit *k* are the design choices while λ_i, the file request rate distribution, and *M(k)*, the number of nodes in the *k*-hop neighbourhood, are inputs that the system designer must provide for the specific application scenario being investigated. It is noticed that interestingly the incremental gain from increasing the scope of the query (extending the region of dissemination) flood beyond 4 hops was minimal. Therefore, it is suggested that the number of hops needs to be set 4 as dissemination beyond 4 hops does not benefit the query hit ratio.

2. 3. 3 Directed Flooding (Map-based or Geographic Forwarding)

As indicated by its name, the flooding of data is restricted to specific directions or geographic areas. Therefore, by deploying this strategy, flooding of data in directions that does not benefit dissemination is limited. The research carried out in [18] does not primarily employs this approach to solve broadcast storm problem rather it strives to route the data to specific target areas in which generated data must be disseminated. Therefore, data dissemination is restricted to specific areas and can be used to reduce message overhead. There are several protocols proposed in this work pushing data to be forwarded to specific directions and areas that it needs to be. It is worth mentioning that these approaches exploit the geographical position of each vehicle available using GPS.

This research work basically focuses on the propagation of potentially dangerous events or an accident that may cause congested roads. It is mentioned in the paper that after having a car crash the affected vehicle generates different messages that need to be disseminated in different areas named as “target zones”. As depicted in the Figure 2.4, three messages are generated each with different target zone. M_1 is the message that is routed toward nearest ambulance and police stations. M_2 is the message that needs to be delivered to the vehicles within one mile approaching the accident area informing them to slow down. M_3 is propagated to the closest highway entrances north of the accident and informing them about likely traffic congestion.

Figure 2.4: A Sample Accident Scenario on a Highway [18]

M_1 can be delivered in a unicast fashion to the police and emergency personnel. However, M_2 and M_3 do not have specific destinations. Rather they must reach as many vehicles as possible within their target zones. The main focus of this research is proposing an approach to route messages toward a set of target zones. In order to achieve the aforementioned approach a message propagation function is used. The function encodes both the target zones of a message and the routes that the message should follow to reach them. The idea behind this routing mechanism is that each target zone acts as a mass that determines a gravitational field. The values of the propagation function can be viewed as the values of the potential associated with this field. A propagation function associated with a target zone that is reached by a single major road is shown in Figure 2.5. The function pushes messages along the main road shown by the black line below the function and towards the target zone shown by the black ellipse. It is important to observe that the message originator does not compute a predefined trajectory using the propagation function before sending the message. Rather, the route to the destination is the result of the evaluation of the function at each routing hop [18].

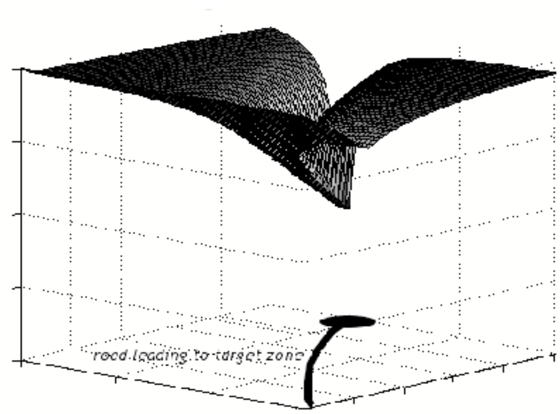


Figure 2.5: A Propagation Function and the Corresponding Target Zone (black eclipse) [18]

Messages should be attracted by the field in the right direction towards decreasing values of the propagation function that is towards areas of minimum potential. As previously mentioned, several routing protocols are proposed in this research. These protocols are divided into two categories: Baseline protocols including One Zero Flooding (OZF) and Distance Driven Probabilistic Diffusion (DDPD); and enhanced protocols including Function-Driven Probabilistic Diffusion (FDPD) and Feedback-augmented Store, Forward Diffusion (FSFD).

In all the proposed protocols in this research, the message transmissions are always broadcast, and forwarding decisions are always taken on the receiver's side. This approach works well in a highly dynamic nature of inter-vehicular networks as it does not require a proactive maintenance of neighbours' information (this is because the neighbour's information easily become obsolete due to high vehicles' speeds). For all protocols it is assumed that once the target zone is reached, the mechanism turns to flooding propagation as long as the message remains on the target zone. The proposed protocols are described briefly in the following [18]:

One Zero Flooding(OZF): In this protocol, the received message is retransmitted if it is received for the first time and also the receiver is in the position where the propagation function returns values lower than at the sender's position. As it can be inferred, this is a directional flooding where messages are broadcasted only towards areas where the propagation function returns the lowest values.

Distance-Driven Probabilistic Diffusion (DDPD): Basically, it is a simple extension to OZF with the addition of a probabilistic decision. The higher probability is given to the vehicles located further.

Function-Driven Probabilistic Diffusion (FDPD): This protocol uses the values returned by the propagation function in order to calculate forwarding probability. As such, higher values of the propagation function correspond higher chances of forwarding a message.

Feedback-augmented Store and Forward Diffusion (FSFD): This protocol deploys store and forward techniques. These techniques are useful for sparse network condition when the connectivity between the sender and the target zone is not guaranteed. It is also mentioned that deploying store and forward technique can be helpful in avoiding local minima, dealing with non-convex propagation functions, or avoiding physical obstacles hampering communication, e.g., buildings [18]. In the proposed store and forward technique a timeout is associated with each received message. Each received message is locally cached, and, when the associated timeout expires, the message is rebroadcasted and the timeout is rescheduled. The timeout is cancelled when the corresponding message is heard from another node lying at a position where the propagation function returns a value lower than at the local position. In other words, the periodic message propagation is halted as soon as a node realizes the presence of another node doing the same from a better position (i.e., lower values) with respect to the propagation function.

Function Driven Feedback-augmented Store and Forward Diffusion (FD-FSFD): The previous protocol is extended with the same probabilistic scheme used in FDPD.

Direction-aware Function Driven Feedback-augmented Store and Forward Diffusion (DFD-FSFD): In this protocol, direction of movement is taken into account by the store and forward techniques so that only nodes moving towards lower values of the propagation function are used to carry messages. For that matter, the angle between the direction of node movement and the gradient of the propagation function at the receiving node's position is considered.

The comparison made between the simple flooding and proposed protocols shows that deploying the protocols can have significant impact on message delivery ratio and generated network traffic in both dense and sparse road traffic conditions.

2. 3. 4 Aggregation (Map-based or Geographic Forwarding)

Aggregation is a technique proposed in some research works in order to avoid broadcast storm problem. Research effort [1] considers penetration and scalability as two major challenges that can be faced in Inter-Vehicular Communication (IVC)-based applications. It is believed that with low market penetration rate, in the majority of the time there is no or only a very limited number of communication partners available within transmission range. Therefore, the average range in which information can be distributed is small. Furthermore, Scalability becomes an issue once a higher market penetration is reached. In order to avoid overload conditions (or broadcast storm problem named in this research), the amount of data transferred needs to be restricted.

To solve these two challenges, Segment-Oriented Data Abstraction and Dissemination (SODAD), a method for data dissemination for comfort applications, is proposed in [1]. SODAD can be used to create a scalable decentralized information system even if only 1% – 3% of all vehicles are equipped with an IVC system. The advantages of the proposed approach are demonstrated by a Self-Organized Traffic Information System (SOTIS), which offers very detailed traffic information for the local area of a vehicle. It should be noted that scalability is achieved by restricting the method to the dissemination of map/position-based data.

SODAD can be divided into two phases: 1) map-based data abstraction; 2) data dissemination. In the first phase, SODAD generates map-based data abstraction. It is assumed that each vehicle is equipped with a digital map. The map is divided into segments of a known length, which can vary based on the type of road that is considered. Figure 2.6 shows an example in which vehicles driving on a highway and country side road choose two different road-segment100m and 200m lengths automatically and adaptively. The optimal segment size depends on application and road type; decreasing the segment size increases the level of detail of available information, but also leads to a higher data rate. Due to the digital map and a standardized selection of the segment size, each segment can be identified by a unique identifier. Each node generates new information for all segments in transmission range. This is done either by sensing the information itself or by receiving information observed by other vehicles.

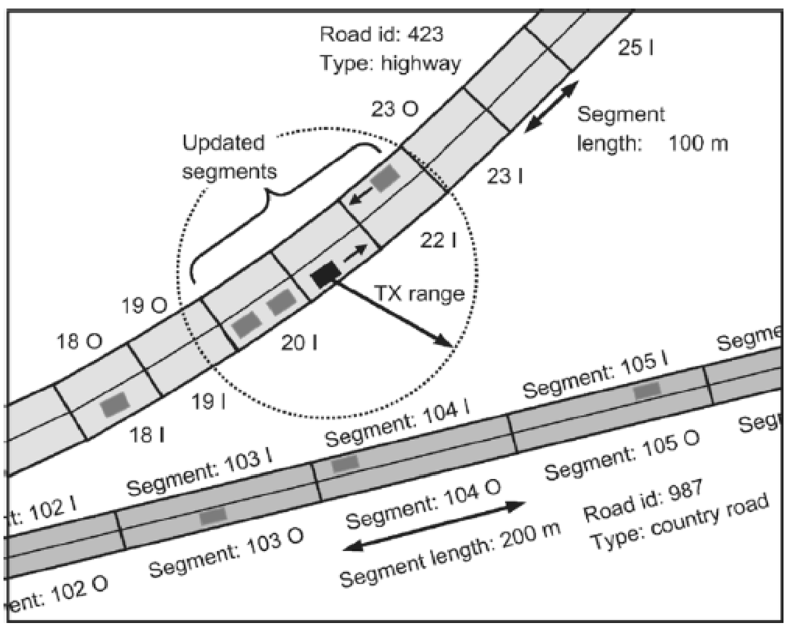


Figure 2.6: Map-Based Data Abstraction [1]

In the data-abstraction process, a data-aggregation function is applied: If N information values d_1 , d_2, ..., d_N have been received/sensed at node n for a segment i , the new information value $s_{n,i}$ is calculated by applying the aggregation function $a(.)$ proposed by [1] and presented in the following.

$$s_{n,i} = a(d_1, d_2, \ldots, d_N).$$

The nature of the aggregation function depends on the application; for example, the mean of d_1 , $d_2, \ldots, d_N$ can be calculated or the maximum can be chosen. Additionally, a time stamp $t_{n,i}$ is set to the current global time which can be obtained through GPS receivers. The tuple $(s_{n,i} , t_{n,i})$ presents the information available for a segment at a node. This process leads to the scalability of the information system because only one tuple per segment is distributed. As it can be inferred, vehicles adapt their transmission behavior based on segment information broadcasted by other nodes. Thus, overload conditions are avoided and the data rate for an application is the result of segment length, area to be covered, and the frequency with which the per segment information changes [1].

The second phase of SODAD is the dissemination of per-segment information. In order to achieve data dissemination over large distance under low marker penetration circumstance, the following two principals are applied [1]:

- Local Broadcast: All data packets are transmitted in the form of local (1-hop) broadcasts. Nodes are never directly addressed and no routing of data packets is performed.
- Application Layer Store-and-Forward: Information which is received at a node can be analyzed and further compared with the information currently available. When the information is more accurate and more relevant than the previously received information, it will be stored onboard. If message *m* containing information for S various segments with IDs $i_1, \ldots, i_S$ is received at node *n* , the

tuples *($s_{n,k}$, $t_{n,k}$)*are updated based on the time stamps proposed in [1] and shown in the following :

$$S_{n,k} \leftarrow \begin{cases} S_{m,k}, & if\ t_{m,k} > t_{n,k} \\ S_{n,k} & Otherwise \end{cases} \tag{5}$$

$$\mathrm{t_{n,k}} \leftarrow \max(t_{m,k}, t_{n,k}), \quad k = i_1, \cdots, i_S$$

In the above formula, $S_{m,k}$ and $S_{n,k}$ are the information values for segment with ID in the message and at the node, respectively, and $t_{m,k}$, $t_{n,k}$ are the corresponding time stamps.

In the research [1], an application of SODAD is presented and is called SOTIS. SOTIS is a typical case where the application of SODAD is advantageous. For each road segment that a vehicle drives, it records the observed average velocity. The aggregation function is defined in a way that the data value for a segment at node is the mean of the vehicle's own velocity and other vehicles in the transmission range [1].

$$s_{n,i} = a(d_1, d_2, \cdots, d_{k+1}) = \frac{1}{k+1} \sum_{k=1}^{k+1} d_k \tag{6}$$

Figure 2.7 illustrates the structure of SOTIS. Traffic information in the form of tuples *($s_{n,k}$, $t_{n,k}$)* is collected in the knowledge base which is one of the main components in Figure 7. It contains the traffic information for all segments in the local area. Information is discarded if it is outdated or the knowledge base's capacity is reached. A traffic analysis can be carried out in each car using the information stored in the knowledge base. This analysis determines which information needs to be included in the next broadcast data packet. Overload situations can be avoided using the adaptation of the data generation rate to the local conditions.

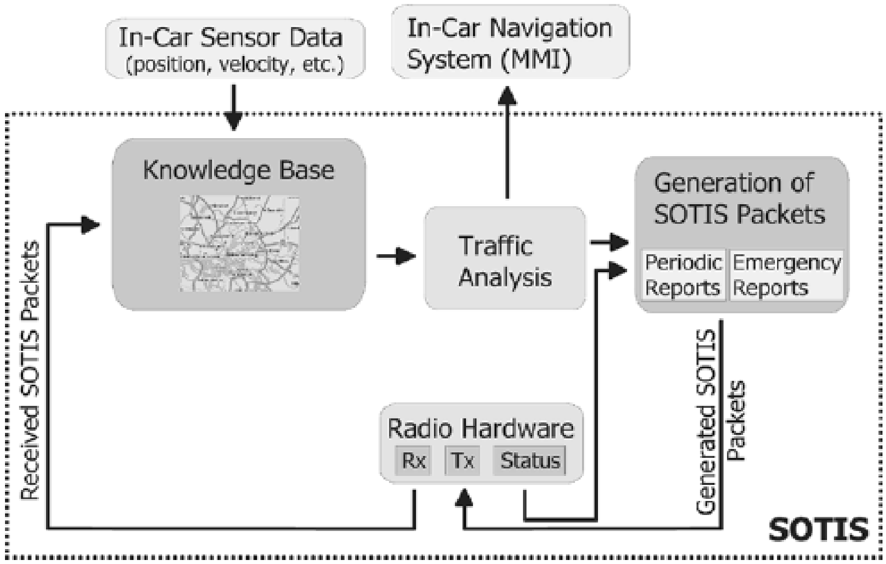


Figure 2.7: Structure of SOTIS [1]

In the research [1], adaptive broadcasting scheme is also introduced. Broadcast messages (considered in this research) were generated at constant intervals and the transmission rate/transmission power of the vehicles was assumed to be fixed. It is believed that adaptive information dissemination in the vehicular ad hoc network is a challenging task. This is due to the different network densities which can be experienced on the road network instantly. A large transmission range with short transmission interval in a low traffic density is beneficial. However, this situation is led to a decrease of the available transmission bandwidth for an individual vehicle. Moreover, an overload condition in a high traffic density situation can be experienced. To that extend, an adaptive approach is proposed in which transmission interval is adapted to the local environment and knowledge gained from received packets in order to: 1) reduce the delay with which information is propagated; 2) favor the propagation of significant changes; 3) avoid redundant transmissions; and 4) occupy less bandwidth in cases of congestion.

A default transmission interval (T_{upd}) small enough to recognize a vehicle passing by at the maximum relative velocity is chosen. This default interval is adapted according to two kinds of observed events: 1) provocation: which is an observed event that reduces the time that elapses until the next broadcast packet is transmitted; 2) mollification which is an observed event that increases the time that elapses until the next broadcast packet is transmitted. Upon the reception of a data packet, its content is examined in order to update the vehicle's knowledge base. Moreover, it is determined if a provoking or mollifying event has occurred. Based on the comparison of the received data and its time stamp within the knowledge base for each individual road segment, a weight $w_{m,n}$ of a received message m at node n is calculated. It indicates the discrepancy of the received per-segment data compared to the node's previous knowledge. The message's calculated weight is compared to the mollification and provocation weight. Therefore, the remaining time until the next transmission of a traffic analysis for the respective road segments will be increased or decreased based on the comparison's result.

Reference [19] is another research work using aggregation in order to limit the number of broadcast messages and thereby solving broadcast storm problem. It considers that moving vehicles on the road exchange information about the position and speed of each other. Therefore, by receiving this information, each individual vehicle is able to view and assess the traffic and road condition in front of it. It also mentions two main mechanisms for data (position and speed) dissemination; 1) flooding; 2) diffusion. In the flooding mechanism, each individual vehicle periodically broadcasts information about itself. Whenever a vehicle receives a broadcast message, it stores it and immediately forwards it by rebroadcast the message. In the diffusion mechanism, each vehicle broadcasts information about itself and the other vehicles it knows about. Whenever a vehicle receives broadcast information, it updates its stored information and defers forwarding the information to the next broadcast period, at which time it broadcasts its updated information.

Due to the magnitude of disseminated data (speed and position of each individual vehicle), flooding is not scalable. Therefore, diffusion is the preferred mechanism since the number of broadcast messages is limited and no flooding is used. Another concern may rise in this approach proposed in this research is that dissemination of position and speed of each individual vehicle, requires a lot of memory and bandwidth. However, it is noted that the deployed approach does not suffer from memory and bandwidth limitation due to the small size of stored data and applied aggregation methods.

In the developed framework, traffic view, each vehicle stores records about itself and other vehicles it knows about. Each record consists of the following fields:

- ID: Uniquely identify the records belonging to different vehicles.
- POS: The current estimated position of the vehicle.
- SPD: Used to predict the vehicle’s position if no messages containing information about that vehicle is received.
- BT: The global time at which the vehicle broadcasts that information about itself.

Data aggregation is performed based on the date semantics. For example, the records from two vehicles can be replaced by a single record having minor error if the vehicles are close to one another as well as moving with relatively the same speed. This way, more new records can be delivered in certain period of time and the overall system performance is improved.

A single aggregated record will represent information about a set of vehicles. In an aggregated record, the *ID* field is extended to a list of vehicles' *ID*s while the other fields such as position, speed, and broadcast time remain as single values for all the vehicles stored in the record. Basically, if the records (ID_1, POS_1, SPD_1, BT_1)… (ID_n , POS_n, SPD_n, BT_n) are being aggregated, and d_i is the estimated distance between the current vehicle and the vehicle with ID_i , the aggregated record is defined and proposed in [19] as shown in the following equations. It should be reminded that the terms used in the equations have been already defined in the text.

$$(\{ID_1, \cdots, ID_n\}, POS_a, SPD_a, BT_a)\ where$$

$$POS_a = \sum_{i=1}^{n} \alpha_i \times POS_i$$

$$SPD_a = \sum_{i=1}^{n} \alpha_i \times SPD_i$$

$$BT_a = \min\{BT_1, \cdots, BT_n\}$$

$$\alpha_i = \frac{(\sum_{i=1}^{n} d_i) - d_i}{(n-1)\sum_{i=1}^{n} d_i}$$

The records for aggregation are selected only based of their relative distances. Whenever a node receives a record including information about some vehicles, it first examines the information in that record against the validated records already available. If the record contains information about some vehicles which the node already knows, the following steps will be taken:

1) If the broadcast time of the records is greater than the broadcast time of the stored record, it means the new record is fresher, and therefore the node removes the corresponding vehicle ID from its stored record,
2) Otherwise, the new record contains older information, and hence the node removes the corresponding vehicle ID from the received record.

In the research presented in [19], two different algorithms are described for aggregation, ratio-based algorithm and cost-based algorithms which are describes below.

The ratio-based aggregation algorithm divides the road in front of the vehicle to a number of regions *(r_i)*. For each region, an aggregation ratio *(a_i)* is assigned. The aggregation ratio is defined as the inverse of the number of individual records that would be aggregated in a single record. Each region is assigned a portion (p_i where $0< p_i < 1$) of the remaining free space in the broadcast message. The aggregation ratios and region portion values are assigned according to the importance of the regions and how accurate the broadcast information about the vehicles in that region is needed to be. For example, assigning decreasing values to the aggregation ratios and equal values to portion parameters will result in broadcasting less accurate information about regions that are farther away from the current vehicles. Juts reminded that optimum aggregation ratio is introduced in order to prevent over-aggregating the records.

Cost-based aggregation algorithm assigns a cost for aggregating each pair of records, and whenever it needs to aggregate two records, the two that correspond to the minimum cost are chosen. It is assumed that if the two records storing aggregated information about s_1 , s_2 number of vehicles, with a relative distance of d_1 and d_2 ,respectively, then the cost can be calculated using the following equation.

$$cost = \frac{|d_1 - d_2| \times s_1 + |d_2 - d_a| \times s_2}{d_a} \tag{7}$$

Where d_a is the relative distance of the aggregated group of records. This formula is calculated

such that it:

- Assigns a high cost for the vehicles that are relatively close to the current vehicle $(1/d_a)$
- Strives to minimize the error introduced during the merging $(| d_i - d_a|)$ and
- Minimizes the number of the vehicles affected by the aggregation (s_i).

With respect to the research carried out in reference [13], the information dissemination for spatio-temporal traffic information such as parking place availability has been investigated. It is noted that searching for the free parking spaces in urban traffic conditions is a serious mobility problem and causes a lot of economical damages; thus, the proposed parking place search algorithm presents a solution to inform drivers about the parking place situation under urban traffic conditions. The algorithm exploits broadcasting techniques for information dissemination and takes the spatio-temporal character of parking places into account. The information exchanged between vehicles and road side parking fees payment terminal is categorized into two groups: atomic and aggregated information. Atomic information represents the availability of free parking places coordinated by one parking terminals and aggregated information represents summarized information about an area covering more than one parking terminals. Compared with broadcasting atomic information, broadcasting aggregated information significantly reduces the overall needed bandwidth. Hence, each vehicle aggregates received information before it distributes it to other vehicles.

Aggregation of multiple information atoms results in the processed information that covers a greater geographical range. Moreover, due to their more generalized nature, aggregates are relatively more time-stable, as compared to atomic information. These longer validity periods are indicated as timestamps in the aggregates. Generalization of information in aggregates leads however to lesser accuracy, which decreases with increase in distance to a parking area. The loss of accuracy is controlled by applying some selection strategies.

The time interval between subsequent broadcasts is exploited to sort cached information and to generate new information for other vehicles. In this phase a vehicle replaces older information with newer ones and builds aggregates for different spatial aggregate levels. The aggregation is performed by using an overlay grid of a hierarchical quad-tree structure. As depicted in Figure 2.8, four aggregates of a lower level cover the area of a higher level aggregate.

The algorithm distributes aggregates as wireless messages over wider areas, but keeps the distribution of atomic information confined to local proximity. This way, two major goals are achieved: First, compared with broadcasting atomic information over the entire topology, bandwidth consumption is reduced. Second, aggregates about suitable parking areas are distributed over large distances which could provide vehicles entering in a large area for an initial orientation to parking situation from a macro-perspective. The distribution of atomic and aggregated information is controlled by selecting a subset of all received information with specific attributes.

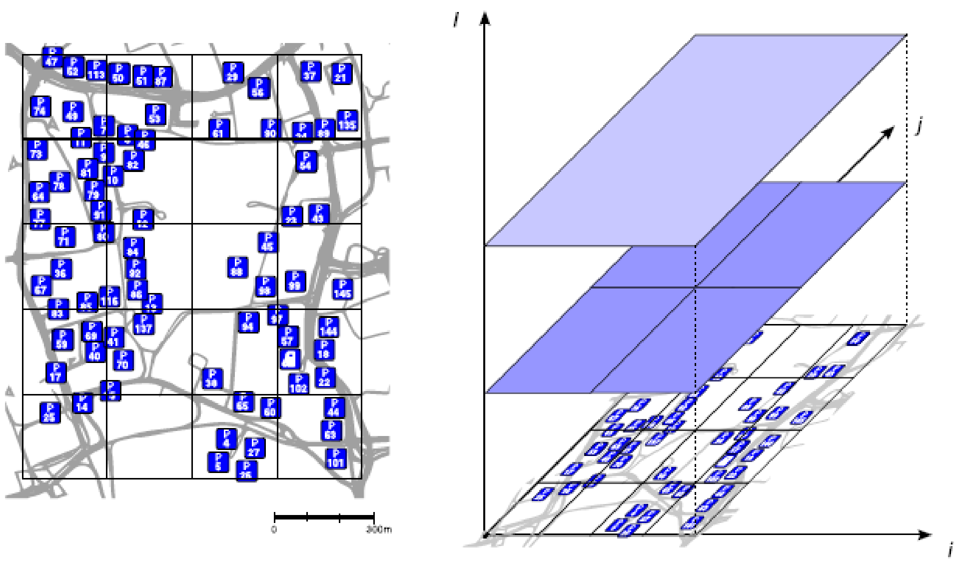


Figure 2.8: Adopted Aggregation Scheme [19]

The distribution of atomic and aggregated information is controlled by selecting a subset of all received information with specific attributes. In the developed algorithm proposed in [19], the selection is based on relevance which normally explains about the applicability of some information. The relevance of a resource report *R* is calculated through a relevance function *r(R)*. The objective, by applying a selection strategy, is to disseminate information in a user-centric approach. In other words, the driver receives inaccurate information about regions farther away and precise information about its local neighbourhood. Received inaccurate information, i.e. aggregates of different levels, is used to determine the best suited parking area. Two different relevance functions are proposed for atomic and aggregate information. For the relevance of atomic information *r(R)*, two factors are considered: 1) the age of a resource; and 2) the distance *d* to a resource. The distance is converted into time by assuming an average speed *v* of vehicles in urban traffic conditions. The formula for the calculation is as follows:

$$r(R) = -\frac{d}{v} - t \tag{8}$$

Once the records are ranked using the above equation, top *m* entries are selected and local distribution is ensured. The relevance function used for aggregates is proposed by [19] and shown in the following:

$$r(A) = \begin{cases} -t & : vehicle\ inside\ aggregate\ A \\ \frac{1}{n}\left(-\frac{d(A)}{v} - t\right) & : vehicle\ outside\ aggregate\ A \end{cases} \tag{9}$$

Once the relevance of aggregates is calculated, they are separately ordered for each level with respect to their relevance. A fixed number of relevant aggregates are then chosen from each of these levels and broadcast to other vehicles.

2. 4 Relaying and Associated Challenges

Relaying is an approach assigning the duty of forwarding a packet to specific node or nodes that satisfy some criteria. As it can be inferred it generates less contention and it is scalable for dense network condition. The main challenges faced in the relay-based approaches include selecting the relay node/nodes and ensuring reliability. Basically, the relay-based data dissemination approaches can be divided into two categories: 1) simple forwarding and 2) map-based forwarding exploiting digital map information and GPS. With respect to the second challenge, ensuring reliability, several solutions such as RTS/CTS and ACK mechanisms are suggested. The research efforts deploying these techniques are described in this section.

2. 4. 1 Relaying (Simple Forwarding)

With respect to the research proposed in [21], a new efficient IEEE 802.11 based protocol, Urban Multi-hop Broadcast protocol (UMB), is proposed for ad hoc vehicular networks. The node farthest from the sender of the packet is selected as relay point. UMB is designed to address: 1) broadcast storm, 2) hidden node, and 3) reliability problems in multi-hop broadcast. The UMB protocol is composed of two phases: 1) directional broadcast and 2) intersection broadcast. In the first phase, sender nodes try to select the furthest node in the broadcast direction to assign the duty of forwarding and acknowledging the packet without any apriori topology information i.e., sender selects the furthest node without knowing the *ID* or position of its neighbours. In the second phase, there are some repeaters installed at each intersection to disseminate the packets in all directions. It is shown through simulation in this research that the UMB protocol outperforms other broadcast protocols. Concisely, the proposed protocol achieves the four goals explained in the following:

1) Avoiding collisions due to hidden nodes: In order to decrease the effect of hidden nodes, a mechanism similar to RTS/CTS handshake in point-to-point communication is employed;
2) Using the channel efficiently: Forwarding duty is assigned to only the furthest vehicle in the transmission range without using the network topology information;
3) Making the broadcast communication as reliable as possible: To achieve the reliability goal, an ACK packet is sent by the vehicle which was selected to forward the packet; and
4) Disseminating messages in all directions at an intersection: New directional broadcasts are initiated by the simple repeaters installed at the intersections according to the intersection broadcast mechanism.

In order to select relay node the protocol divides the road portion inside the transmission range into segments which are created only in the direction of dissemination. If there is more than one node in the furthest non-empty segment, this segment is divided iteratively into sub-segments with smaller widths. If these segment based iterations are not sufficient to select only one node, the nodes in the last sub segment enter to a random phase. As a result of iteratively dividing the segments, the protocol can adapt itself to light or heavy vehicle traffic conditions. When the vehicle traffic is light, even a large sub-segment width in the first iteration can be sufficient to select the furthest vehicle. For heavy vehicle traffic conditions, sub-segment width is reduced in each iteration. As an example, for a communication radius of 400 m and 10-way segmenting, the sub-segment width is reduced to 4 m in the second iteration, which is unlikely to contain more than one vehicle per lane. In this example, if the furthest vehicle cannot be selected in the second iteration, there is no need to further segment the 4 m range. Therefore, the random selection is performed starting the third iteration. In this work, RTS and CTS are referred to as Request to Broadcast (RTB) and Clear to Broadcast (CTB), respectively.

In a RTB packet, in addition to the transmission duration, source node includes its position and intended broadcast direction. If the source wants to disseminate the message in more than one direction, a new RTB packet should be generated for each direction. When the nodes in the direction of the dissemination receive the RTB packet, they compute their distance to the source node. Based on this distance, they send an energy burst (channel jamming signal) called black-burst. Black-burst is used to select the furthest node by letting receivers sending black-burst signals proportional to their distance to the source. Since the position information of all nodes is unique, using the position information to determine the length of the black-burst gives us the capability of selecting the furthest node. The length of the black-burst signal in the first iteration is computed as follows [21]:

$$L_1 = \left\lfloor \frac{\hat{d}}{Range} \times N_{max} \right\rfloor \times SlotTime \tag{9}$$

Where L_1 is the black-burst length in the first iteration, d is the distance between the source and the vehicle, *Range* is the transmission range, N_{max} is the number of segments created, and *SlotTime* is the length of one slot. As a result of this computation, the furthest node sends the longest black-burst. Nodes send their black-burst in the shortest possible time (SIFS) after they hear the RTB packet. At the end of the black-burst, nodes turn around and listen to the channel. If they find the channel empty, it means that their black- burst was the longest and they are now responsible to reply with a CTB packet after a duration called CTBTIME, where SIFS < CTBTIME < DIFS. If they find the channel busy, it means that there are some other vehicles further away and they do not try to send CTB packet. When there are more than one vehicle in the furthest non- empty segment, they all find the channel empty after sending their black-bursts and continue to send CTB packets. However, since all vehicles start sending the CTB packets at the same time, their CTB packets will collide. When the source node detects a transmission but cannot decode the CTB packet, it detects the collision and repeats the RTB packet after SIFS time as shown in Figure 2.9 (a). This time, only the nodes which have sent CTB packets join the collision resolution. In order to pick only one node, the furthest non-empty segment is divided into N_{max} sub-segments. This process continues iteratively until a successful CTB packet is received by the source or D_{max} iterations are completed. The length of the black-burst for the i^{th} iteration (L_i) is computed as follows [21]:

$$L_1 = \left\lfloor \frac{\hat{d} - Llongest\ _{i-1} \times W_{i-1}}{Range} \times N_{max} \right\rfloor \times SlotTime \quad i = 2, 3, \cdots, D_{max} \qquad (10)$$

$$W_i = \frac{Range}{N_{max}^i}$$

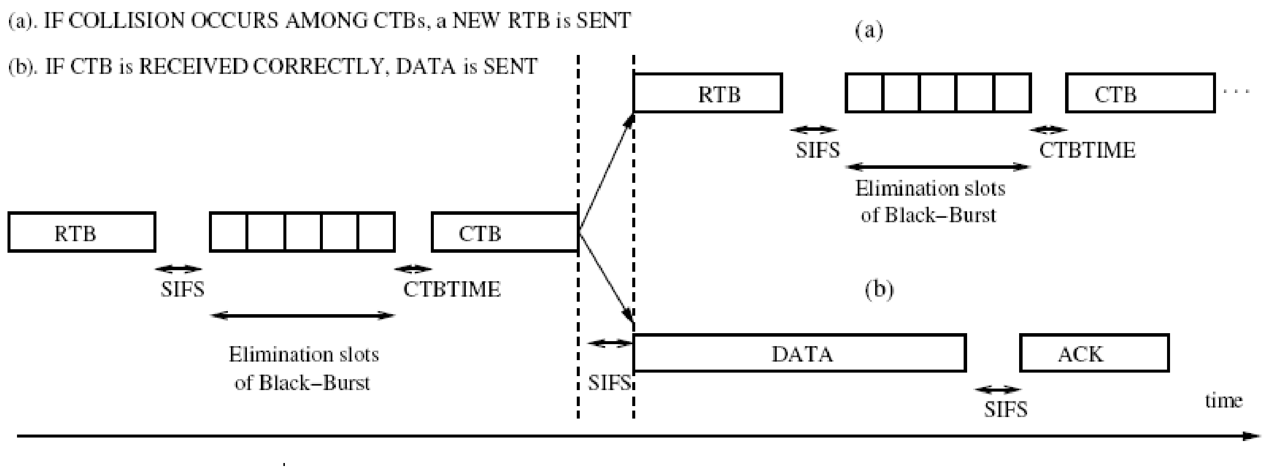


Figure 2.9: (a) RTB/CTB handshake, (b) DATA/ ACK [21]

After receiving a successful CTB, the source node sends its broadcast packet as shown in Figure 2.9(b). In this broadcast packet, the source node includes ID of the node which has successfully sent the CTB. It is referred to this node as the corresponding node of the source. This node is now responsible for forwarding the broadcast packet and sending an ACK to the source. This ACK packet ensures the reliability of packet dissemination in the desired direction. Although all other nodes between the source and the ACK sender receive the broadcast packet, they do not rebroadcast or acknowledge it. If the ACK packet is not received by the source before the ACK timeout, the source goes back to the first segment based iteration after a random amount of time. Details of this back off procedure are the same as those of the IEEE 802.11 standard when ACK is not received [21].

When there is an intersection in the path of the packet dissemination, new directional broadcasts should be initiated to all road directions at the intersection. Since there is a repeater at the intersection, it is the best candidate to initiate the directional broadcasts. This is because, among other nodes, repeaters have the best line-of-sight to the other road segments, especially when there are tall buildings around the intersection.

When a node is selected to forward a packet and it is outside the transmission range of a repeater, it continues with the directional broadcast protocol as described. On the other hand, if the node is inside the transmission range of a repeater, the node sends the packet to the repeater using the point-to-point IEEE 802.11 protocol. It should be noted that each node knows the locations of itself, intersections, and repeaters with the help of the GPS and digital road map. According to the proposed protocol, a node sends RTS to the repeater and only the repeater replies with the CTS packet if the channel is empty. Upon receiving the CTS packet from the repeater, the node sends the DATA packet and the transmission ends when it receives an ACK packet from the repeater. After receiving this broadcast packet, the repeater initiates a directional broadcast in all road directions except the direction from which the packet was received. An example of intersection handling is illustrated in Figure 2.10 which shows that vehicle A uses the directional broadcast to reach B. Note that A is out of the transmission range of the repeater C. On the other hand vehicle B is in the transmission range of repeater C; therefore vehicle C uses IEEE 802.11 protocol to communicate with repeater C. Once repeater C receives the message, it initiates directional broadcasts to the north and south directions. Since the repeater D is in the transmission range of repeater C, it also sends the packet to repeater D using IEEE 802.11 protocol.

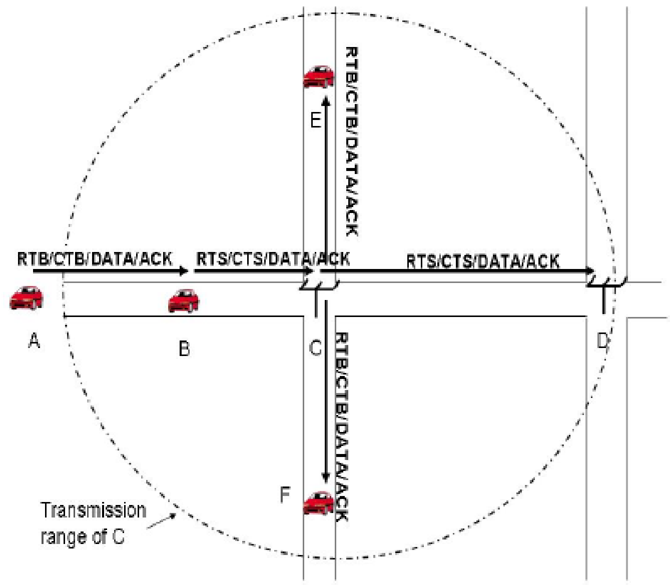


Figure 2.10: UMB Protocol [21]

2. 4. 2 Relaying (Map-based / Geographic Forwarding)

With respect to the research carried out in reference [3], the relaying is used in order to disseminate data further. The relay point that forwards the message further is called “message head” which is defined as massage holder closest to the destination region. The proposed algorithm is called MDDV (Mobility-Centric Data Dissemination for Vehicular Networks). MDDV is designed to exploit vehicle mobility for data dissemination, and combines the idea of opportunistic forwarding, trajectory based forwarding and geographical forwarding. Vehicles perform local operations based on their own knowledge while they collectively achieve a global behavior. Opportunistic forwarding is used when the network is fragmented and end to end connectivity does not exist. As suggested in such cases messages are stored and forwarded as opportunities present themselves. Trajectory based forwarding directs messages along predefined trajectories. It was presented to work well in a dense network. V2V networks are considered as an application of trajectory based forwarding because messages are moving along the road graph. Trajectory forwarding can help limit data propagation along specific paths and thus reduce message overhead. It is considered that a forwarding trajectory is specified extending from the source to the destination (trajectory base forwarding), along which a message will be moved geographically closer to the destination (geographical forwarding). It is assumed that vehicles know the road topology through a digital map and its own location in the road network via a GPS device. The message dissemination information, e.g., source id, source location, generation time, destination region, expiration time and forwarding trajectory, etc, is specified by the data source and is placed in the message header.

A forwarding trajectory is specified as a path extending from the source to the destination region. The road network can be abstracted as a directed graph with nodes representing intersections and edges representing road segments. Geographical forwarding attempts to move the message geographically closer to the destination. For an ad-hoc network deployed in a two-dimensional area, geographical distance is often defined as Cartesian distance [22]. However, in V2V networks, geographical distance has to be defined as graph distance [23].

The dissemination length of a road segment is used as the weight for the corresponding link in the abstracted road graph. It should be mentioned that for calculation of the dissemination length, the road distance and traffic condition are taken into account. This is because short road distance not necessarily means fast data delivery; rather, high vehicle density leads to fast information propagation. The directed path with the smallest sum of weights from the source to the destination region on the weighted road graph is used in the trajectory forwarding. The relay point that forwards the message further is called "message head" which is defined as massage holder closest to the destination region along the forwarding trajectory.

Due to lack of precise knowledge of the participating vehicles about the message head, some situation may raise in which messages are lost. To address this issue, MDDV allows a group of vehicles near the real message head to actively forward the message instead of the message head vehicle only. The group membership changes as the actual message head moves toward the destination region. There is a tradeoff between delivery reliability and message overhead: larger groups mean both higher delivery reliability and higher message overhead.

Generally, MDDV can be divided into two phases: forwarding phase and propagation phase. In the first phase, the data is forwarded to reach the destination region and in the second phase, the data is propagated to reach all the receivers in the region.

With respect to the research carried out in reference [24], the problem of efficient data delivery when a vehicle issues a delay tolerant data query to some fixed sites is discussed. Basically, it is investigated how to efficiently route the packet to that site and receive the reply within reasonable delay. The proposed Vehicle-Assisted Data Delivery (VADD) is based on the idea of carry and forward mechanism in which predictable mobility affected by traffic pattern and road layout is used. It is assumed that vehicles are equipped with pre-loaded digital maps, which provide street-level map and traffic statistics such as traffic density and vehicle speed on roads at different times of the day. The main purpose of VADD is to find an efficient path to the destination. As depicted in Figure 2.11, it is assumed that a driver approaches intersection I_a and wants to send a request to the coffee shop at the corner of intersection I_b. To forward the request through (I_a - I_c – I_d- I_b) would be faster than through (I_a-I_b), even though the latter provides geographically shortest possible path. The reason is that in case of disconnection, the packet has to be carried by the vehicle, whose moving speed is significantly slower than the wireless communication. Therefore, the geographically longer connected path is more efficient than the shorter disconnected path.

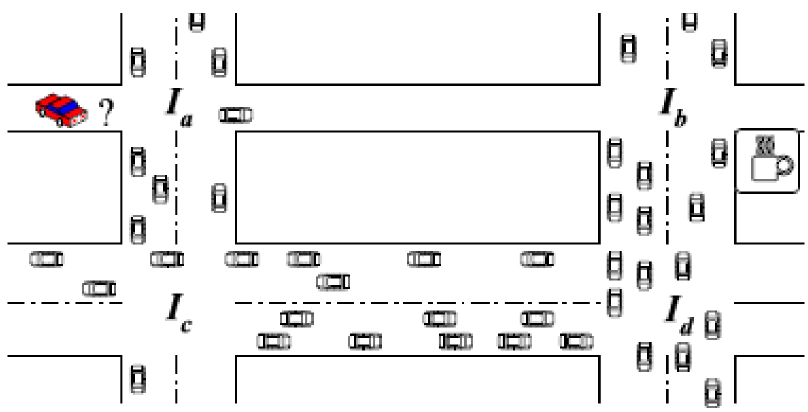


Figure 2.11: Find a path to coffee shop [24]

VADD has three packet modes: intersection, straight way, and destination based on the location of the packet carrier. By switching between these packet modes, the packet carrier takes the best packet forwarding path. Among the three modes, the intersection mode is the most critical and complicated one, since vehicles have more choices at the intersection.

The paths with less delivery delay are more efficient; therefore, expected packet delivery delay is calculated at each intersection and based on the calculation result, forwarding decision will be made. It should be noted that in VADD, vehicular network is represented by a directed graph, in which nodes represent intersections and edges represent the roads connecting adjacent intersections. The direction of each edge is the traffic direction. The packet forwarding delay between two adjacent intersections is the weight of the edge which is used in the calculation of expected packet delivery. The expected delivery delay formula is as follows [24] :

$$D_{mn} = d_{mn} + \sum_{j \in N(n)} (P_{nj} \times D_{nj}) \tag{11}$$

$$d_{i,j} = \begin{cases} \alpha . l_{ij} & \text{if } \dfrac{1}{\rho_{ij}} \leq R \\ \dfrac{l_{ij}}{v_{ij}} - \beta \cdot \rho_{ij} & \text{if } \dfrac{1}{\rho_{ij}} > R \end{cases}$$

where

$D_{i,j}$ denotes the expected packet delivery delay from I_i to the destination if the packet carrier at I_i chooses to deliver the packet following road $r_{i,j}$

$P_{i,j}$: the probability that the packet is forwarded through road $r_{i,j}$ at I_i

$N(j)$: the set of neighbouring intersections of I_j

$r_{i,j}$: the road from Ii to Ij

$l_{i,j}$: the euclidean distance of $r_{i,j}$

$v_{i,j}$: the average vehicle velocity on $r_{i,j}$

$\rho_{i,j}$: vehicle density on r_{ij}

$d_{i,j}$: the expected packet forwarding delay from I_i to I_j

In each intersection, a scenario can be assumed in which whether the packet should be forwarded to the vehicle geographically close to the ultimate destination or to the vehicle moving in the direction of ultimate destination. In order to address this issue, two forwarding protocols are proposed 1) location first probe; and 2) direction first probe. It is discussed [24] that the first approach generates routing loops at intersection and it is also proven that the second approach is free from routing loops at intersection areas.

2.5 Opportunistic Forwarding

Network fragmentation may happen due to the low market penetration rate at least at the early stages of introducing the technology or due to low traffic density periods. Therefore, this issue is addressed in some of research efforts and data dissemination approaches are proposed such that continuous network connectivity cannot be guaranteed.

With respect to the role-based mulitincast protocol proposed in [16, 25] the main objective is to achieve maximum reachability in a sparsely connected network. In the proposed approach, each node keeps a set named at neighbouring set and retransmissions are based on changes in the neighbour sets. The details of this protocol is already discussed in a timer-based forwarding section.

The proposed approaches in the reviewed literatures present the idea of carry and forward as the only applicable strategy when the network fragmentation. With respect to the research carried out in reference [20], an opportunistic packet relaying is proposed for disconnected vehicular ad hoc network, named as OPERA. In OPERA, the packet progresses towards destination opportunistically, by a combination of data muling and local routing with the help of both co-directional and oncoming clusters. It should be noted that a cluster refers to the group of vehicles that are in a direct radio transmission with one another and have the same direction.

In this research, some mathematical expressions are proposed such as the expected slot for a specific car, the probability of having disconnected periods and expected cluster size, both as a function of traffic density and communication range. The analytical expressions show that the network fragmentation or clustering is present even in relatively dense traffic condition [20].

In a given time interval, beacon message is sent which is used for cluster formation and cluster maintenance. Figure 2.12 shows the cluster formed in the road segment. It should be mentioned that head and tail vehicles in a cluster (maintained proactively) play a especial role in OPERA and are denoted by h(.) and t(.) .

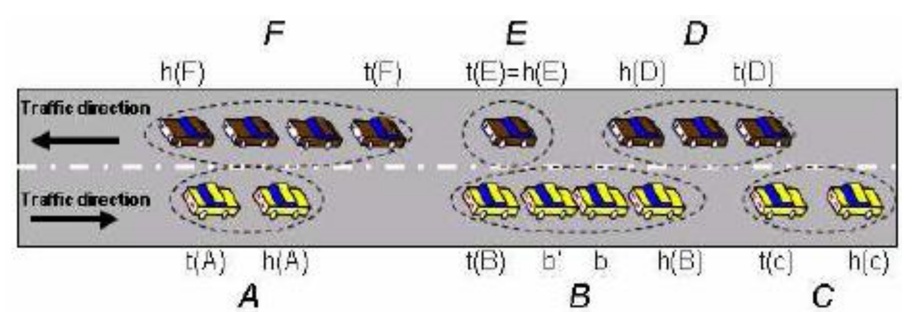


Figure 2.12: Clusters on a Two-Lane Undivided Roadway[20]

Most of the proposed routing protocols suggest that the message needs to be delivered to the cluster in the opposite direction and this process (sending the packet between clusters in both directions) continues until the packet is reached to its destination. However, OPERA offers a different approach. It believes that there are some cases may rise such as the one depicted in Figure 2.13.b in which sending the packet in opposite direction not only is not beneficial but also a lot of resources may be wasted at no gains. As an example, it would have been much better for car *a* not to send the packet to car *b* at all and carry the packet for some time and send the packet to *g* when they are in a direct radio contact. OPERA attempts to speed up the packet delivery time by opportunistically selecting a locally-optimal route towards the destination using only local connectivity information. A packet "may hop" between clusters or cars moving in opposite lanes until eventually it reaches its destinations. In this sense, OPERA is actually a hybrid protocols it alternates between applying proactive routing and data muling. The above literature reviewed in this chapter is categorized in a schematic manner in the following:

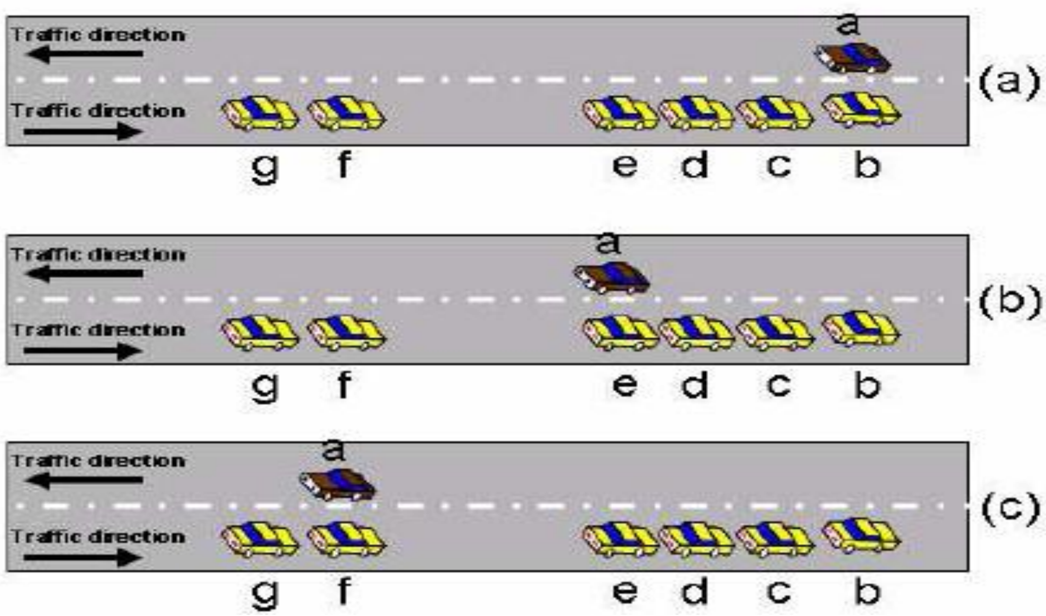


Figure 2.13: OPERA: A Motivating Example [20]

Flooding

[16]:

- Flooding based solution
- Nodes wait a time proportional to the distance from the source before rebroadcasting

[2]:

- Combining probabilistic broadcast technique with timer based suppression
- Broadcast suppression techniques:1) weighted p-persistence (vehicles located further have higher probability for retransmission), 2)slotted 1-persistence (vehicles have to retransmit with probability 1 at the assigned time slot and shorter waiting time will be assigned to the vehicles locate further 3)slotted p-persistence(vehicles have to retransmit with probability p at the assigned time slot and shorter waiting time and higher probability will be assigned to the vehicles locate further)

[17]:

- A push model for disseminating advertisements to vehicles
- Flooding overhead of query disseminations(initiated by vehicles) constrained by the number of hops
- Presenting an analytical model to estimate the performance impact of scope of query flooding(number of hops) on the query hit ratio

[1]

- Vehicles sensing data for on-board traffic information system
- Data dissemination is reached by abstracting the map into adaptive segments and aggregation information (aggregation function)
- By restricting the method to the dissemination of map/position-based data, scalability is achieved.
- Adaptive broadcast intervals based on provocation and mollification events to favor traffic condition

[13]

- Informs drivers about parking place situation under urban traffic conditions
- Proactive dissemination scheme, periodic broadcast interval to disseminate received atomic and aggregated information
- Takes spatio-temporal character of parking places into account
- Map is subdivided to overlay grids and information is classified into different levels

Relaying

[21]:

- Segment the road in the dissemination direction iteratively
- Select the node in the furthest segment as relay by using black-burts(farthest node sends longest black-burst)
- RTS/CTS like mechanism (RTB/CTB)
- Ack packet is set by vehicle which was selected to forward the packet
- Repeaters are used at intersections to propagate to different directions

[11]:

- Propose a data pouring and buffering dissemination scheme
- Disseminate data from data center to many vehicles
- Nodes maintain neighbour list and select farthest node as relay
- Dissemination zone defined as rectangle area and expiration time are attached as data delivery information
- RTS/CTS and indirect ack is used for reliability
- Ibers are deployed at intersections to broadcast data to the cross roads

[3]

- Opportunistic, trajectory (directing messages along predefined trajectories) and geographic forwarding
- Vehicles have road map and know source and destination regions
- Deliver messages to their destinations ASAP
- Road network abstracted as a directed graph
- Dissemination length is assigned to each link as a weight(road segment) which takes road distance and traffic condition into account
- Message head defined as message holder closest to the destination region along the forwarding trajectory
- Group of vehicles near the message head can forward the data
- Forwarding phase to reach the destination region and propagation phase to reach all the receivers in the region

Fragmented Network and Opportunistic Forwarding

[16, 25]:

- Retransmissions based on changes in the neighbouring list

[20]:

- An opportunistic packet relaying for disconnected vehicular ad hoc network
- Packet progresses towards destination opportunistically, by a combination of data muling and local routing with the help of both co-directional and oncoming clusters
- Cluster refers to the group of vehicles that are in a direct radio transmission with each other and have the same direction
- Mathematical expressions provided such as the expected slot for a specific car, the probability of having disconnected periods and expected cluster size, both as a function of traffic density and communication range
- Beacon message is sent for cluster formation and cluster maintenance.
- Head and tail vehicles in a cluster play an especial role
- Effective forwarding message between clusters in the co-directional and oncoming clusters

2. 6 Summary

In this chapter, the literatures related to data dissemination in vehicular networking environment were extensively reviewed. The issues associated with data dissemination were studied. Basically, depending on the type of application considered (either safety or comfort applications) in each research work, some data needs to be transmitted among vehicles. However, the inherent VANET characteristics such as different network density and fast movement of vehicles make data dissemination quite challenging. The VANETs characteristics and their differences with MANETs were pointed out in Section 2.1, followed by Section 2.2 which presented the classification of data dissemination approaches.

Two types of underlying network were assumed: 1) the network established among vehicles and some fixed infrastructures installed on road sides which lead to V2I and I2V data dissemination; and 2) the network solely established among vehicles named as VANETs and lead to V2V data dissemination.

Push-based and pull-based are two approaches considered in V2I and I2V. In the push-based approach, data is disseminated to anyone and it is suitable for popular data which is in the interest of anyone. In the pull-based approach, the network entities are able to query the required information and this approach is suitable for unpopular data propagation. Therefore, generated cross traffic can cause interference and collisions among propagating data packets.

Section 2.3 and 2.4 present flooding and relaying, respectively, which are the two proposed approaches for V2V. In the flooding, every node participates in the data dissemination and reliable and quick data propagation is its advantages. However, it is not suitable for dense network condition due to its high message overhead. In the relaying approach, the duty of forwarding is assigned to less number of vehicles and generated overhead is less. Therefore, although it is suitable for dense networks, selecting the relay points and ensuring reliability are its disadvantages.

Generally, flooding generates a lot of message overhead and so there are several approaches proposed to reduce the number of retransmissions, categorized as: 1) simple forwarding; and 2) map-based or geographical forwarding. In the first category, packet retransmissions are reduced by simply waiting prior to retransmissions proportional to the distance from the source, and also limiting the number of hops that the packet gets transmitted. In the second category, the map and geographical information are exploited and the packet is disseminated to specific directions. Therefore, the packet is not flooded in the entire network and data dissemination is restricted to specific geographical regions.

In most of the studies deploying flooding or relaying as a means of data dissemination, it is assumed that the network is fully connected; however, due to low market penetration rate and low traffic density periods, this assumption does not hold all the time. Therefore, some opportunistic data dissemination approaches are proposed in partitioned or fragmented networks and are discussed in Section 2.5. The main approach proposed for data dissemination in sparsely connected network is store and carry mechanism in which the data will be stored at the node until some nodes are available. This is the only applicable strategy in a sparsely connected network as there is no other option available.

Chapter 3

Effects of the Propagation of Warning Data

3.1 Introduction

This chapter presents an investigation of the effects of the propagation of warning data among vehicles in road networks, that is, how extending the region of data dissemination may affect the paths taken by the vehicles and the number of vehicles involved in retransmitting the message. The consideration of data dissemination in VANETs includes the transfer of information to intended receivers while meeting specific design objectives, which include low delay, high reliability, low memory occupancy, low message overhead, and the informing of additional vehicles in the case of an emergency.

Section 3.2 describes the types of various data content that must be transmitted in a variety of applications. Section 3.3 presents an overview of the system that has been used in the implementation of the developed concept. The effects of data dissemination were measured using two metrics: communication cost and additional travel cost, as defined and explained in Sections 3.4 and 3.5, respectively. The steps taken to implement the proposed concept and the results obtained are described in Section 3.6, and the chapter then ends with concluding remarks.

3.2 Types of Data Content

Several applications use vehicular networks as the basis of data dissemination among vehicles. Depending on the type of application and its objectives, different types of data must be propagated among the vehicles. The three most common types of data and their corresponding applications are:

- One important type of application, which is also a focus of this research, disseminates data that corresponds to hazardous and unexpected incidents or events taking place on road networks. The importance of this type of application lies in saving human life as well as in conserving the enormous amounts of time and fuel that are wasted when vehicles in road network either are not being informed or are inadequately being informed .
- In some types of applications, the focus is on the ability of vehicles to query a specific target and on the way responses are routed to the origin of the query.
- Other applications enable vehicles to estimate traffic conditions based on the data (e.g., direction, location, and velocity) transmitted among them.

The first type of application focuses on the dissemination of traffic information that is spatio-temporally sensitive. This attribute implies that both the location and timing of the traffic information should be taken into account with respect to data dissemination. For example, if an incident takes place at a specific location, the "spatio" part of the attribute implies that this incident is not likely to be of interest for vehicles located 100 kilometers away from the incident, and the "temporal" part of the attribute means that information about the incident will be much less useful two hours after the incident.

Clearly, extending the region of data dissemination means that more vehicles are informed and can make better decisions regarding their path along the road. However, when the region of data dissemination is extended, the data may be accessed in some geographical areas where it is neither relevant nor beneficial. Furthermore, extending the region of data dissemination can also raise the communication cost. When a communication medium is shared, particularly during period of high traffic density, unwise flooding or relaying the packet may generate high message overhead. As a result, delays and packet collisions may lead to a situation in which the packet is not disseminated within or at the appropriate time. It is worth mentioning that delays have an undesirable impact on warning and safety messages which require very low message latencies.

In this research, two metrics are defined: communication cost and additional travel cost. Communication cost is defined as the minimum number of vehicles required to broadcast the message further. Additional travel cost is defined as the cost differences associated with paths that are calculated before and after information propagation. This research investigates how communication cost and additional travel cost change as the region of propagation is expanded.

3.3 System Overview

Because a vehicular network is constructed among equipped vehicles that are moving on road segments, the layout of the road network was adapted as the network topology. A road network is considered to be a two-dimensional square grid and represented by a graph. The nodes and arcs of the graph represent the crossroads and the roads in a transport network, respectively. A cost is assigned to each road (arc) in the assumed transport network, which represents the level of congestion on that road segment. For the research carried out in [24], the vehicular network was also represented as a directed graph, and a weight that was assigned to each link was considered to be the forwarding delay between two adjacent intersections. For this study, the weight was incorporated in order to calculate the optimal forwarding path for the propagation of each packet.

It is assumed that the vehicles are equipped with navigation systems that employ Global Positioning System (GPS) receivers, a wireless network interface for inter-vehicle communication that complies with standards such as 802.11p or Dedicated Short-Range Communications (DSRC), and an Onboard Diagnostic Interface (ODI). The ODI acquires data from several mechanical and electronic sensors installed on the vehicle such as acceleration and speed sensors installed on vehicle. The underlying network is assumed to be constructed as a pure ad hoc network. One-hop is defined as the distance between two neighbouring intersections, and it is assumed that one hop can be up to 1000 meters when the DSRC is deployed.

3.4 Communication Cost

Communication cost is defined as the minimum number of vehicles required to broadcast the message throughout the road network. For the purposes of the investigation of the effects of data dissemination, an ideal broadcasting scheme and a flooding-based broadcasting scheme are assumed.

3.4.1 Ideal Broadcasting Scheme

In the ideal scenario, each node receives only one copy of the packet; in other words, the packet is not sent to any nodes more than once. It is assumed that a message starts to propagate at an intersection and that the constructed vehicular network is fully connected so that at least one vehicle is present at each intersection and broadcasts the message further. The ideal broadcasting scheme is displayed in Figure 3.1.

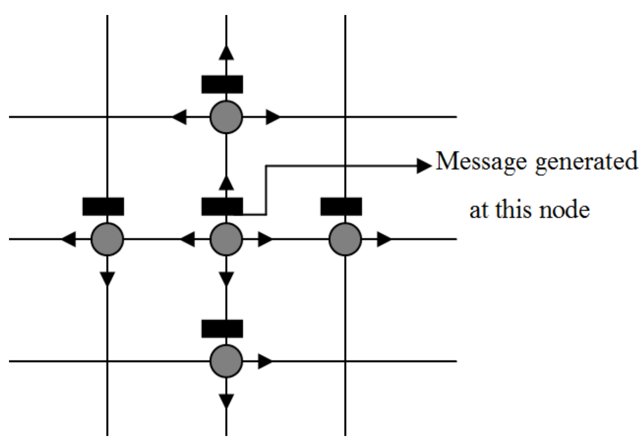


Figure 3.1: Ideal Broadcasting Scheme

3.4.2 Flooding-Based Scheme

In a flooding-based broadcasting scheme, when a vehicle receives a packet, the identification assigned to the packet is checked. If the packet is received for the first time, it is rebroadcast to all neighbours; otherwise, it is discarded. The flooding-based scheme is shown in Figure 3.2.

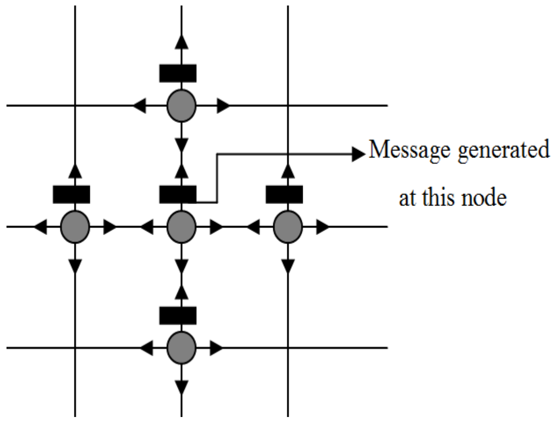


Figure 3.2: Flooding-Based Scheme

3.5 Additional Travel Cost

This section describes how propagating any specific event over further hops in the network can affect the shortest-path cost taken by vehicles from the source to an intended destination. Additional travel cost is defined in order to quantify the cost imposed on vehicles when they move one hop closer to the event on their known shortest path from their source toward their destination and when they are informed about the event at that hop. The additional travel cost for any vehicle at hop j^{th} ($1 \leq j \leq$ maximum number of hops in the assumed network) is determined as follows:

$$Additional\ travel\ cost = \left|C_{sh-path} - (C_1(j) + C_2(j))\right| \tag{1}$$

where

$C_{sh-path}$ is the shortest path cost from source to destination
$C_1(j)$ is the shortest path cost from source to the point j-hop away from the event
$C_2(j)$ is the shortest path cost from the point j-hop away from the event to the destination

For a better understanding, the concept of additional travel cost can be clarified by means of the example shown in Figure 3.3. As can be seen, a road network with 25 intersections is assumed, and a random cost is assigned to each road segment. The shortest-path cost for the source located at the 17th intersection (n_{17}) toward the intended destination at the 25th intersection (n_{25}) is highlighted on the road network (Figure 3.3). It is assumed that the shortest path is calculated prior to the beginning of the trip.

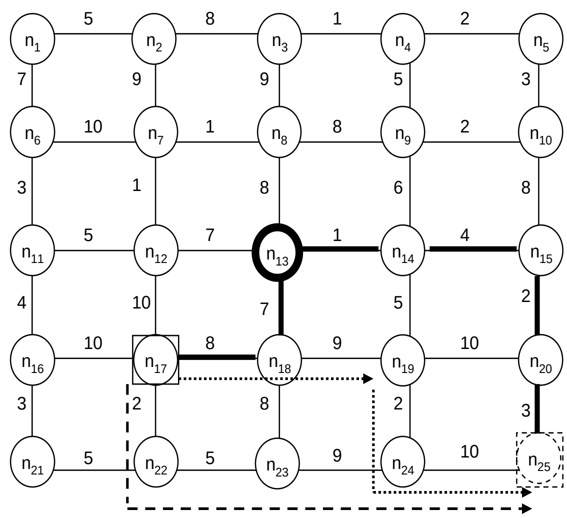


Figure 3.3: An Example Illustrating the Additional Travel Cost Concept

As shown with a solid bold line in Figure 3.3, the shortest path from n_{17} to n_{25} is the following sequence of nodes: < $n_{17} \rightarrow n_{18} \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{15} \rightarrow n_{20} \rightarrow n_{25}$ >. The total cost of the shortest-path is therefore 25 (8+7+1+4+2+3). It is assumed that an unexpected event starts propagating at the 13 th node (n_{13}) which is placed on the shortest-path cost as calculated by the vehicle. This event causes congestion on the links that end at n_{13}, and the costs assigned to those links increase accordingly. If the event is not propagated, the vehicles are unaware of the incident. Therefore, they choose their path based on their former pre-calculated shortest path without knowing that taking that current path has a high cost associated with it. At this point, it is important to know how additional travel costs change while the vehicles are moving one hop closer to the event, and they are being informed about the event in that hop. It should be remembered that the additional travel cost indicates how vehicles can benefit from being aware of an event while they are moving closer to that event by one more hop.

If the packet is propagated to one-hop neighbours (i.e., n_8, n_{12}, n_{14}, and n_{18} in Figure 3.3), the shortest path from n_{17} to n_{25} is the following sequence of nodes, indicated by the dotted line: < $n_{17} \rightarrow n_{18} \rightarrow n_{19} \rightarrow n_{24} \rightarrow n_{25}$ >. The corresponding additional travel cost is calculated as <|25-(8+21)| >, which equals 4. When the packet is propagated to two-hop neighbours, n_{17} is informed about the event, and the shortest path at that point has the following sequence of nodes, as shown by the dashed line: <$n_{17} \rightarrow n_{22} \rightarrow n_{23} \rightarrow n_{24}$ n_{25} >. The corresponding additional travel cost is calculated as <|25-(0+26)|>, which equals 1. As can be seen, when the vehicles are further from the event and are informed about the event, the additional travel cost is less than or equal to that of the situation when the vehicles have reached a location one hop closer to the event.

When *k* vehicles are involved, the additional imposed cost for *k* vehicles at hop j^{th} (1= < j <= maximum number of hops in the assumed network) passing through the event on their pre-calculated shortest paths is determined as follows:

$$Additional\ travel\ cost(j) for\ k\ vehicles = \sum_{i=1}^{k} \left| C_{sh-path} - (C_1(j) + C_2(j)) \right| \qquad (2)$$

3. 6 Implementation

In this section, the steps needed in order to implement the concept described (e.g., additional travel cost) in the proposed road network are discussed.

3.6. 1 Network Representation and Labeling Method

The road network that was considered for the implementation is a two-dimensional square grid defined as a graph G = (N, A) consisting of a set N of nodes and a set A of arcs. The associated numerical values n=|N|, a=|A|, and $c_{i,j}$ indicate the number of nodes, the number of arcs, and the cost assigned to the arc (road) between node n_i and node n_j, respectively. The nodes and arcs of the graph represent the crossroads and the road in a transport network, respectively. There are also costs assigned to each road (arc) in the assumed network. The cost assigned to each link indicates the level of congestion between two neighbouruing intersections. All roads are assumed to be bidirectional with the same cost assigned to both directions. The graph described is implemented as two two-dimensional arrays, in which the first array maintains the adjacent nodes for each node in the network (adjacencyArray) and the second array holds the cost assigned to the existing links specified in the first array (costArray). Figure 3.4 shows a road network in a graph representation in which m represents the number of crossroads in each dimension. Figure 3.5 shows the, “adjacencyArray” and “costArray” arrays for the graph shown in Figure 3.4.

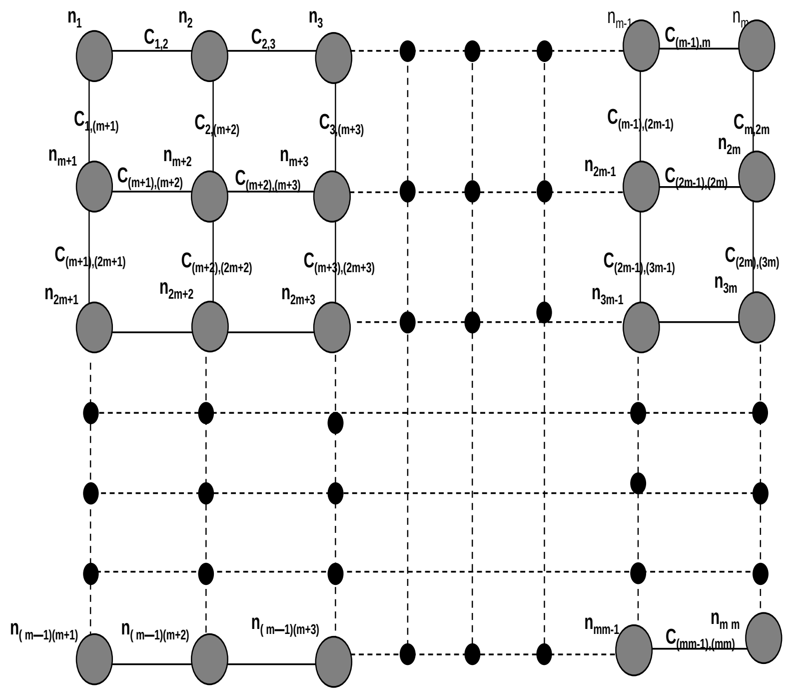


Figure 3.4: Road Network of *m* Intersections in Each Dimension

To carry out the implementation, a network of 625 intersections was assumed and the event to be propagated was placed at the centre of the road network. It should be noted that Dijkstra's algorithm was used to find the shortest-path cost from a source to a destination. Additional details about the use of Dijkstra's algorithm for finding shortest paths is included in the research presented in [26]. The following steps were taken for the implementation:

- Setting an event at a specific node which will be propagated from that point,
- Generating a set of random source-destination pairs,
- Applying Dijkstra's algorithm for each pair and thus finding the shortest path from that specific source to the specific destination for a vehicle,

- Finding those source-destination pairs that will pass through the event on their pre-calculated shortest path toward intended the destination, and
- Assigning an infinity cost to the links that end at the intersection where the event occurs.

$$
\begin{array}{c}
n_1 \\ n_2 \\ n_3 \\ \vdots \\ n_{m-1} \\ n_m \\ n_{m+1} \\ n_{m+2} \\ \vdots \\ n_{mm}
\end{array}
\begin{pmatrix}
n_2 & n_{m+1} & 0 & 0 \\
n_1 & n_3 & n_{m+2} & 0 \\
n_2 & n_4 & n_{m+3} & 0 \\
\vdots & \vdots & \vdots & \vdots \\
n_{m-2} & n_m & n_{2m-1} & 0 \\
n_{m-1} & n_{2m} & 0 & 0 \\
n_1 & n_{m+2} & n_{2m+1} & 0 \\
n_2 & n_{m+1} & n_{m+3} & n_{2m+2} \\
\vdots & \vdots & \vdots & \vdots \\
n_{mm-1} & n_{m(m-1)} & 0 & 0
\end{pmatrix}
\Rightarrow
\begin{array}{c}
n_1 \\ n_2 \\ n_3 \\ \vdots \\ n_{m-1} \\ n_m \\ n_{m+1} \\ n_{m+2} \\ \vdots \\ n_{mm}
\end{array}
\begin{pmatrix}
c_{1,2} & c_{1,m+1} & 0 & 0 \\
c_{1,2} & c_{2,3} & c_{2,m+2} & 0 \\
c_{2,3} & c_{3,4} & c_{3,m+3} & 0 \\
\vdots & \vdots & \vdots & \vdots \\
c_{m-1,\, m-2} & c_{m-1,m} & c_{m-1,2m-1} & 0 \\
c_{m-1,m} & c_{m,2m} & 0 & 0 \\
c_{1,m+1} & c_{m+1,m+2} & c_{m+1,2m+1} & 0 \\
c_{2,m+2} & c_{m+1,m+2} & c_{m+2m+3} & c_{m+2,2m+2} \\
\vdots & \vdots & \vdots & \vdots \\
c_{m\,m,\, mm-1} & c_{mm-1,\, mm} & 0 & 0
\end{pmatrix}
$$

Figure 3.5: “adjacencyArray” and “costArray” for the Graph Shown in Figure 3.4

3.6.2 Results of the Implementation

As shown in Figure 3.6, the communication cost and the additional travel cost were plotted so that the dashed and circle-pointed graphs show how the communication cost changes when the number of hops propagated increases. The circle-pointed graph depicts the ideal broadcasting scheme, and the dashed graph depicts the flooding-based scheme.

As can be seen, when the number of hops propagated increases, the communication cost increases and saturates after a few hops. This result is due to the boundary limitation of the assumed network. It can be inferred without a boundary limitation, the communication cost would continue to increase. Therefore, if the boundary limitation is ignored, the communication cost *(com_cost)* can be depicted as a second-degree polynomial function (quadratic function), as expressed by Equation (3). The solid graph represents the additional travel cost (*ad_tr_cost*) and shows a negative exponential decay as a function of the number of hops propagated. The analytical expression obtained is expressed as Equation (4).

$$com\_cost = c_a\left(x^2 - x + \frac{1}{c_b}\right) \cong cx^2 \;\; for\; x = 1,2,\cdots \tag{3}$$

$$ad\_tr\_cost = c_p e^{-c_q x} \;\; for\; x = 1,2,\cdots \tag{4}$$

where x is the number of hops propagated in both equations. The plots adjacent to the additional travel cost and the flooding-based scheme graphs represent the analytical graphs written as Equations (4) and (3), respectively. The additional travel cost indicates that when vehicles are farther away and are informed about the incident, more efficient and effective paths are calculated because they take into account the updated information related to the current congestion level when they calculate the new shortest path.

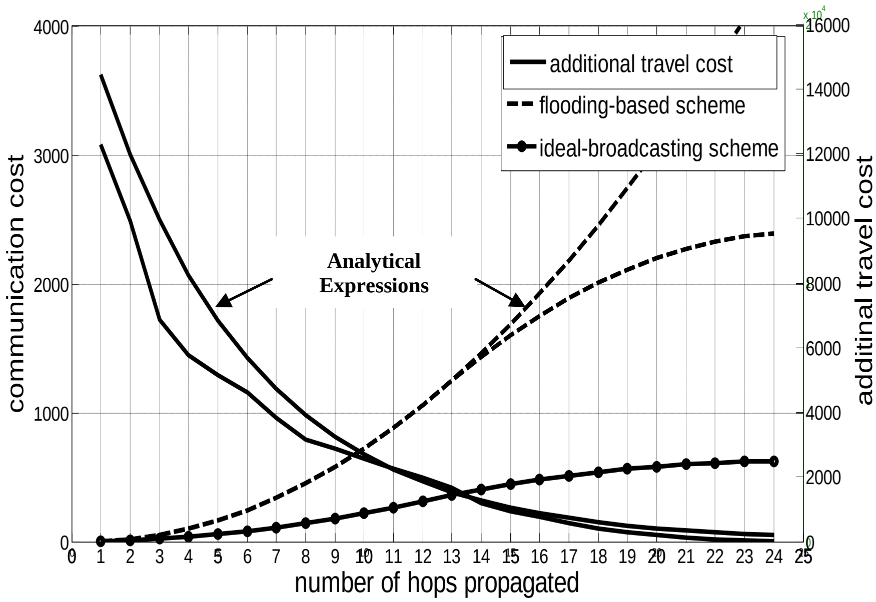


Figure 3.6: The Communication Cost and the Additional Travel Cost

Figure 3.7 shows another graph in which the communication cost (on the *x*-axis) is plotted against the additional travel cost (on the *y*-axis). This graph shows the relationship between the two costs and how they influence each other. The relation between the two costs appears to be a negative exponential decay, as expressed in Equation 5 and plotted in Figure 3.7 with a dashed line.

$$ad\_tr\_cost = c_1 e^{-c_2 x} \tag{5}$$

where *x* represents the communication cost.

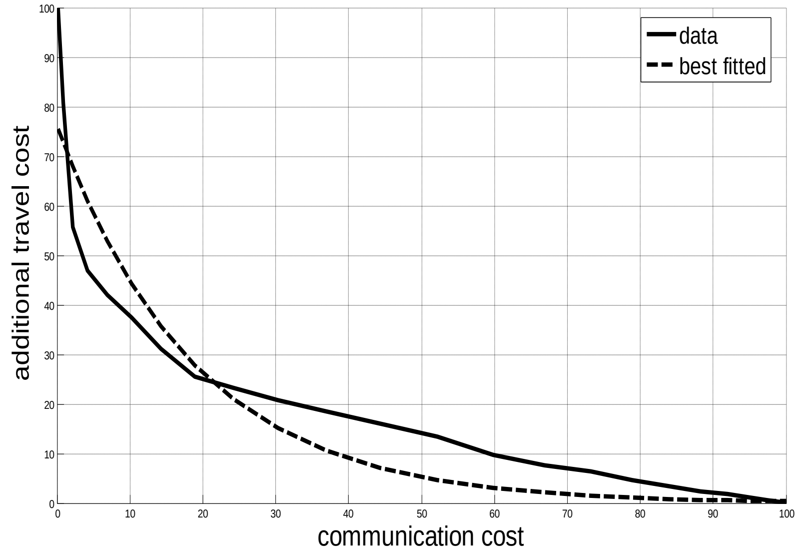


Figure 3.7: The Communication Cost Plotted Against the Additional Travel Cost

3.7 Summary

This chapter presented the investigation of the way extending the region of data propagation may influence both the paths taken by the vehicles and the number of vehicles involved in broadcasting message further. To this end, the communication cost and additional travel cost were defined and the relationship between them was investigated. The additional travel cost metric was used in order to show how the calculation of the shortest path based on the updated information received at each hop may affect the paths taken by the vehicles. The lower costs are associated with paths calculated based on updated information. The results show that extending the region of propagation increases the communication cost and decreases the additional travel cost. As can be inferred from the result, while the vehicles are far from the event and informed about it, they can choose better paths with less associated congestion because they can calculate the shortest path based on updated information regarding the current congestion levels on the road segments.

Although extending the region of propagation informs more vehicles on the road, it also increases communication cost and causes undesirable consequences such as delays. There is an effective region for event propagation: the data needs to be propagated in that specific region, which is called “Region of Interest (RoI).”

In Chapter 4, an effective data dissemination scheme is presented using the concept of the RoI to indicate the effective region throughout which the data should be propagated. The factors that influence the determination of the RoI are also explained.

Chapter 4

Effective Dissemination of Warning Messages in Vehicular Ad Hoc Network

4.1 Introduction

A new scheme for effectively disseminating warning messages among vehicles is presented in this chapter. The main purpose of the scheme is to propagate warning messages effectively so that the traffic density and the type of warning message needed to be disseminated are taken into consideration. The propagation of data is restricted to the Region of Interest (RoI) based on traffic density and the type of message corresponding to the incident that is occurring. This chapter includes a description of these categories of incidents followed by an explanation of the RoI. The simulation of the proposed scheme for three types of traffic density is presented, along with the results obtained. The chapter is then summarized.

4.2 Protocol Description

When an unexpected event or incident is detected, an appropriate message is generated and propagated in order to inform the vehicles in the network about the incident. It should be mentioned that deploying a variety of sensors on the vehicles allows the incidents to be detected so that an appropriate warning message can be initiated (e.g., activation of an air bag in a car crash). As discussed in Chapter 3, this type of information is spatio-temporally sensitive, which implies that the location and timing of the incident have to be taken into consideration with respect to the propagation. For example, information regarding any incident can be beneficial to vehicles that are located in the vicinity of the incident. Warning messages are also delay sensitive, and the delay has a very undesirable effect on the dissemination of the warning data. As can be inferred, the region of data dissemination needs to be restricted in order to provide efficient propagation of the warning data. Therefore, a strategy that restricts data dissemination so that the most vulnerable vehicles are informed will decrease the number of messages generated and thus reduce the amount of overhead.

As discussed in Chapter 2, to reduce packet overhead some approaches are proposed. Deploying a relay strategy whereby assigning the task of data retransmission is assigned to a selected relay node or nodes can be a suitable approach for effective data dissemination. However when a relay strategy is used, the traffic density can be an important factor because with lower traffic density, such a strategy may not be as effective as pure broadcasting. In the developed scheme, of all a vehicle’s neighbours, only one vehicle located in the RoI participates in packet retransmission. The relay is selected in a distributed manner and there is no need for any extra information to be exchanged in order for the relay to be determined. From the information received in the warning message, each vehicle can determine whether or not it becomes the relay.

In the new effective data dissemination scheme, the region of data dissemination, designated as the RoI, and the traffic density are both taken into consideration. RoI is defined as the geographical region in which the warning message is transmitted so that the optimum number of vehicles affected an the incident are informed.

4.2.1 Determining the Relay Point

As suggested by [21], the relay is the neighbour furthest away from the sender and is located at the edge of the transmission range. The presented scheme assumes that traffic density is a priori knowledge and takes it into account for calculating the specific border area that may contain the relay point. As can be inferred, when the traffic density is high, this area must be narrower, whereas it should be wider when the traffic density is low. The next sections present an investigation of the way changing this area based on traffic density improves the performance with respect to data dissemination.

When traffic density is high, several vehicles might be located in the relay area. This challenge can be resolved if a random waiting time is assigned to each vehicle located within the relay area. The vehicle with the shortest waiting time then retransmits the packet. This research also studied how assigning a random waiting time according to the traffic density benefits performance with respect to data dissemination. Therefore, vehicles that receive a warning message should not rebroadcast it immediately; the responsibility of broadcasting should be assigned to the relay node.

4.2.2 Packet Header

When a packet is generated at the point where an incident takes place, specific information needs to be included in the packet header:

- The ID assigned to the generated packet (idOfPacket)
- The direction of the traffic (direction)
- The time that the packet is generated (timeOfGeneration)
- The position of the incident (position)
- The position of that vehicle that detected the incident for the first time or the position of the vehicle (relay) retransmitting the packet (posOfTransVeh)
- The time required for the incident to be resolved (timeOfResolve)
- Calculated RoI (regionOfInterest).

With respect to the second last point, the assigned time for an incident to be resolved is dependent on the type of incident that takes place. More discussion is provided in the following sections. Figure 4.1 shows the information enclosed in a data packet, and Figure 4.2 displays the class diagram for class "*Packet.*"

idOfPacket	direction	timeOfGeneration	position	posOfTransVeh	timeOfResolve	regionOfInterest

Figure 4.1: The Packet Format

4. 3 Factors Affecting the Region of Interest (RoI)

Several factors may influence the determination of the RoI, the main ones of which are briefly introduced below:

```
Packet
----------------------------------------------------------------
- int idOfPacket
- int direction
- int timeOfGeneration
- int position
- int posOfTransVeh
- int timeOfResolve
- int regionOfInterest
----------------------------------------------------------------
+  Packet(int  id,int  dir,  int  t  ,int  pos,int
        posOfvehTransmitted,   int   resTime,   int
        regOfInterest )
+ int  getPacketID()
+ void setPacketID(int id)
+ int  getPacketDirection()
+ void setPacketDirection(int dir)
+ int  getPacketGenerationTime()
+ void setPacketGenerationTime(int t)
+ int  getPacketPosition()
+ void setPacketPosition(int pos)
+ int  getPosOfTransVeh()
+ Void setPosOfTransVeh(int posOfvehTransmitted)
+ int  getPacketTimeOfResolve()
+ void setPacketTimeOfResolve(int resTime)
+ int  getRegionOfInterest()
+ void setRegionOfInterest(int regOfInterest)
```

Figure 4.2: Class Diagram for Class "*Packet*"

1) Type of warning messages: The RoI for warning messages reporting a severe incident or event should be different from and wider than the RoI for warning messages reporting insignificant incidents. For example, the RoI for a severe car crash must be wider than that for a vehicle deviating and causing a negligible problem. The time for resolving an incident is a reasonable indication of the

severity of the incident. In the scheme developed in this research, the time factor is taken into account and is discussed in the following subsection.

2) Layout of a road network: The geographical location of the incident is an influential factor in the determination of the RoI. If an accident has taken place on a highway, for example, the RoI for such a roadway must be different from the RoI for an incident that has taken place on an urban roadway. The difference is due to the variation in road characteristics, such as speed, direction, and movement patterns.

3) Capacity of alternative roads: If vehicles are to change their direction to available alternative roadways because of the message received about an incident on the main road, the alternative roadways may reach their maximum capacity. In other words, broadcasting may cause congestion on the alternative roads.

4.3.1 Types of Informing Messages

The informing messages that need to be propagated will vary due to the wide variety of incidents that may happen on a road. Incidents can be divided into three categories:

1) Severe incidents or events: These events have a serious impact on traffic flow, and therefore, long-lasting congestion is an inevitable consequence.
2) Moderate incidents or events: These types of events can still have a negative impact on traffic flow, but the consequence is not as severe as with the first category.
3) Slight incidents or events: Although these types of incidents can slightly impact traffic flow, they can be resolved in a short time.

Incidents falling into the above three defined categories can be differentiated according to time in which they can be resolved. Therefore, the objective is to determine how far a message should be propagated in order to effectively inform vehicles about an incident when the above three categories are considered. To achieve this objective, the concept of applying the time required for resolution of an incident, called the resolve time, has been introduced and is described in the following section.

4.4 The Deployment of the Region of Interest (RoI)

The effectiveness of the developed scheme is due to the deployment of the RoI concept. The RoI, as shown in Figure 4.3, is defined as the distance from which the vehicles are approaching the incident with an average speed V (m/s) and during a time interval T, which represents the time for resolution of the incident. Therefore, only vehicles that are confined to the RoI are informed about the incident. So that the propagation of the message is restricted to the RoI, the following steps are taken by the vehicles receiving the message:

- The distance between the vehicle that is receiving the message and the location of the incident, which is enclosed in the data packet header, is determined by obtaining the current location of the vehicle through GPS receivers; if the distance is equal to or less than the RoI, then the vehicle is located in the RoI.
- If the determined distance is greater than the RoI, then the message is discarded because the vehicle is located beyond the RoI.

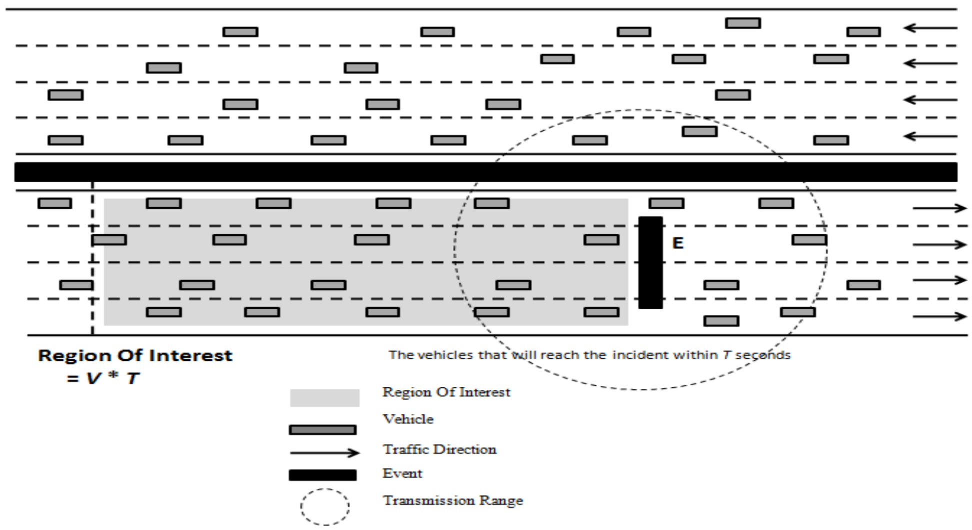


Figure 4.3: Determining the RoI

Figure 4.3 illustrates an incident with a resolve time of T (s) taking place at point E. When the average of the vehicles speed V (m/s) and the traffic density D (vehicles/km) are available, the RoI can be calculated using the following equation:

$$\text{RoI} = V * T \tag{1}$$

When an incident takes place on a roadway, the vehicles may be in one of three possible geographical positions:

- Some vehicles may be in a position beyond the incident. These vehicles should not retransmit the message further because they are already beyond the incident, and there is no benefit in their being informed.
- Some vehicles may be positioned before the incident but not within the RoI. In other words, they reach the RoI when the incident is resolved. As with the first group, there is no benefit in informing them.
- Other vehicles are within the RoI when an incident takes place, and these vehicles should be informed about the incident.

As shown in equation (1), the vehicle's speed is required for the calculation of the RoI. It is assumed that traffic statistics such as traffic density and vehicle speed at different times of day, are a priori knowledge. The research [24] also assumes that the vehicles are equipped with pre-loaded digital maps through which the above traffic statistics are available at street level. The research [24] has mentioned that such digital maps have already been commercialized [27].

A flowchart diagram of the developed scheme and corresponding procedural illustration of the scheme are shown in Figures 4.4 and 4.5, respectively. The methods used to describe the scheme are presented in Table 4.1.

Table 4.1: The Methods Used to Describe the Proposed Scheme

Name	Description
checkBuffer(packet)	Returns true if duplicate packet is not received, false otherwise;
conditionSatisfy()	Returns true if neverSeen, evalMovingDitrection, evalRegionofInterest and evalRelayArea all are return true, false otherwise;
eventDetector()	Returns true if an incident is detected, false otherwise;
evalMovingDirection(Packet P, Vehicle vehicle)	The direction of the packet is compared with the direction of the vehicle receiving the p. Returns true if it has the same direction as the packet, false otherwise;
evalRegionofInterest(Packet P, Vehicle vehicle)	Returns true if the vehicle is located at the RoI, false Otherwise;
evalRelayArea(Packet P, Vehicle vehicle)	Returns true if the vehicle is placed in relay area, false otherwise;
genRndWatingTime()	Generates random waiting time;
generatePacket()	The packet corresponding to the incident will be generated;
neverSeen(packet)	Returns true if the packet is received for the first time, false otherwise;
refreshPacket(Packet P)	Position of the chosen relay is rewritten at the "posOfTransVeh" portion of the packet header.
sendPacket(Packet P)	The packet p will be retransmitted to all neighbours in transmission range.
timeExpire()	Returns true if the assigned random waiting time is expired, false otherwise;

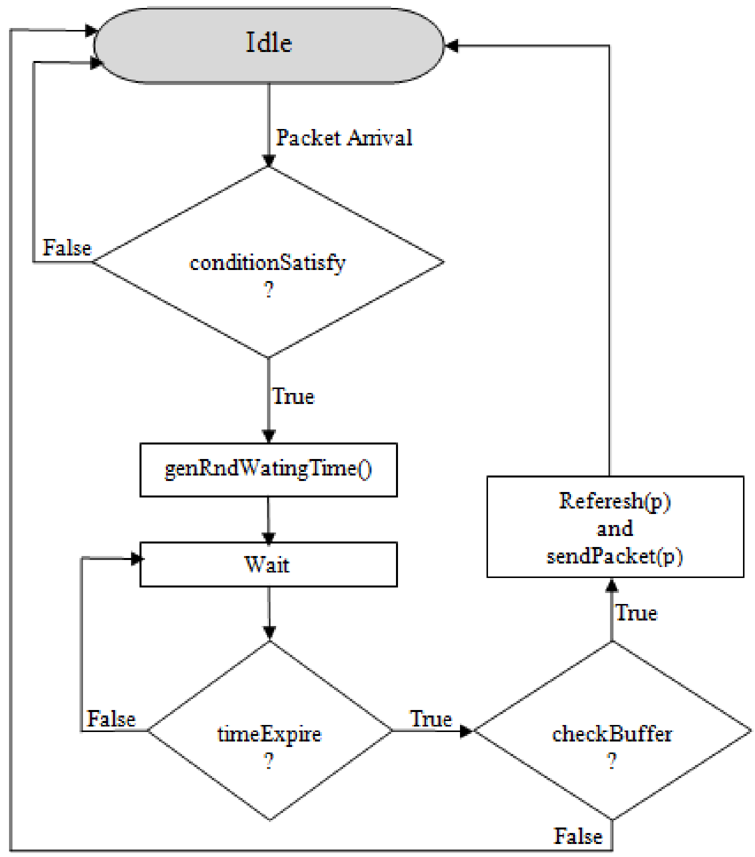


Figure 4.4: Flowchart Diagram of the Proposed Scheme

```
if (eventDetector()==true){
   Packet p=generatePacket();
   sendPacket(p);
  }
For all the vehicles in the transmission range {
    if (neverSeen(p)==true && evalMovingDirection(packet,
          this.vehicle) == true && evalRegionofInterest(packet,
          this. vehicle)==true && evalRelayArea(packet,
          this.vehicle)==true){
          time=genRndWatingTime();
           if (timeExpire){
              if(checkBuffer(p)){
                 refreshPacket(p)
                 sendPacket(p)
              }
            }
 }
```

Figure 4.5: Procedural Illustration of the Proposed Scheme

4.4.1 Assumptions Made

In the development of the scheme, the following assumptions were made:

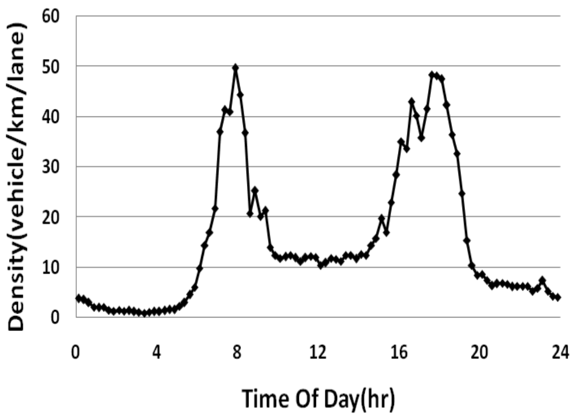
1) The vehicles are equipped with navigation systems that employ Global Positioning System (GPS) receivers, a wireless network interface for inter-vehicle communication that complies with standards such as 802.11p or Dedicated Short-Range Communications (DSRC), and an Onboard Diagnostic Interface (ODI). The ODI acquires data from several mechanical and electronic sensors installed on the vehicle.
2) The underlying network is assumed to be constructed as a pure ad hoc network. Deploying the GPS means that the location of vehicles is available at any time.
3) Traffic density and average speed are a priori knowledge.
4) An ideal media access control/physical (MAC/PHY) layer is assumed, whereby packet arriving at a network layer is transmitted immediately without any contention at the MAC layer, and all the packets transmitted arrive at the intended destination without error.

4.5 Simulation

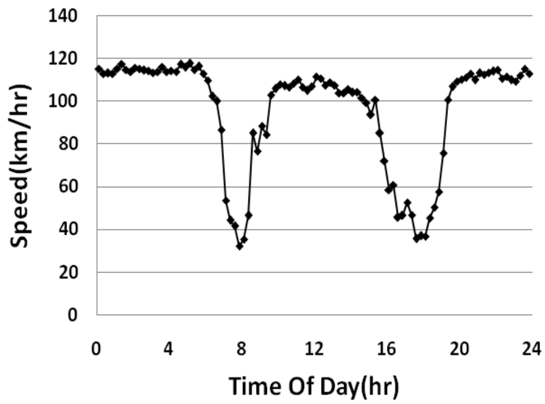
To simulate the proposed scheme, a straight segment of a highway with three lanes was modeled, and the vehicles driving on the highway were generated in a random manner using the exponential distribution. The MATLAB function exprnd(*MU*) was used to generate exponential random numbers with a mean value of *MU*.

4.5.1 Traffic Statistics

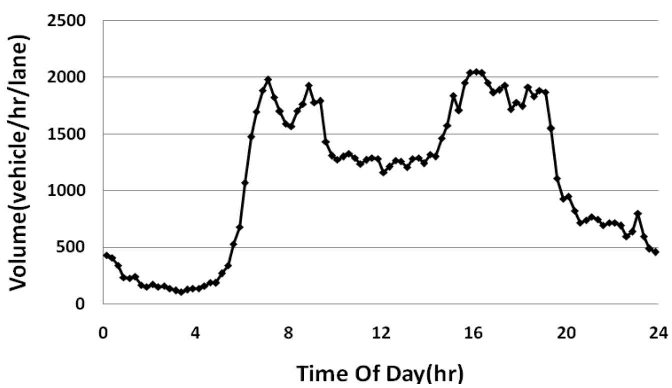
In the developed scheme, it is assumed that the traffic statistics are available such as traffic density and average speed at different times of day. To carry out the simulation, the data obtained from the dual loop detector station 401DW0090DEC, located in the eastbound collector lanes of Highway 401, was used [28]. Figures 4.6 (a), 4.6 (b), and 4.6 (c) display density (vehicle/km/lane), speed (km/hr), and volume (vehicle/hr/lane), respectively at different times of day on a selected segment of Highway 401.



(a) Density (vehicle/km/lane)



(b) Speed (km/hr)



(c) Volume (vehicle/hr/lane)

Figure 4.6: Traffic Statistics Obtained from the Dual Loop Detector Station

Figure 4.7 shows the relationship between the traffic density and the speed derived from the data obtained. Equation (2) is derived from the data (the best fit) and is also plotted in Figure 4.7.

$$\text{Speed} = -1.8227(\text{Density}) + 123.17 \tag{2}$$

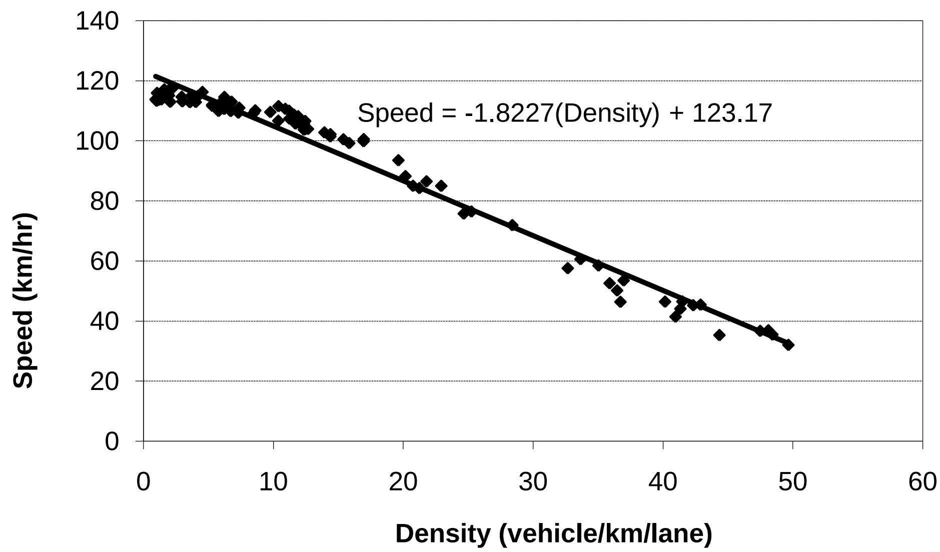


Figure 4.7: Traffic Density and Corresponding Speed

To implement the developed scheme, three types of traffic traces corresponding to high, moderate, and low traffic densities were generated. A random vehicle was chosen and, accordingly, a warning packet was generated in order to inform other vehicles. A resolve time of 10 minutes (600 seconds) was assigned to the generated warning packet. The transmission range was assumed to be 500 m.

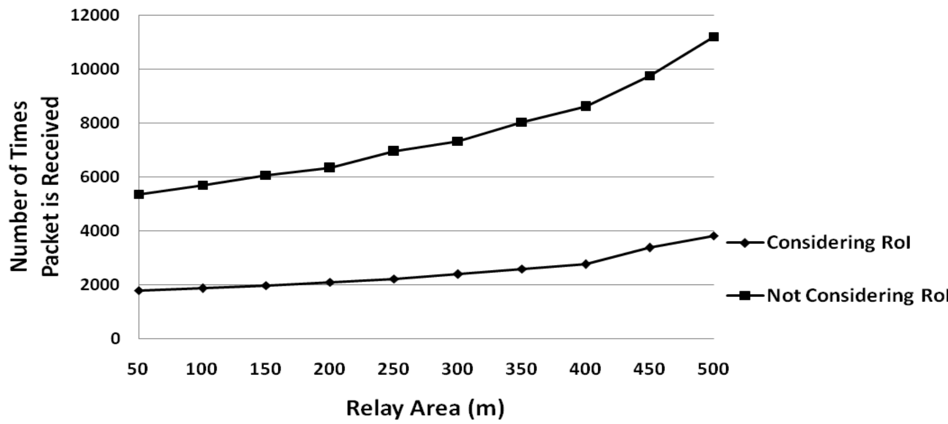
4.5.2 High Traffic Density

As shown in Figure 4.6 (a), the traffic density was assumed to be 50 vehicle/km/lane and the corresponding speed was calculated using Equation 2.

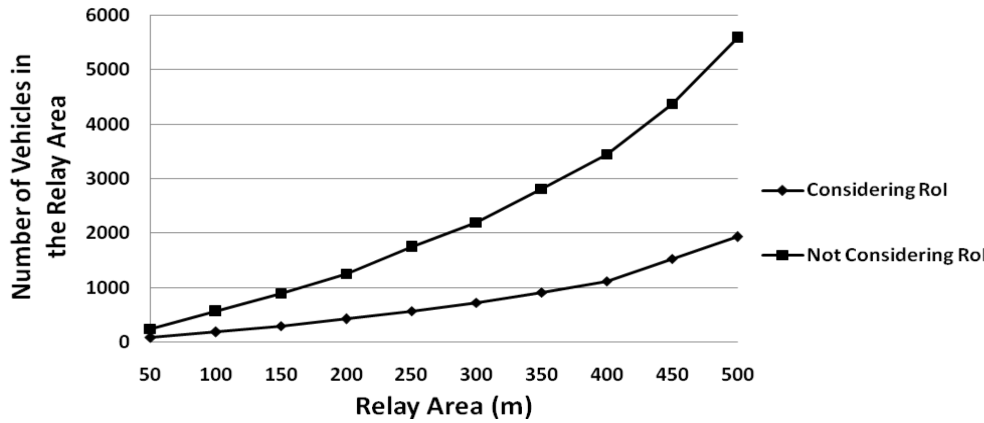
Figure 4. 8 shows the result obtained for two cases in which the generated warning message was propagated: 1) the RoI is calculated and the message is not retransmitted beyond the RoI, and 2) the message propagation is not restricted to the RoI and the message is propagated to the entire simulated area. Figure 4.8 (a) shows how many times a specific packet is received when the message is transmitted both within and beyond the RoI. As explained in Subsection 4.2.1, the determination of the relay area is an important factor in effective message propagation because the number of times a specific packet is received depends on the relay area. The objective is to determine how the number of packet receptions changes when the relay area is expanded. As shown in Figure 4.8 (a), the number increases when the relay area is extended.

From Figure 4.8 (a) it can be inferred that a wider relay area in the proposed scheme may result in the choice of relay point that is not necessarily the furthest vehicle from the packet sender. This result is due to the random waiting time assigned to the vehicles within the relay area. As well, in compared to a wider relay area, a narrower relay area provides a higher possibility of the choice of a relay point (i.e., the vehicle that finally retransmits the packet) that is further from the sender. As a result, the number of packet receptions is lower, and consequently, less redundancy occurs.

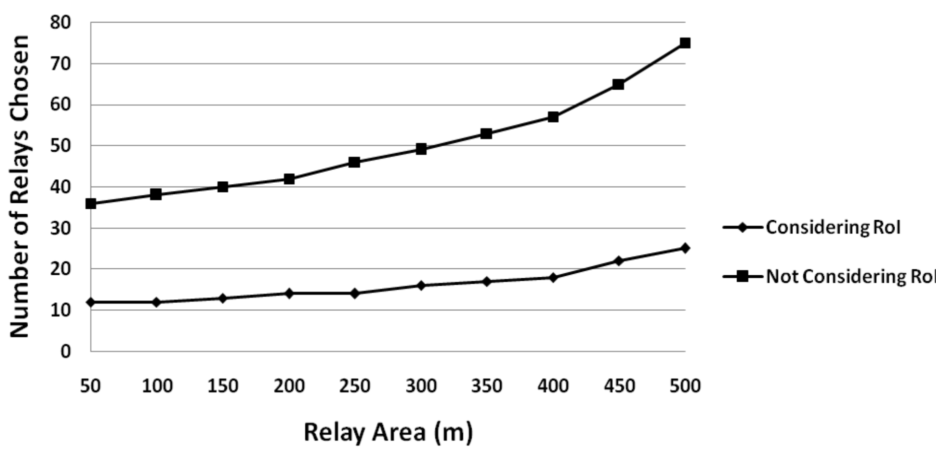
Figures 4.8 (a), 4.8 (b), and 4.8 (c) depict three pairs of graphs that illustrate the influence of the RoI (both within and beyond) with respect to each pair. When the RoI is not considered, the number packet receptions, the number of vehicles at the relay area, and the number of relays chosen are all significantly increased, as shown in Figures 4.8 (a), 4.8 (b), 4.8 (c), respectively.



a) Packet reception



b) Number of vehicles in the relay area



c) Number of relay vehicles chosen

Figure 4.8: Warning Message Propagation (Considering RoI and Not Considering RoI) in High Traffic Density

Figure 4.9 shows the excessive number of times that a packet is received when the message propagation is not restricted to the RoI. These results imply that the number of messages shown have been received and no benefit is obtained from receiving them.

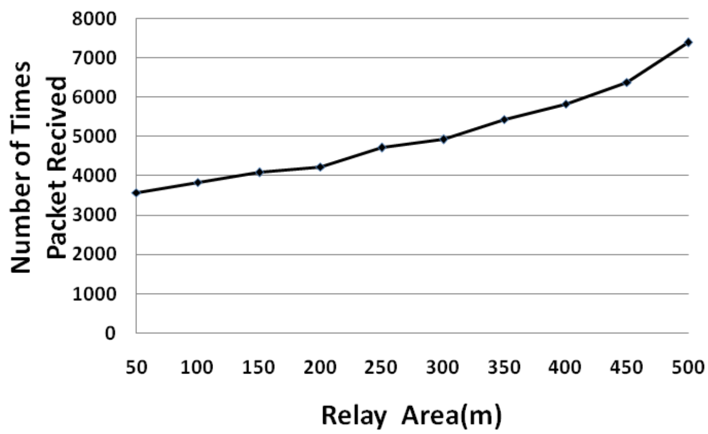


Figure 4.9: Excessive Number of Packet Receptions

It can be inferred from the above figures and explanations that in cases of high traffic density and considering the assumed road network (highway road structure), the network is fully connected and even a relay area with a width of 50 m is sufficient for selecting the relay point for retransmitting packets.

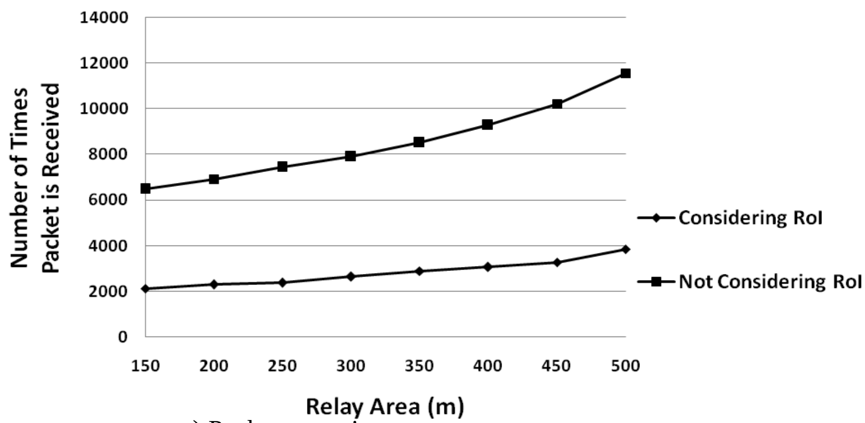
4.5.3 Moderate Traffic Density

The graphs used in the previous section were also plotted for moderate traffic density (i.e., traffic density = 20 vehicle/ km/lane), and the results were obtained, as shown in Figure 4.10. The results of the simulation reveal that when the traffic density is moderate, the relay area should be greater than 150 m. As shown in Figure 4.10, the relay area increases from 150 m outward because a relay area less than 150 m entails the possibility of not having any vehicle in the relay area for that assumed traffic density.

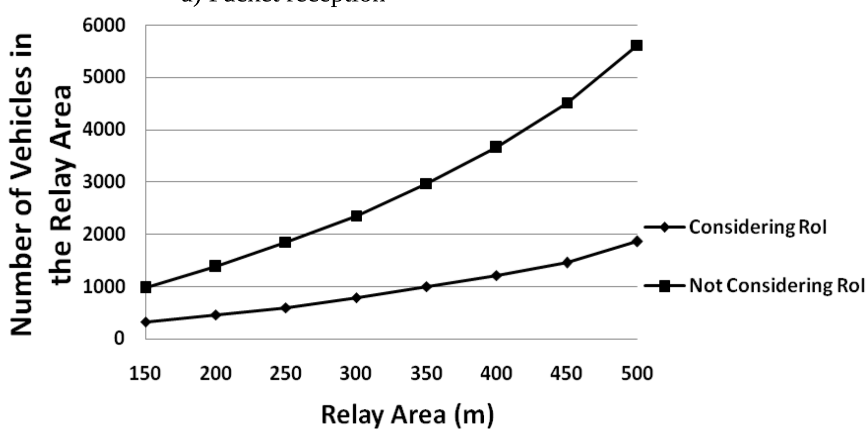
4.5.4 Low Traffic Density

Based on the results shown in Figure 4.11, when the traffic density is low (10 vehicle/km/lane), the relay area must be greater than 250 m in order to find at least one vehicle within the relay area and to avoid a disconnection in data dissemination.

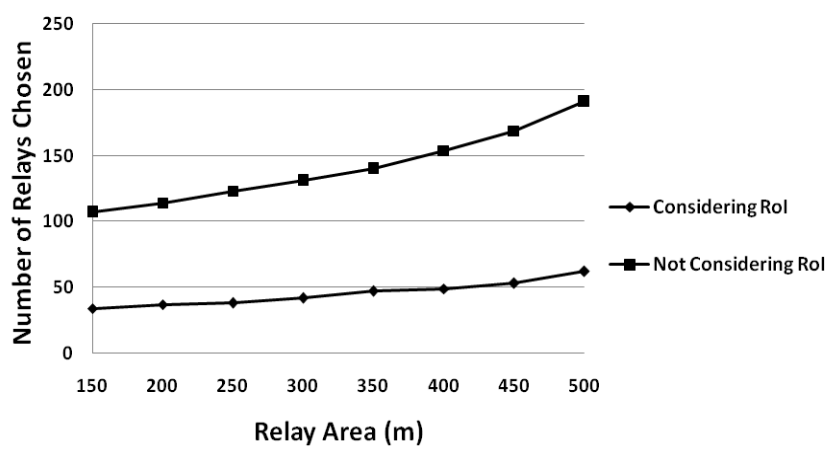
It should be noted that at some times during a day, when the traffic density is very low, e.g., in the early morning and around midnight, as shown in Figure 4.6, finding a relay point may not be feasible because very few vehicles travel at those times. As discussed in Chapter 2, the only practicable strategy in such a situation (sparse and disconnected network) is the carry-and-forward strategy. With this strategy, the message is carried by a vehicle and is forwarded when another vehicle or vehicles are present and can retransmit the message. In the scheme developed in this research, if a vehicle notices that it is operating in such a low traffic density condition, then it will change to the carry-and-forward mechanism.



a) Packet reception

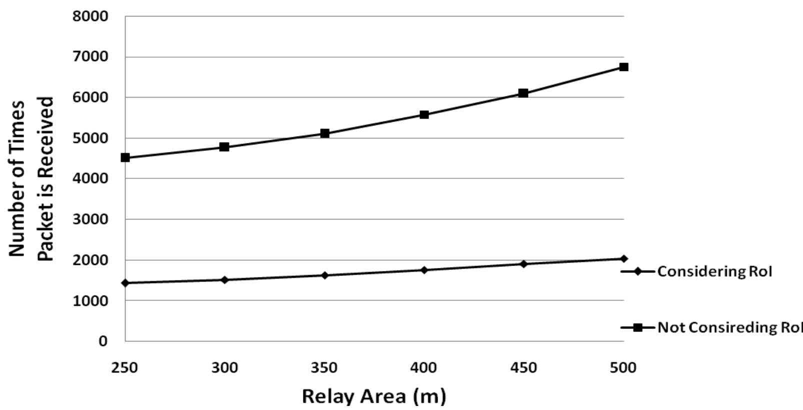


b) Number of vehicles in the relay area

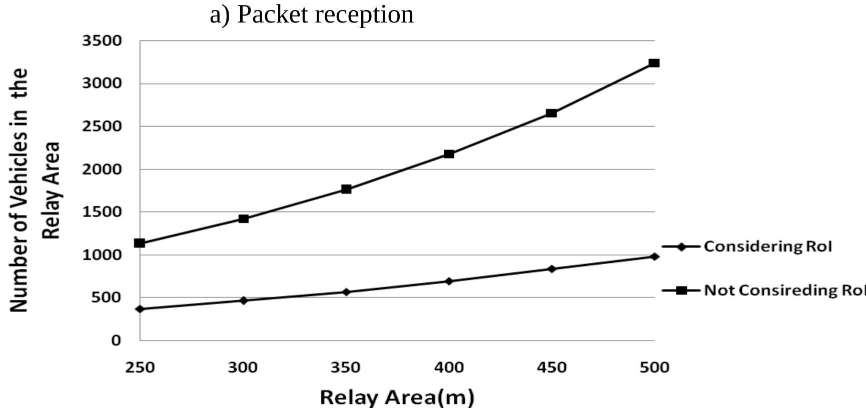


c) Number of relay vehicles chosen

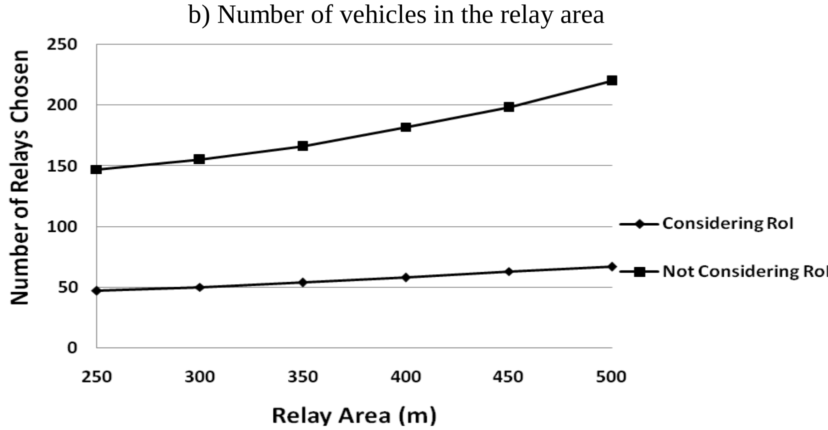
Figure 4.10: Warning Message Propagation (Considering RoI and Not Considering RoI) in Moderate Traffic Density



a) Packet reception



b) Number of vehicles in the relay area



c) Number of relay vehicles chosen

Figure 4.11: Warning Message Propagation (Considering RoI and Not Considering RoI) in Low Traffic Density

4.5.5 Discussion of the Results

The proposed scheme was applied for three traffic density conditions: high, moderate, and low, as presented in Subsections 4.5.2, 4.5.3, and 4.5.4, respectively. The results of the simulation indicate that when traffic density is high, 50 m is sufficient length for the area in which the relay region is determined because high traffic density, there is at least one vehicle located in the relay area that can retransmit the packet. As the results indicate, it can be inferred that using a wider relay area in the developed scheme may result in the choice of a relay point that is not necessarily the vehicle furthest from the packet sender because of the random waiting time assigned to the vehicles within the relay area. Furthermore, compared with a wider relay area, a narrower relay area provides a higher possibility of a relay point (i.e., the vehicle that finally retransmits the packet) being chosen that is further from the sender. As a result, the number of times that the packet is received is lower, and consequently, less redundancy occurs.

The results also indicate that when traffic density is moderate, the relay area should be greater than 150 m. This distance is greater than the length of 50 m for the relay area obtained when the traffic density is high because the traffic is less condensed in moderate traffic conditions, and thus, the relay area needs to be wider so that at least one vehicle can be found as a relay. Similarly, the results indicated that the relay area should be wider when the traffic density is low, wider than 250 m, so that at least one relay point can be found, given the assumed low traffic conditions.

As shown in Figures 4.8, 4.10, and 4.11, consideration of the RoI can be beneficial in achieving effective data dissemination. When the RoI is considered, the number of packet receptions, the number of vehicles in the relay area, and the number of relays chosen are all significantly decreased. Applying the concept of RoI means that vehicles that do not benefit from receiving the data are simply not informed and also not involved in retransmitting packets.

4.6 Summary

Warning data messages are characterized as spatio-temporal, implying that both the location and the time of an incident must be considered with respect to data dissemination. It is believed that the factors such as the type of warning messages, the layout of the road network, the traffic density, and the capacity of alternative roads influence the determination of the region where the warning message is propagated. In this chapter, a new effective warning data dissemination scheme has been presented. The new scheme considers the type of warning message and the traffic density. The warning messages were divided into three categories, and appropriate resolve times were associated with the incidents. The resolve time of an incident is indicative of the severity of the incident. Using traffic statistics obtained from a detector station, the RoI was calculated and enclosed with the warning message so that the message is not retransmitted beyond the RoI. For more effective message propagation, a relay strategy was applied. It was shown that when traffic density is high, there is at least one vehicle present in the relay area. When the traffic density decreases, the relay area must be extended so that at least one vehicle is present in the area.

In summary, it can be concluded that for an effective dissemination of warning data, the data should be propagated within the RoI. If the data is propagated beyond the RoI, the retransmitted message is received by vehicles that do not benefit from it because those vehicles may already have passed the location of the incident, or when they arrive at the location of the incident, the event may already have been resolved. Furthermore, inappropriate dissemination of warning data may lead to increase of demand of alternative paths and informing the vehicles causes problems on other road segment

Chapter 5

Conclusions

5.1 Introduction

This chapter presents a review of the contents of this thesis and provides a summary of the conclusions and research contributions. It also highlights recommendations and suggestions for future studies of data dissemination in the VANETs environment.

5.2 Research Summary

There are numerous local events or incidents taking place on road networks everyday and congestion and safety hazards are the inevitable consequences of these events. Clearly, providing vehicles with appropriate information about timely incidents and traffic conditions can significantly improve the quality of driving with respect to time, distance, and safety.

High deployment and maintenance costs are inherently associated with infrastructure-based Traffic Information Systems (TISs). Furthermore, they often fail to provide dynamic and timely information to drivers. On the other hand, Vehicular Ad hoc Networks (VANETs) can provide low-cost and effective wireless communication platform and significant coverage areas. VANET operates in the absence of fixed infrastructure forcing the hosts to organize the exchange of information in a decentralized manner. These capabilities have led to proposing various VANET-based applications. Among all the applications envisioned for VANETs, warning and safety applications, in which the vehicles are informed about any hazardous situation or traffic condition, have considerable impacts on the safety of transportation systems. Consequently, enormous amounts of time, cost, and resources can be saved and more importantly, the number of casualties due to accident in road networks can be significantly reduced.

To disseminate the data among equipped vehicles, two approaches are considered: broadcasting and relaying. In broadcasting, every node participates in packet retransmission. In relaying, certain vehicle(s) participate in packet retransmission. The two approaches have their own advantageous and disadvantageous and the deployment of them depends on the type of application.

Extending the region of data propagation may influence the paths taken by the vehicles and the number of vehicles involved in broadcasting message further. An additional travel cost metric shows how the calculation of the shortest path based on the updated information received at each hop may change while the vehicles are informed. As a result, the cost associated with the paths calculated based on updated information is reduced. The results also indicate that by expanding the region of propagation, the communication cost increases whereas the additional travel cost decreases. The discussions of the results led to the determination the Region of Interest (RoI) that represents the effective data dissemination region in which only the appropriate number of vehicles are informed about an unexpected incident.

Although extending the region of data dissemination informs more vehicles and thereby more vehicles make better decisions, it is crucial to consider that in propagation of warning messages, the location and the timing of the incident have to be taken into account. Therefore, warning messages are spatio-temporal sensitive. As it can be inferred, the warning message may be reached to some areas that the data has no relevancy with that region and vehicles are informed with no benefit for informing them. There are certain regions that will be affected by an incident and informing vehicles in the immediate vicinity is effectively helpful.

An effective warning data dissemination scheme has been proposed in this research. Warning data messages are characterized as being spatio-temporal implying that the location and the time of an incident must be considered with respect to data dissemination. Factors such as type of warning messages, the layout of road network, traffic density and also capacity of alternative roads are influential in the determination of the region where the warning message propagates. In the proposed scheme, the type of warning messages and traffic density are taken into consideration in the determination of

RoI. The incidents that may take place are categorized into three categories: severe, moderate, and slight. Different RoIs are associated with each category. As it can be inferred, the more sever the incident is, the wider RoI needs to be. The time of resolve is used to differentiate between the three categories of incidents. The more severe the incident, the higher the resolve time assigned to that incident.

In order to calculate the RoI, the average speed is used and it is assumed that traffic statistics such as traffic density and speed are available. Therefore, the RoI is adapted to the type of warning messages and also traffic density. Each vehicle located at the RoI will be informed and participated in message retransmission.

5.3 Research Contributions

This research has the following benefits and contributions:

- The data dissemination approaches proposed in the vehicular networking environment and the challenges associated with them have been extensively reviewed.
- It has been investigated how extending the region of data dissemination may influence the paths taken by the vehicles while they were informed about an incident as well as the number of vehicles involved in rebroadcasting the message further.
- An effective warning data dissemination has been proposed in which data dissemination is restricted to the RoI. In the proposed scheme, the type of warning messages and traffic density are taken into account.

- The incidents taken place in road networks have been categorized into three groups: severe, moderate and slight and the associated resolve time of the incident indicates the severity of the detected incident. The more severe the incident is, the higher the resolve time will be assigned. Consequently, the RoI is calculated using the resolve time and the average speed. Only vehicles located at the RoI are informed and thus, they participate in message retransmissions.

5.4 Future Research

- As previously mentioned, the layout of the road network and the capacity of the available alternative roads can also affect determination of the RoI. One topic for future research is to investigate the impact of the two factors affecting the determination of the RoI.
- In the implementation of the proposed scheme, highway traffic traces are assumed and a straight segment of a highway with three lanes is modeled. The vehicles driving in the highway are generated in a random manner using an exponential distribution. Obviously, using the real traffic traces on real road networks can improve the accuracy of the proposed scheme rather than randomly generating traffic traces in the assumed road network.
- It is important to further study how the vehicles select the driving route when they are informed about an incident if a real road network layout is used. It can be also investigated that how the traffic statistics such as traffic density and average speed in the chosen alternative roads change due to the incident on the main road.

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