

Semantic and Self-Decision Geocast Protocol for Data Dissemination over Vehicle Ad Hoc Network

by

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Abstract

In this work, we provide a qualitative comparison between existing geocast protocols and then we present an efficient geocast routing protocol for VANET. This protocol is a semantic and self-decision geocast routing protocol for disseminating safety and non-safety information over VANET (SAS-GP). SAS-PG initially executes an algorithm to locally determine the semantic geocast area. Then, the protocol disseminates the information in three phases: Spread, Preserve, and Assurance, which utilize the traffic information system and the digital map. SAS-GP principally employs timer-based techniques in order to avoid overhead and broadcast storm problems; nonetheless, novel factors are enhanced to calculate the timer's values in each phase. Simulation results demonstrate effective and reliable dissemination in terms of delivery ratio and number of false warnings compared to existing protocols when evaluated in high scale and realistic scenarios. Also, SAS-GP performs faster in notifying vehicles resulting in a higher geocast distance before approaching the location of the event.

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Dedication

This is dedicated to my beloved father, mother, brother and sisters.

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Nomenclature

Abbreviations

ASG	Algorithm for determining the Semantic Geocast Area
BPSK	Binary Phase Shift Keying
C2C-CC	Car to Car Communication Consortium
DSRC	Dedicated Short Range Communication
ECIES	Elliptic Curve Integrated Encryption Scheme
EDSA	Elliptic Curve Digital Signature Algorithm
FLEETNET	FLEET Network
FRAME	The Framework Architecture Made for Europe
GPSs	Global Positioning Systems
GSM	Global System for Mobile Communications
GSM	Global System for Mobile Phones
HVC	Hybrid Vehicular Communication System
ICT	Information and Communication Technologies
IST	Information Society Technologies
ITS	Intelligent Transportation System
IVC	Inter-Vehicle communications
MAC	Medium Access Control
NEC	Nippon Electric Company
OFDMA	Orthogonal Frequency Division Multiple Access
OSI	Open System Interconnection
P2P	Peer-to-Peer
PLCP	Physical Layer Convergence Procedure

PMD	Physical Medium Dependent layer
RSUs	Road Side Units
RVC	Roadside-to-Vehicle Communication System
SAS-GP	Semantic and Self-Decision Geocast Protocol for Data Dissemination over VANET
SGD	Semantic Geocast Domain
SNAP	Sub-Network Access Protocol
TDMA	Time Division Multiple Access
UMTS	Universal Mobile Telecommunications Sys- tem
US	United States
V2I	Vehicle-to-Infrastructure communication
V2V	Vehicle-to-Vehicle communication
VANET	Vehicle Ad Hoc Network
vGrid	Vehicular Grid
VisLab	The Artificial Vision and Intelligent Systems Laboratory
WiMAX	Worldwide Interoperability for Microwave Access
WSMP	WAVE Short Message Protocol
WSMs	WAVE Short Messages

Chapter 1

Introduction

With the advancements during last few years, numerous technologies have been exploited to solve and limit transportation issues. Because of the improperly managed traffic systems, thousands of lives are lost due to traffic accidents. According to Transport Canada, about 10433 people were seriously injured because of casualty collisions in 2011 [33]. Additionally, there has been an associated loss of time and financial resources due to these traffic problems. According to European Union [42], the traffic congestion causes an approximate loss of 1% of GDP (€125 Billion), while more than 35,000 citizens are killed in road accidents per year. In addition, 71% of transport CO₂ emission from road is observed, leading to climate change. To address these problems, different solutions have been tried out. Intelligent Transportation System (ITS) embeds vehicles with computing, communication and sensing capabilities for solving traffic problems. European Union defines ITS as a system that solves traffic problems by employing Information and Communication Technologies (ICT) on road infrastructure, vehicles, and passengers [42]. These technologies include hardware embedded in vehicles such as on-board sensors, anti-lock braking systems, camera, navigation systems, radars, road side units, and communication standards such as dedicated short range communication (DSRC), Global System for Mobile Phones (GSM), and operating protocols at various layers of Open System Interconnection (OSI) protocol stack such as access control and routing.

Large automotive companies like GM, Mercedes, Toyota, and BMW promote this system too and employ in-car sensors to enhance the safety and comfort. Cars manufacturers are motivated by the multi-fold and growing in-depth research work and the promising proposed applications. Because of the cost of infrastructure in ITS, Vehicular Ad Hoc Network (VANET) is usually preferred for transport management. It implements wireless technologies such as Dedicated Short Range Communications (DSRC) to communicate via Inter-Vehicle Communication (IVC) manner. Thus, it enables advanced ITS services

including various safety and non-safety applications. Some instances are: warning about accidents, AMBER Alerts, bad road conditions, extreme weather, commercial advertisements, and other generic information services.

1.1 Problem Statement

In safety (and non-safety) applications, the highest delivery ratio and the minimum possible delay are primary goals while trading the lowest overhead in the network. The cost of overhead here is measured and affected by the size of the message and the number of transmissions. On the other hand, safety information should be delivered to the interested vehicles only. In most approaches proposed in literature, vehicles in highways are considered to enter the highway from only one points for each direction.



Figure 1.1: Implemented highway scenario in the literature

In other words, only two lines and two directions with a number of lanes are considered and the surroundings between highway and inter-connected roads and bridges are excluded (Figure 1.1). Figure 1.2 shows how 3 km of a highway in Ottawa colored in blue is connected to other streets that are not considered in the implementation of all existing approaches. Thus, designing an algorithm that determines these vehicles considering the high mobility of vehicles, spatiotemporal variations, and the different levels of density in the network is a very challenging desire.

Geocast, which is the delivery of information to vehicles in a specific region, has a vital role to play in addressing these issues. The safety (and non-safety) messages are always

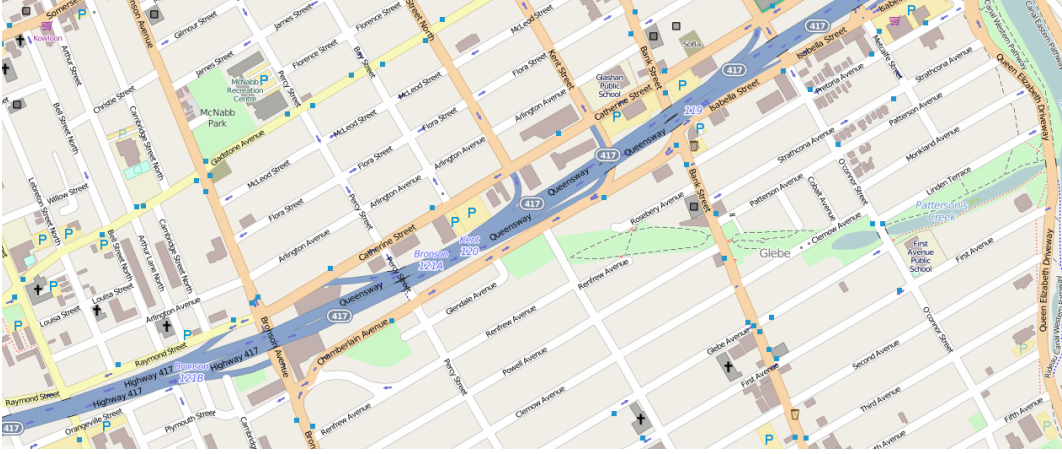


Figure 1.2: Realistic highway scenario (Queensway, Ottawa, Canada) [77]

required to be sent to a specific region. Geocast by definition is an optimal solution for routing and data dissemination in such network's environment and represents a special form of multicast addressing protocols that are used by MANETs. It is a silver bullet in VANET's applications that necessitates delivering information to specific regions and more specifically in safety applications. Thus, the objectives of this work is to

- identify various issues generally in VANET and specifically in data dissemination
- study and analyze existing methods of determining the interested vehicles
- study and analyze different geocast protocols for disseminating information over MANET and VANET
- design a sufficient algorithm that determines the interested vehicles
- design a potential geocast protocol that is reliable and effective for dissemination between the interested vehicles

1.2 Motivation

Achieving objective Quality of Service (QoS) is the essential goal when disseminating safety information over a virtual network of vehicles. Data dissemination refers to the delivery of data between vehicles in the Vehicle Ad Hoc Network (VANET) whereas safety information refers to critical events happening on the roads that could cause loss of lives and fatal accidents. Less-critical events that are costly like traffic congestion should be

considered too. For instance, the traffic congestion as mentioned in section 1 causes an approximate loss of 1% of GDP (€125 Billion) in Europe only and makes a hidden impact on businesses because public employees spend a significant number of hours daily in traffic jams and reach their offices tired due to traffic jams. The importance of the problem can be understood by the large number of enabling applications that try to solve the daily lost of hundreds of lives and the economic impacts of traffic accidents and congestions.

VANET is more complex than MANET due to the extreme speed of vehicles and rapid changes in topology, which results in poor level of connectivity. Furthermore, this rapid change in topology is predictable by the existence of digital maps and the real-time defined locations of vehicles using Global positioning System (GPS). Because of the cost of infrastructure in ITS, Vehicular Ad Hoc Network (VANET) is usually preferred for transport management. It implements wireless technologies such as Dedicated Short Range Communications (DSRC) to communicate via Inter-Vehicle Communication (IVC) manner. Thus, enables advanced ITS services including various safety and non-safety applications. Some instances are: warning about accidents, AMBER Alerts, bad road conditions, extreme weather, commercial advertisements, and other generic information services. It is assumed that there are no supporting roadside units, mobile towers or cellular services. However, we assume that a vehicle is able to acquire its location by being equipped with a GPS device or a robust localization system [26] [25]. The proposed algorithm and protocol should be implementable inside the city and on highway. Moreover, a digital map is always accessible by all vehicles in which they are able to obtain different types of information: possible routes, distances, minimum and maximum allowed speed on highways, roads, or streets, and live traffic information. Therefore, our motivation is drawn and research objectives are identified according to the remarked issues above.

1.3 Contributions

In this thesis, we present a geocast routing protocol for reliable and effective dissemination of safety and non-safety information named Semantic and Self-Decision Geocast Protocol for Data Dissemination over VANET (SAS-GP). The major contributions of this work are shown as follows:

- To adapt different traffic and maps data, we propose an algorithm for determining Semantic Geocast Domain. The Algorithm for determining the Semantic Geocast Domain overcomes the limitations of polygon algorithm by locally computing the geocast area. The algorithm also reduces the overhead head by dynamically eliminating the areas that are not interested as time goes by. It also helps in reducing the

overhead caused by false warnings sent to vehicles within the transmission range of the vehicles that are on the border of the geocast area.

- SAS-GP enhances novel factors to calculate the waiting time between retransmissions in order to reliably disseminate the information and efficiently utilize the available resources in the medium, the traffic information system, and the digital map information. Thus, overhead is avoided and a high delivery ratio is achieved.

1.4 Organization of the Thesis

The rest of the thesis is in five chapters. In Chapter 2, we present a background information about ITS in general and VANET addressing most important research issues in these two fields. Literature review and technical information about data dissemination and geocast routing protocol is detailed and analyzed in Chapter 3. In Chapter 4, our proposal is presented. The evaluation of our proposal is performed in Chapter 5. Chapter 6 concludes this thesis and draws some directions for future work.

Chapter 2

Background Information

Rapid developments have been observed in the domain of mobile computing during the last few years. Advanced forms of computing gadgets such as laptops, personal digital assistants, smart phones, tablets, Global Positioning Systems (GPSs) and handheld digital devices have evolved. These developments have given rise to a revolutionary transformation and the computing has now been weaved into daily lives. A person can simultaneously exploit the capabilities of multiple miniaturized devices for the desired services. These services can be used at anytime and anywhere; if a person is travelling on the road, for instance, and requires information about nearby restaurants, shopping malls, fuel stations, and parking lots, his or her GPS has the full capability to receive this information from satellite network or cellular network. To truly realize the vision of pervasive computing, modifications are required in existing networking technologies and protocols [132]. It is not possible to employ a wired network for connectivity among hosts. Additionally, one cannot assume presence of prior infrastructure for realization of such applications. Such scenario demands network establishment on the fly between a set of mobile hosts without any dependence on prior infrastructure. These types of networks are titled Mobile Ad Hoc Network (MANET).

2.1 Mobile Ad Hoc Network (MANET)

A Mobile Ad Hoc Network (MANET) is defined as a self-organized network constructed between mobile devices that communicate directly via wireless connections or indirectly via intermediate nodes [93]. The network topology is arbitrary and the network is formed for a specific purpose and limited time. The nodes in the network can have similar or heterogeneous capabilities. Therefore, the network can be formed between vehicles, people

(with mobile devices), and infrastructure units. Another important attribute of MANET is the ability of multi-hopped routing. The nodes that are in direct range can directly communicate with other nodes. However, those that are not within the direct communication range use in-between nodes to route packets. Besides self-organization, MANETs are also fault-tolerance networks [51]. The nodes can perform maintenance tasks or recovery mode in case of link failures [12]. The properties of MANETs provides multi-fold benefits and they are useful in virtually any scenario requiring a cadre (framework) of mobile users lacking infrastructure support and demanding information sharing with each other. Disaster recovery, transport management, and battlefield operations are some of the potential applications that MANETs are able to perform.

MANET requires taking care of different unique challenges [80]. The links are asymmetric, unreliable, and have limited capacity. The nodes are low-powered, mobile, and often can operate in hostile environments and the network topology changes very rapidly. The nodes are required to maintain the neighborhood information continuously. For routing, it requires a routing table, which also requires continuous update and maintenance. However, due to infrastructure-less nature, there are no in-built security mechanisms available [120]. It is required to collaborate with other nodes for maintaining security (and other network operations), yet the collaborating nodes cannot be completely trusted. There has been a massive amount of research effort put in during last few years on solving the above-mentioned challenges. Some of these solutions can be seen in [116] [13] [23]. With the usage of wireless networks steadily increasing, the desirability of cars network has come into being. It is a special type of MANET that forms a wireless network between vehicles, known as Vehicle Ad Hoc Network (VANET).

2.2 Vehicle Ad Hoc Network (VANET)

Vehicular Ad Hoc Networks (VANETs) were first introduced as an amalgamation of Inter-Vehicle communications (IVC) and Mobile Ad hoc Networks (MANETs). This concept of vehicular network, which was firstly introduced by Delphi Delco Electronics System and IBM Corporation, has now evolved into the idea of VANETs. VANET, undeniably, is receiving vigorous attention from car manufacturers, as well as serious considerations from researchers and the entire world [87]. VANET has been emerging as a viable alternative to address transportation problems. It is a subtype of ad hoc network that uses on-road vehicles as nodes. The vehicles can communicate with roadside infrastructure. However, inter-vehicular communication is considered as the primary objective of such networks. VANET possesses most of the properties of MANET. Some of the key differences are as

follows [115]: The nodes in VANET travel in large groups with very high speed. The network is more dynamic as compared to MANET. The multi-hop paths have a shorter life. Additionally, if two vehicles are moving in an opposite direction, they will not remain in contact with each other for more than a few seconds. This also causes frequent disconnection and partitioning of the network. Specifically in low-density scenarios, there are no intermediate nodes that can help in maintaining connectivity among farther nodes. These problems can be addressed to some extent by deployment of road-side relay nodes, called Road Side Units (RSUs).

While car manufacturers are already competing in introducing some features of promising cars that are commercially successful like visual parking aid, advanced Global Positioning System (GPS) that has lifetime traffic and digital map updates, and in-car sensors, research is being carried out even more competitively and on a higher scale in order to accomplish the future cars. In the direction of testing the proposed applications, various studies, simulations, and real implementations have been performed. Some, like Nippon Electric Company (NEC), initiated real-world test network implementation aimed at investigating the effectiveness of communications between vehicles. NEC's projects like FLEET Network (FLEETNET) create inter-vehicle communication in pursuance of advanced features such as emergency warnings [16]. While these types of experiments only test the feasibility of installing a wireless system in a vehicle, more recent researches have gone a step ahead and have reached partial success in implementing VANETs [56]. Google driverless car and The Artificial Vision and Intelligent Systems Laboratory (VisLab)'s driverless car are atoms of how future automated vehicles will be [31] [53]. For standardization purposes and to control extensive research in VANETs, the Car to Car Communication Consortium (C2C-CC) industry in cooperation with European and international standardization organizations established the idea of having standards for Vehicle-to-Vehicle communication (V2V) and Vehicle-to-Infrastructure communication (V2I) that can span all cars brands, considering that the idea of VANETs is not just limited to communication between cars and proceeds to establish communication between infrastructural units and vehicles. SAFESPOT, a combined project initiated by the European Commission Information Society Technologies, aims to enhance safety by delivering warnings either by local or remote road side infrastructural units. This means that the driver can detect the rear and blind front spot, as well as side crash warning [74]. Moreover, more recent studies focus on restricting communications between vehicles without the aid of the expensive infrastructures [74]. So safety can be enhanced in areas where fixed infrastructures are destroyed, or overloaded. Further studies propose protocols and applications to increase VANETs' functionalities [17] [118] [18] [48] [24]. Several changes and improvements to the actual communication infrastructure have also been proposed with the help from both theoretical

algorithms and life-like simulations [56] [53] [6] [48]. The goal is to design and achieve Intelligent Transportation System (ITS).

2.2.1 Intelligent Transportation System (ITS)

Intelligent Transport Systems (ITS) is defined as the integration between various information and communication technologies for improving the quality of the transportation system. The transportation system can be road, rail, water, air transport, and navigation systems. ITS comprises an array of tools in an integrated manner to a transportation system for enhancing the efficacy and safety of systems [39]. The technologies that can be employed are a combination of traffic engineering, software, hardware, and communication technologies. Information technology, electronic engineering, satellite communication and sensors also have equally important roles in realization of ITS system. An ITS system encompasses in-vehicle, inter-vehicle, and vehicle-to-roadside communication. Next section 2.2.1.1 presents an overview of intelligent transportation system. It discusses architecture, protocols, applications, existing projects and issues of ITS.

2.2.1.1 Classification of Intelligent Transportation Systems

In earlier days, different approaches were adopted for solving transport problems [100]. For instance, an FM channel broadcast traffic information to users, variable message signs placed in specified locations on road warned users about changing conditions, and electronic toll collection systems worked without disruption of traffic flows. Vehicles were also equipped with onboard controls, anti-lock braking systems, cameras, navigation systems, radars, and other sensors. These items of equipment could observe traffic in real-time and warn drivers about traffic situations. With the advancements in technology, we have seen incorporation of computing, sensing, and communication among vehicles to solve the traffic problems. Some of the early projects on ITS system were based purely on pre-installed infrastructure [137]. These vehicles communicate with roadside units for obtaining traffic information. During last few years, inter-vehicle communication has also been exploited. The vehicles organize themselves in the form of a network without any support from infrastructure. These vehicles exchange information with each other. Such networks are called Vehicular Ad Hoc Network (VANET). The advantage of VANET is that vehicles on the site are more informed about the current situation, and does not require any configuration. According to Sichitiu *et al.* [137], an ITS system can be roughly classified into three major categories:

1. **Roadside-to-Vehicle Communication System (RVC):** The communication takes place only between vehicles and roadside units. For instance, a traffic signal can communicate with vehicles on the road, or an advertising entity (fuel station, shopping malls, and restaurants) broadcasts its offers. Similarly, infrastructure gateways can provide high speed Internet to all vehicles travelling on the road.
2. **Inter-Vehicular Communication System (IVC):** The communication takes place only among vehicles that organize themselves on the fly in the form of vehicular ad hoc network. There can be single-hopped or multi-hopped communication. Such networks are useful for short range communication such as lane merging and collision avoidance. Section 2.2 discusses vehicular ad hoc network system in detail.
3. **Hybrid Vehicular Communication System (HVC):** The main reason to use them is to extend the range of RVC, enabling long range transmission. Hence, the vehicles can communicate with infrastructure directly or via intermediate vehicles as routers, when road-side infrastructure is not in range.

2.2.1.2 Architectures of Intelligent Transportation System

An architecture provides the structure specification, behavior, and integration of a system with respect to its surrounding. There are several ITS architectures currently available. An ITS architecture generally evolves at a country or institutional level and provides high level abstraction that can be extended during implementation. There have been several architectures proposed at country-level or institutional level. Next section 2.2.1.3 discusses two main ITS architectures proposed by United States (US) Department of Transportation and European Union.

2.2.1.3 National ITS Architecture - US Department of Transportation

The US Department of Transportation has proposed a framework called The National ITS Architecture to enable wide scale adoption of ITS system [129]. This proposed framework essentially provides the definition, plan, and a level of integration for the national intelligent transportation systems. This is done by defining a set of ITS' functions that are necessitated by users, physical entities/subsystems that perform each function, and an integration level of functions and systems by identifying flow of data and information. Figure 2.1 shows the proposed architecture and the interconnections between elements in the form of block diagrams. The architecture includes description about layers, logical and physical architecture, and services provided by an ITS; the description of each of them is as follows:

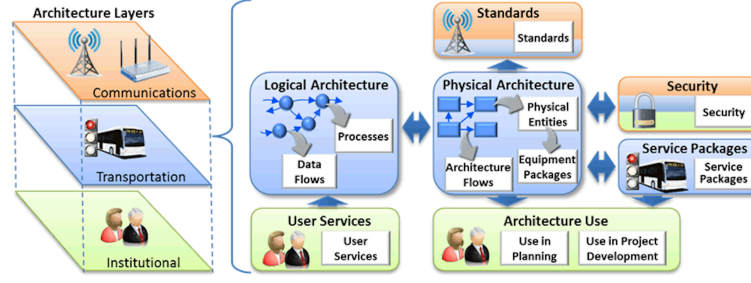


Figure 2.1: The National ITS Architecture – US Department of Transportation [129]

1. **Layers:** The framework comprises three layers as shown on the left. The institutional layer deals with the institution level issues (regulations, monitory issues, implementation, and jurisdictional hierarchy) needed for implementation and maintenance of ITS. The Transportation Layer defines the transportation services. It describes the various systems involved, interfacing, and also data items involved for these services. The communication layer deliberates on networking technologies to support the ITS system.
2. **User services:** The user services describe the capabilities of ITS system from the perspective of a normal user. 33 services have been defined under 8 categories. These categories are: travel and traffic management services, public transportation management, electronic payment, commercial vehicle operations, emergency management, advanced vehicle safety systems, information management, maintenance and construction management.
3. **Logical architecture:** Logical architecture expresses the functional processes and information flows of a system that are desired to accomplish user services. The processes collaborate with each other and exchange information to provide user services. The architecture highlights the lower level interaction for different subsystems of ITS, and independent of institution and technology.
4. **Physical architecture:** The physical architecture describes the physical components of ITS. For instances, vehicles, drivers, roadside units etc. The architectural flows that interconnect the systems are also within the physical architecture.

2.2.1.4 The Framework Architecture Made for Europe (FRAME)

The FRAME Architecture is proposed by European Union [85]. It provides a reference framework comprising high level requirements and details for deploying an integrated ITS

solution in European countries. The requirements are provided for various applications and services of ITS in a way that makes them referred during implementation. This also ensures interoperability across ITS systems deployed in different countries. Using the architecture, subsets can be created and used on their own [133]. Figure 2.2 illustrates the processes of creating and updating FRAME architecture. These processes contain the following activities:

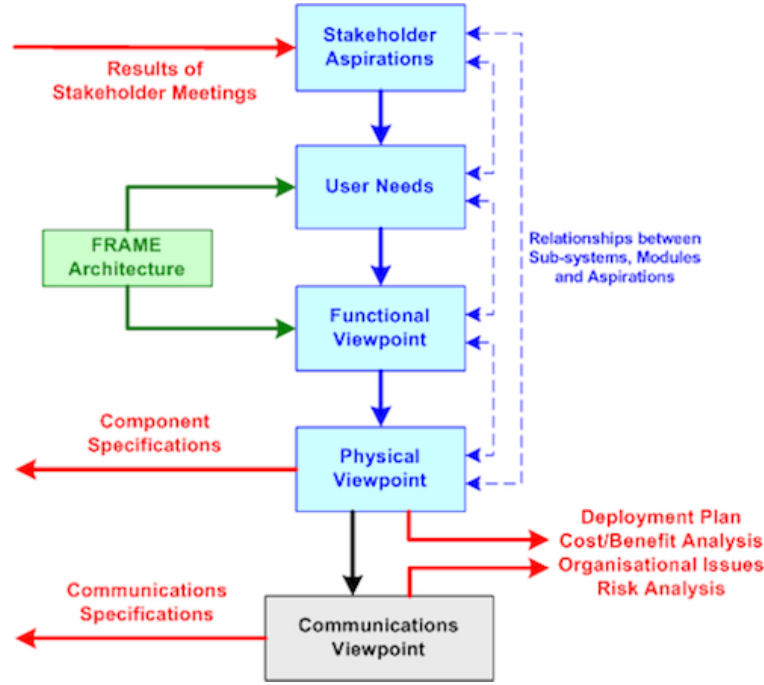


Figure 2.2: The methodology for creating FRAME Architecture - European Union [85]

1. **Stakeholder aspirations:** These are statements about the expectations of stakeholders. Stakeholders are people who want ITS, use ITS, regulate ITS, or implement ITS.
2. **Documenting user's needs:** The user's needs are specified in a concise and consistent manner based on stakeholder's aspirations.
3. **Identify functional/logical viewpoint:** The functionalities required to satisfy user's needs and stakeholder's aspirations are identified. These are essentially data flow diagrams and context diagrams. The former shows the flow of data, data stores, and terminators. The latter shows the external systems that communicate with ITS.
4. **Physical viewpoint:** The various items of the logical viewpoint are mapped by architecture team to a location (sub-system or module).

5. **Communications viewpoint:** The data flows between subsystems or modules are identified as communication channels.
6. **Traceability:** Similar to software engineering, a traceability matrix shows the relationship between stakeholders' aspirations and physical viewpoint.

The scope of FRAME covers areas such as fee collection, emergency notification and response, management of public transport, and enforcement of laws.

In addition to the architectures discussed above, several other architectures have been proposed. A list of ITS architectures for Italy, Australia, Brazil, and other non-European countries can be seen in [94]. Based on this study, following features should be stipulated by an ITS architecture:

- **Logical system components:** ITS architecture should outline the high level building blocks that should be implemented for its realization. The logical architecture of National ITS US Architecture describes the functional components of the system. In a similar manner, the logical viewpoint of EU FRAME Architecture also identifies the functionalities required to meet end-user requirements.
- **Physical blocks:** The functionalities of system are mapped to physical blocks of system. The physical architecture of National ITS US Architecture describes the various components involved including vehicles, drivers, and road side units. The physical viewpoints of EU FRAME Architecture also map the functionalities to physical subsystem or module.
- **Services:** An architecture should outline various services provided by ITS. For instance, National ITS US Architecture enlisted 33 services related to traveling, safety, and Mobile-commerce (M-commerce). Similarly, EU FRAME Architecture covers various services, for example in the domain of toll fee collection and transport management.
- **Data flows:** Finally, the various data flows among systems are also covered by the architecture. The logical architecture of National ITS describes low level interaction and physical architecture describes high level interaction of different sub-systems. The communication viewpoints of EU system identify the data flows as channels of communication.
- **Stakeholders' collaboration/requirements:** The institutional layer of US system deals with institutional level issues. In the same way, EU system begins with identification of end-user requirements and also proposes a traceability matrix to map between stakeholders requirements and physical viewpoints.

2.2.2 ITS Services and Applications

By employing ITS systems, various types of innovative services and supportive applications can be deployed.

2.2.2.1 ITS Services

In the literature, various types of services have been discussed for ITS systems [42] [108] [94]. Some of these services are:

- **Traffic information services:** such as historic and real-time traffic data.
- **Travel information services:** such as public transport route schedules and fares. This will enable better travel planning, booking and adaptation.
- **Weather information services:** such as temperature and rain alerts.
- **Parking information services:** for safe and secure parking places and their reservation.
- **Emergency calls:** to provide a very fast response for emergency services after the occurrence of an accident.

2.2.2.2 ITS Applications

Based on services discussed above, numerous innovative applications can be supported. These applications are either safety or non-safety applications.

1. **Safety applications:** In these applications, messages are exchanged to eliminate or minimize the loss of lives, money, time, and improve the safety of passengers. The exchanged information can be vehicles' speed and position, intersections, and road conditions such as icy or flooded roads. The information can be also used to avoid collisions and road accidents. Some of these useful and life-critical applications can be:

- **Collision avoidance:** Vehicles can work in collaboration to detect possible collisions in advance. If the chance of collision is sensed, an alert can be sent to the driver and vehicles with his/her range. Similarly, inter-vehicular communication can be used to assist the vehicles in lane changing, reducing the chances of any collision. The emergency brakes of vehicles can also be monitored and concerned (preceding and surrounding) vehicles can be notified ahead of time.

- **Enforcing traffic rules:** The speed and position of the vehicle and current status of traffic signals can be used to determine if a vehicle is in the risk of violating traffic rules. The vehicle can be notified about any possible violation by broadcasting road regulations.
 - **Proactively managing collision:** Based on the exchange information, vehicles can sometimes assess that a crash is unavoidable. Some systems also allow drivers to notify in case of control-loss. In such cases, appropriate measures can be taken in a proactive manner to minimize the loss. For instance, some car components (actuators, extensible bumpers, or auto-brakes) can be activated to reduce the impact. The drivers can be notified and seat belts can be fastened. The exchanged information can be used to also inform the rescue team.
2. **Non-safety applications:** In addition to safety applications, VANET is also used for providing comfort and entertainment for passengers [27] [29]. Information about weather and traffic can be provided for plan trips. The details about the locations of nearby restaurants, gas stations or stores can be obtained. Peer-to-Peer (P2P) applications, like music and video sharing, chatting, and social networking are also achievable. Passengers can search for a gateway to browse Internet, check emails, and perform other business operations. Users on the road can also be presented with advertisements, news, and entertainment contents during their trip.

2.2.2.3 Communication Standards

In term of standardization, diverse enabling standards and technologies have been proposed for communication. Here we classify these standards by either being applied in short or long communication ranges.

2.2.2.4 Standards for Short Communication Range

Various frequencies have been allocated for communication bandwidth all over the world [1]. In USA and Canada, Dedicated Short Range Communication (DSRC) is in use. In European countries, a spectrum aligned with DSRC is used. In Japan, they use the Association of Radio Industries and Businesses STanDard (AIRB STD –T55), which is an upgraded version of DSRC and is infrastructure-based. Table 2.1 summarizes these standards, and their bands and data rates.

Table 2.1: Summary of various standards for short-range communication

Country	Standard	Band	Data Rate
North America	DSRC	902-928 MHz	500 kbps
Europe	DSIRC aligned	5.885-5.905 MHz	384 Kbps - 4 Mbps
Japan	ARIB	Uplink 5835-5840 MHz 5845-5850 MHz	1-4 Mbps
		Downlink 5790-5795 MHz 5800-5805 MHz	

- **Short range communication:** As discussed earlier, a spectrum aligned with DSRC is in use in Europe. For this purpose, a 10 MHz band from 5.795 to 5.805 GHz is allocated for road transport and traffic telematics. Two national channels on the band 5.805-5.815 GHz are reserved. The downlink rate is 500Kbps and uplink is 250Kbps. A layered architecture has been approved comprising physical, data link, and application layers.
- **Association of Radio Industries and Businesses Standard (ARIB STD):** The Japanese use Association of Radio Industries and Businesses standard (ARIB STD) for ITS communication. The STD-T55 standard was used for Electronic Toll Collection System. The standard's uplink frequency range is 5835-5840 and 5845-5850 MHz, while 5790-5795 and 5800-5805 MHz bands are used for downlink. For modulation, Amplitude Shift Key (ASK) is used with a data rate of 1Mbps and with 8 slot TDMA/FDD. This enables 8 vehicles in an area of 30 meters. Recently, a new standard STD-75 is proposed. Table 2.2 provides a comparison between these two standards.
- **Dedicated Short Range Communication (DSRC):** In North America, a dedicated band called Dedicated Short Range Communication (DSRC) is reserved. The band ranges from 902 to 928 MHz and provides short-range communication and low

Table 2.2: A comparison between STD-55 and STD-75

Criteria	STD-T55	STD-T75
Modulation	ASK	QPSK, ASK
Data Rate	1 Mbps	1 - 4 Mbps
Number of vehicles / 30 meters	8	56

data rates. Figure 2.3 shows the Open Systems Interconnection model (OSI) of DSRC comprising its layers and sub-layers [74].

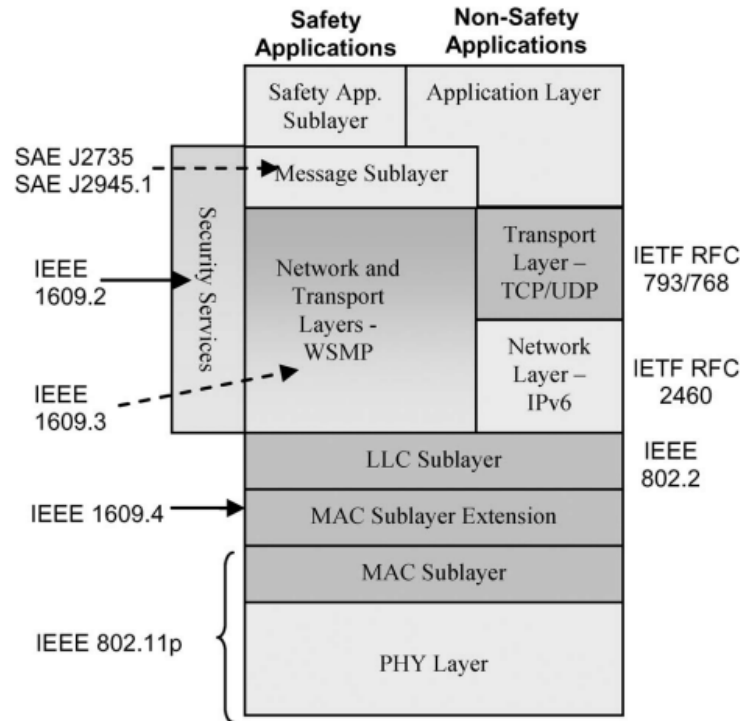


Figure 2.3: Layered architecture of DSRC in North America [74]

1. **Physical layer:** The physical layer utilizes IEEE 802.11p Wireless Access for Vehicular Environments (WAVE), and the physical layer itself is split into two sub-layers: Physical Medium Dependent layer (PMD) and Physical Layer Convergence Procedure (PLCP). Physical medium dependent layer (PMD) interfaces with wireless medium. This sub-layer utilizes Orthogonal Frequency Division Multiplexing (OFDM) for data transmission. It uses several sub-carriers for transmitting data. Four types of modulations can be used on an OFDM

channel, each providing different data rates. These modulation schemes are: i) Binary Phase Shift Keying (BPSK), that utilizes two phases separated by 180° ii) Quadrature Phase Shift Keying (QPSK), that utilizes four points iii) 16-Quadrature Amplitude Modulation (16-QAM), that utilizes 16 points based on the combination of amplitude and phase variations iv) and 64-Quadrature Amplitude Modulation (64-QAM), that utilizes 64 points. A PMD transmitter is requested by PLCP (discussed below) for transmitting frame. PLCP provides the coded bits corresponding to OFDM symbol, data rate, and transmission power [22]. The transmitter performs OFDM modulation to send the data. In a similar manner, PMD receivers perform demodulation while receiving the data. Physical Layer Convergence Procedure (PLCP) maps MAC frame to Physical Layer Protocol Data Unit (PPDU). From the Mac sub-layer, PLCP receives the MAC layer frame that contains its length, transmission data rate, and transmission power. It passes this information to PMD for transmission.

2. **Data link layer:** The data link layer is split into two sub-layers with an extension.

The lowest layer is the **Medium Access Control (MAC)** sub-layer that provides access to the medium efficiently. Two categories of rules are required. Session rules define steps taken to communicate with layer 3. The frame-by-frame rules are defined for managing each transmission. For access control, IEEE 802.11 defines the idea of Basic Service Set (BSS) involving multiple stations that decide to interchange data. The BSS can be infrastructure-less or independent. The former is based on access points, while in the latter; the nodes are responsible for cooperatively beaconing a frame that contains the presence of BSS and its parameters. However, in vehicular environments, the communication remains only for a few seconds. For this purpose, IEEE 802.11p WAVE amendment is proposed. It allows nodes outside the context of current BSS.

The **MAC sub-layer extension** utilizes IEEE 609 for the purpose of channel switching. It is useful while operating in a multi-channel environment. The standard defines an extension enabling MAC to operate on multiple radios and effectively exchanging between channels. For this purpose, the concepts of control channel and time division are proposed. The channels are split into one control channel, and several service channels. The time is allocated for either alternate control or service channel. During control interval, devices switch to control channel and listen for services offered in neighbors. The devices can

then give the access to the particular service channel and frequently go back to the control interval.

Finally, the **Logical Link Control sub-layer (LLC)** uses IEEE 802.2 and Sub-Network Access Protocol (SNAP). It comprises fields such as: DSAP and SSAP address, control, OUI, Ether type, and LLC body.

3. **Network and transport layer:** IEEE 1609 defined a low overhead layer with three protocols for one-hop transmission called WAVE Short Message Protocol (WSMP), that has a minimum overhead of only 5 bytes. The WAVE Short Messages (WSMs) comprise a variable length header and variable length payload. A WSMP message includes version, provider service identifier, extension fields, WSMP WAVE element Id, length, and WSM data. IEEE 609.2 is utilized for security services such as authentication and message encryption. For message authentication, digital signature based on Elliptic Curve Digital Signature Algorithm (EDSA) is used. Two types of encryption algorithms are used. The first scheme is a symmetric algorithm based on Advanced Encryption Standard (AES). The second type of encryption is asymmetric algorithm called Elliptic Curve Integrated Encryption Scheme (ECIES).
4. **Message sub-layer:** SAE J2735 provides different types of safety and non-safety messages. Each message is composed of data frames and data elements. The data frame comprises a set of data elements and/or other frames while the essential data structure of a message is the data element. The standard defines various types of messages such as generic message, basic safety message, common safety request, emergency vehicle alert message, intersection collision avoidance, map data, etc. Finally, issues like transmission rate, power, and accuracy are addressed by SAE J2945.1.
5. **Application layer:** The application layer utilizes the lower layers for different types of safety and non-safety applications. It comprises application processes and supporting protocols to provide different services.

2.2.2.5 Long Range Communication Standards

Different communication standards are also available for long range communication; some of these standards, not to mention all since this study does not use any of these long range standards, are:

- **Worldwide Interoperability for Microwave Access WiMAX (IEEE 802.16):** a communication standard based on IEEE 802.16 that provides data rates up to 1 Gbps. WiMAX utilizes different techniques such as antenna diversity and Orthogonal Frequency Division Multiple Access (OFDMA) for improving data transmission [101].
- **Global System for Mobile Communications (GSM):** divides the communication region into cells. The users in each cell are connected to a base station. GSM provides different types of data and voice services.

2.2.3 ITS Hardware

An ITS system requires different types of hardware for realization of various types of applications. This includes:

- **Vehicle:** Most of the vehicles should be equipped with capabilities for sensing, computing and storage. The advancement in technology enables miniaturization and vehicles are now equipped with few powerful micro-controller devices [14]. A real-time operating system is running on these systems. The vehicles also have a GPS device for determining the location. There can also be digital maps on vehicles for different types of applications.
- **Infrastructure:** Besides vehicle, there is a hardware infrastructure that is pre-installed for various purposes. For instance, sensors can be embedded or installed at roadside units to disseminate status of roads periodically in case of maintenance or severe weather conditions. Inductive loop detectors can be placed on roads to detect passing by vehicles. This can be used to count number of vehicles, their speed, weight and distances in order to use such information in determining the traffic level and the pavement maintenance and reconstruction requirements.

2.2.4 Major ITS Projects

Several research projects have been done on solving ITS problems during the past few years. Some of these projects focused on specific issues, while others focused more on applications.

- **FleetNet:** The project was supported by the German Ministry of Education and Research and directed by DaimlerChrysler AG [56]. The objective was to deploy a wireless ad hoc network that communicates in inter-vehicle manner. The network should enable cost efficient information dissemination to vehicles and provide various location-based services. The network comprises moving cars and other stationary members like vehicles and roadside stations. The stationary members can additionally work as internet gateways. The overall project included hardware selection, protocol design, marketing, and standardization of the solutions. Various services were provided by the project; some of them are:
 - **Cooperative driver assistance:** Exchange of information about unexpected and sudden brakes, cars that are getting closer for more than the assumed safe

distance, and position of cars that are around the receiver and are entering the same lane.

- **Decentralized floating of car data:** Instead of using an infrastructure, sensed traffic data is transmitted by utilizing vehicles in the opposite direction.
 - **User communication and information services:** Different types of comfort applications are provided. For instance, passengers are able to interact and play games. Different types of business applications are also envisioned. Companies can install stationary gateways that broadcast marketing information. Shopping malls and fast food chains can also market their offers and take vehicle orders.
- **CarTalk:** CarTALK 2000 lasted for three years and was financed by the Information Society Technologies (IST) Cluster of the 5th Framework Program of the European Commission. It had two primary objectives [102]. The first objective was to evolve a cooperative cruise control system. Secondly, a self-organized VANET was to be established as a future communication standard. Several associated issues are addressed from building until delivering such system. Some are analyzing potential applications, developing software and algorithms, and demonstrating them in actual scenarios. In addition, market introduction strategies such as cost/benefit analysis and legal matters are also addressed. For dissemination of information, the communication is limited here to few nearby vehicles. Following this communication approach was to improve the overall scalability and performance of the system. The project concludes with defining an open architecture for vehicle electronics and open decentralized communication system. Three safety applications were identified: information and warning, communication-based longitudinal control, and cooperative driver assistance. The integration of hardware, communication, and algorithm was also performed. Finally, the project shows the feasibility of the proposed applications based on socio economic assessments.
 - **Vehicular Grid (vGrid):** Grid computing is a collection of loosely coupled resources for their optimal utilization [6]. The resources can be computers, storage, or bandwidth. Vehicular Grid (vGrid) is proposed as an integration of ad hoc networking and grid computing. The grid is formed between resources of vehicles and roadside infrastructure that are interconnected in ad hoc network manner. The grid can be used to solve various traffic problems. The motivation and the basic idea behind the use of grid is to enable a new generation of complex scientific and engineering applications that formerly was not possible with the computing power of the

individual vehicle. These applications will combine data coming from diverse sources (from computation, experimentation, and sensors). These data are used to provide useful insights into complex phenomena.

2.2.5 Research Issues in ITS

Any ITS requires addressing various issues spanning across all the layers of Open System Interconnection (OSI) stack [42] [117] [63]. Few of the issues are discussed briefly in this section. A detailed discussion in the context of VANET is provided in Chapter 3.

- **Standards:** An ITS system requires development of standards for deployment of hardware and communication infrastructure [42] [63] [11] [54]. This includes making clever choices at various layers of OSI stack such as physical layer technologies, medium access, routing, and interoperability in application layers. The necessary standards should also provide interoperability among heterogeneous systems, promoting compatibility and continuity.
- **Interoperability:** Interoperability is the ability of two systems to work in collaboration by exchanging a set of messages among them. An ITS should be developed based on public and open standards for communication [42]. It should be available to all entities involved (i.e. application and service suppliers and users).
- **Security and Privacy:** In ITS, there are different types of associated security issues. For instance, the provision of various types of services (as discussed earlier) requires consumption of personal data. This can lead to privacy issues. Some form of regulation is required for the protection of individuals and on the free movement of such data [42]. The exchange of data must be carried in a secured manner to prevent unauthorized access, which might lead to damage to the system.
- **Deployment and maintenance:** The integration of diverse technologies (Information Technologies (ITs), electronics, and sensors) demands a unified framework. Such a framework should facilitate in coordinated and coherent deployment of ITS hardware. It should also provide information exchanges across different organizational and institutional boundaries. A relevant issue is the seamless migration of technologies from a manual to a fully automated system [63]. Most of the ITS systems critically depend on proper function of its devices and underlying communication. Therefore, once the infrastructure is deployed, it must be continuously maintained.

- **Accuracy and reliability of services:** An ITS system must employ mechanisms to provide accurate and reliable information services [63]. This involves electronic data exchange between the authorities and stakeholders to enable timely update of information.
- **Integration with vehicle:** The integration of vehicle requires equipping the vehicles with essential hardware, development of communication architecture, protocols and interfaces, and the use of a standard process for adoption [42].
- **Training:** The training of driver is a complex process. If the new generation drivers are trained for the future ITS, they will not have expertise for manual control. A co-ordinated effort is therefore required with the government so that future requirements for education and training of drivers can be established [63].
- **Human factor issues:** There are several human factor issues to be resolved [117] [63]. The criteria have to be designed and evaluated for human machine interface for safety purposes. Behavior studies are required for adaptation to ITS technologies and subsequent impact on safety. Similarly, an understanding of peoples' behavior and opinion on ITS applications is required.
- **Cost benefit analysis:** The estimation of benefits provided by ITS should be evaluated against its cost [63] by arising several questions. The various benefits provided by ITS should be evaluated first. Then, the second question is to quantify those benefits. Two sub-questions arise: What is the process of quantifying those benefits? And what is the process used to measure those benefits?
- **Modeling, simulations and testbeds:** It is not possible to completely evaluate all the algorithms and technologies of ITS on the road due to safety, financial, technological, and other practical issues [63]. Hence, alternative tools are required to enable development, testing, and analysis of various algorithms.
- **Information dissemination:** One of the most important issues in ITS is the dissemination of information to relevant nodes. In infrastructure-based ITS, the vehicles can disseminate information to roadside units. Other vehicles can inquire information from the roadside units or these units can periodically broadcast data. However, in infrastructure-less ITS i.e. VANET, data dissemination becomes a very challenging task. Different obstacles such as high mobility of vehicles, spatiotemporal variations, and node's density emerge in these networks. Various approaches to information dissemination have been proposed in the literature. A detailed discussion on data dissemination in VANET will be provided in Chapter 3. Geocasting is one of the

promising approaches and is based on dissemination of information to a particular region where all the nodes in this region are expected to receive the information.

2.2.6 Communications in VANET

To shed the light on such important theme, one can point out that in VANET every vehicle acts as a router in order to transfer/obtain the required data to/from the existing vehicles in the network that can be designed to work in the infrastructure-to-vehicle (IVC) manner and/or vehicle-to-vehicle (V2V) manner. Therefore, VANET can be employed in safety and control applications, and as well as location-based services. There are no limits for storage capacity and power consumption in VANET, whereas the nodes' position can be specified by employing a positioning system [73] [44]. Linking such definition, features of VANET appear to be the same as the features of MANET, especially in these characteristics: self-management, self-organization, low bandwidth, and the shared radio transmission. However, the critical theme in operating VANET comes from the high speed of vehicles as well as the uncertain mobility [36]. This in turn can suggest that designing an effective routing protocol requires upgrading MANET architecture, simply in order to accommodate such quick mobility of VANET nodes effectively. Hence, the matter is critical to reiterate such key characteristics of VANET, which in turn can be considered for designing a wide range of routing protocols [83]. Every node in VANET is assumed to have real-time information of its position. Generally, a GPS receiver is installed in the vehicles to provide such information. In situations where GPS is not available or if more robustness is desired, other position determination techniques such as Trilateration, Dead Reckoning, Cellular Localization, or a combination of them can be used [26] [25] [106] [46] [45]. In addition to GPS, the nodes are also equipped with other hardware and onboard sensors. The sensors can observe different types of events that can be disseminated to other nodes. Additionally, the vehicles are not constrained by resources such as for storage capacity and power consumption. The mobility of nodes in VANET is predictable by paths on maps when compared to MANET. The movement of the nodes is constrained to streets. A mobility model that combines digital maps and vehicles is mostly used to predict the movements of nodes for operations of various algorithms during simulation. The problem is exacerbated further due to variations in street structure, node density, speed, and in the presence of buildings, trees and other obstacles. VANET protocols demand high and strict requirements of Quality of Service (QoS). For instance, opportune and infallible delivery of messages to all the vehicles is very critical in safety applications, which will be discussed more in section 2.2.6.1. A delay of few seconds can cause serious accidents and loss of lives, Therefore, maintaining high data rate is very significant and a must in such life critical

network.

2.2.6.1 Types of messages in VANET

Using VANET, different valuable applications can be introduced. In order to achieve these applications, vehicles exchange messages to keep each other informed about the road's current situation. The information comes from sensors or obtained from other nodes. According to [78], there are four types of messages exchanged among vehicles. These messages are classified as safety, traffic, infotainment, and entertainment messages. Safety information includes position, speed, temperature, wheel angle, and vehicle dimensions. Safety information includes position, speed, temperature, wheel angle, and vehicle dimensions, unlike traffic information that contains less-critical traffic details such as regional weather forecast, prediction of traffic jams, alternative route assistance, road condition information, and messages to acquire help (such as car maintenance). Different types of infotainment messages can be exchanged such as gaming, chatting, social networking, and file sharing. Finally, content like files, music, videos or other data can be obtained by means of few transactions [78]. The discovery of information and then utilizing it is a real challenge in vehicular ad hoc network [73]. Existing literature provides application-oriented taxonomies of various communication messages exchanged among vehicles. In this study, messages in VANET are classified based on their raw nature and the level of criticality into five categories: Alerts, Warnings, Information, Inquiry, and Content. Table 2.3 shows this classification and also the example scenarios where each class can be used.

2.2.6.2 Research Issues in VANET

There are different issues that should be considered when comparing or designing a protocol on VANET. These issues are raised from different characteristics of VANET. Achieving reliable applications requires addressing these issues for employing QoS.

2.2.6.3 Layered Architecture Issues

At the physical and Medium Access Control (MAC) layers, there are issues related to efficient sharing of medium catering to varying node density as well as complying with different QoS requirements. Most of the physical layer solutions for VANET are based on IEEE standards such as IEEE 802.11a, b, g and p [127]. A small number of proposals based

on other standards are also proposed. For instance, FleetNet uses a physical layer based on Universal Mobile Telecommunications System (UMTS) radio hardware that uses terrestrial radio access time division duplexing (UTRA-TDD) [80]. As far as MAC layer protocols are concerned, there are two general schemes for providing medium access control: 'Controlled Access' and 'Random Access'. Controlled access can be provided to medium using Time Division Multiple Access (TDMA) or Token ring. Random access scheme transmits the frame to the medium and then observes if a collision has occurred. In case of collision, the packet is sent again. Because of the infrastructure-less and dynamic nature, random access protocols are ideally suited for VANET [56]. Some of the MAC layer protocols for VANET are based on extending existing IEEE protocols. For instance, the MAC layer of IEEE 802.11p is based on WAVE protocol that allows nodes to simultaneously exchange between channels and transceiver [90].

2.2.6.4 Routing Issues

Because the nodes move at fast speed compared to MANET, routes are created and broken very frequently. Routing protocols should be robust enough to track these changes in topology. One approach is to use the existing protocols proposed for MANET. As VANET has the location information about nodes, various position-based routing protocols have been presented. Based on the specific requirements and VANET's characteristics, other types of routing protocols for VANET are also proposed. The following sections discuss some of these protocols. There have been various approaches to classify and categorize routing protocols over VANET [94] [37]. These classifications were based on either the way routing tables are updated (periodically or on-demand) or propagated (hierarchy, clusters, flat). In this study, a different classification is presented in terms of the properties of the destination and how a message should be sent to it.

- **Unicast protocols:** In unicast protocols, a message is delivered to only one single destination. These types of protocols are mainly categorized as proactive, reactive or hybrid protocols. In proactive routing protocol, information about routes (next hop, distance to destination, and sequence number) can be exchanged proactively after a few seconds. Well-known proactive routing protocols in the literature are Destination Sequenced Distance Vector routing (DSDV) [66], Optimized Link State Routing (OLSR) [40], and Wireless Routing Protocol (WRP) [103]. DSDV is based on periodic dissemination of messages that are accumulated by receiving nodes in order to maintain the routing table. OLSR broadcasts link state information with neighbors that can use the shortest path algorithm to compute next hop. Unlike

DSDV, WRP maintains multiple tables (distance table, routing table, link cost table, and message retransmission list) to have more accurate view of the network and to solve issues like count-to-infinity problem. The drawbacks of proactive routing are the overhead of routes dissemination without considering network parameters (channel capacity and network congestion) and bandwidth consumption. As the routes are always computed, the route discovery step is not required which results in minimum end-to-end delay compared to reactive protocols. Therefore, proactive protocols are suited for real-time applications.

There is another category of routing protocols that discovers the route only when a delivery of a packet to a specified endpoint is ordered. Hence, route discovery latency is associated with these protocols. These kinds of protocols are named reactive routing protocols. Some of the examples of reactive protocols are Dynamic Source Routing (DSR) [72], Ad hoc On-Demand Distance Vector routing (AODV) [111], Temporally Ordered Routing (TORA) [109], and Associativity Based Routing (ABR) [125]. DSR is a source routing protocol in which the way to be traversed is attached to the message. AODV is based on broadcasting of route discovery request by a source and intermediate nodes. The intermediate node maintains a temporary return way towards the source. Then, a destination node generates a route reply, which is used by intermediate nodes to deliver a response back to the source, and at the same time create a forward route towards the destination. In ABR, packets are forwarded based on the stability of links.

There is a category of hybrid routing protocols that integrates strength features in proactive and reactive routing protocols together in order to eliminate the disadvantages of each one. Zone Routing Protocol (ZRP), for instance, splits the road into zones. In the zone itself, proactive routing is applied, whereas reactive routing is applied for communication outside the zone. In this way, the overhead of periodic route dissemination in proactive routing is significantly reduced. In addition, the latency in reactive routing is partially optimized.

- **Multicast routing protocols:** In multicast routing protocols, a message is transmitted to a pre-defined set of receivers. These receivers have a unique identity called multicast group address. These types of protocols are suitable for collaborative operations involving more than one node. Multicast routing protocols generally require an establishment of a tree, a mesh, or a combination of both, in order to deliver the multicast message to all the group members. Two examples of multicast routing protocols are Shared-Tree Ad Hoc Multicast Protocol (STAMP) and (MZRP) [34] [142]. STAMP is a scalable Shared-Tree Ad hoc Multicast Protocol that creates a tree

based on the broadcasting capability of the medium. In MZRP, every node proactively maintains routing information for the local neighborhood in its zone. However, multicast tree is only established on demand.

- Broadcast routing protocols:** A broadcast routing protocol uses the multi-hops concept to disseminate a message within the transmission range of each node in order to deliver it outside the transmission range of the source vehicle [7]. Every vehicle that receives the packet, re-broadcast it only if the vehicle is located in the geographic area that is defined as a part the packet. One way is to employ flooding, but this causes very high overhead in the network. Hence, flooding is not useful at all for dense networks. There are specialized protocols that can perform selective broadcasting other than blind broadcasting. For instance, Emergency Broadcast Protocol for Inter-Vehicle Communications (BROADCAST) splits the road into cells and systematizes the vehicles on the road into two-level hierarchies [47]. The nodes at the second level utilize first-level communication to handle emergency message whereas nodes at the first level locally communicate and by default deliver these local exchanges to deliver the message to neighboring cells at the edge of each cell. Another example of broadcast-based protocols is Urban Multi-Hop Broadcast (UMB) protocol, which selects the farthest nodes to rely on the rebroadcasting step of the message [76]. Sun et al. proposed two broadcast protocols: Vector-based Track Detection Protocol (V-TRADE) and History enhanced Vector Track Detection Protocol (HV-TRADE) that work together in order to select a border node for further broadcasting [124].
- Position routing protocols:** Position-based routing protocols are ideally suited for vehicular ad hoc networks because of the nature they work on. Messages are routed towards a specific location (such as GPS coordinates) and are not affected by a very sharply change in topology. In position-based routing protocols, the specific location is stored in the requested packet and each intermediate hop uses its local knowledge of the surrounding nodes to select the best next hop. The neighborhood information is maintained by means of beacon messages that are exchanged continuously. Position-based routing protocols are more robust as compared to topology-driven protocols as they do not require route exchanges or route discovery procedure. A position-based routing protocol also requires a location service running on the network. When an intermediate node does not know the recent location of surrounding nodes, it can query the location service to find the surrounding nodes locations. Three types of forwarding strategies can be used in position-based protocols. First, the node can restrict the forwarding to specific geographical areas called forwarding zone. Secondly, hierarchical forwarding can also be performed. In the third strategy, nodes

can employ greedy forwarding in which the packet is sent to a hop that is in the closest position to the destination.

- **Geocast routing protocols:** From the conceptual view, geocast routing protocol is fundamentally a location-based multicast routing protocol that sends a message to a pre-determined geographical area called zone of relevance. That is, geocasting is a special case of position-based routing, in which a message is routed not to a particular node, but to a specific region. They are useful for VANET as the messages do not have any significance outside the zone, which is the case of most applications. For instance, information about accidents, vehicle speed, and road conditions are important only in a local context. Various geocast protocols for VANET have been proposed and are generally based on directed flooding of messes to reduce the overhead. Some examples of these protocols are Probabilistic Inter-Vehicular Geocast (p-IVG), cached geocast, abiding geocast, and geocache [69] [96] [97] [79]. Chapter 3 discusses geocast routing in details and provides a comparison between existing geocast protocols.

2.2.6.5 Information Dissemination Issues in VANET

A core and challenging issue in VANET is achieving efficient dissemination of safety and non-safety messages to all related nodes in the network. It is one of the most demanding obstacles in VANET. The fast changing topology of network and unreliability of links caused by high mobility of nodes, and infrastructure-less nature of network make it very difficult to disseminate information in the network. In this section, we talk about information dissemination in VANET in general while in the next Chapter 3 data dissemination is discussed in more detail. There have been various approaches to data dissemination proposed in the literature. Existing data dissemination approaches can be categorized as event-driven, scheduled, or non-demand approach. In the event-driven approach, the information is disseminated only on occurrence of some events. They are suitable for applications where on-time delivery of information is a critical requirement like road hazard warning and accident warning. In scheduled dissemination, the information is delivered periodically in a single hop manner to the related nodes. On the other hand, in on-demand approach, the information is disseminated only when it is queried by other nodes. There are addressed issues in the literature to be faced and considered for reliable dissemination of data in VANET. Following are some of these issues [37] [138]:

- **Mobility:** Due to the high mobility of nodes, connections between vehicles vary continuously in terms of bandwidth, data transfer, communication time frame and other parameters. The nodes suffer from frequent disconnection and network partitioning.

Therefore, a data dissemination scheme must be very efficient to optimally spread data (safety and non-safety messages) to other vehicles in the network [49].

- **Diversity:** The vehicles travelling on the road might have varying processing capabilities. In addition, some vehicles move very slowly, while others are travelling at high speeds. Different road sections have different mobility patterns. In a traffic jam, vehicles will travel at a very low speed as compared to low-density scenarios. Thus, the level of density also varies and affects the connectivity. A novel dissemination strategy must consider the right approach to be applicable in this diversity and adapt according to the environment.
- **Scalability:** VANET suffers from scalability problem. As the network density increases, a larger number of nodes will attain for channel access to disseminate the message, resulting in collision. An information dissemination scheme should be scalable and perform smoothly with the rise in the number of nodes. One of the approaches to address this problem is to use a timer or a probabilistic scheme since both provide a solution to this collision.
- **Message prioritization/ differentiation:** As discussed in previous chapters, there are different types of messages to be disseminated. Each of these messages has varying QoS requirements. A priority mechanism should be placed. The mechanism should assign probabilities to messages depending upon the importance of the message. For instance, an urgent alert message should be delivered without any delay, but a non-safety message can be delivered with a delay of a few seconds.
- **Offline mode of operation:** Due to frequent disconnection, vehicles should have the ability to disseminate information to disconnected vehicles. Disconnected vehicles can deliver information to roadside units, when they are at a 1-hop distance or indirectly request the delivery from other vehicles that are able to deliver the information.
- **Trust management:** As will be discussed in the security section, trust management is an important issue. There can be nodes disseminating false information such as traffic accident. A selfish vehicle can manipulate road conditions to reach his destination quickly. Therefore, a data dissemination scheme should have an in-built trust mechanism to ensure cooperation among nodes.

Summing up the discussion; for data dissemination issues, various considerations must be made such as volume of data being sent, data transfer rate, and the probability of the data being received by other nodes. In addition, network characteristics such as network size,

speed of vehicle, and intermittent connectivity should also be considered. These parameters also vary depending upon the type of data and application requirements (latency, jitter, and other QoS parameters).

2.2.6.6 Security Issues

Maintaining security in VANET is very essential and more vital than other ad hoc and sensor networks. Most of the safety applications are designed to save lives and avoid fatal accidents but if any safety message is compromised, this might lead to loss of lives. According to Ghassan Samara et al, there are three general types of malicious attackers in geocasting protocols: the selfish driver who deceives the other node to maximize his profit, the malicious attacker who disrupts the services, and the prankster who is a bored person probing for vulnerabilities [120]. These attackers have general goals of denial of service attack, compromising privacy, and/or displacement flooded information, and can employ different methods to accomplish these duties [121]. For instance, nodes can manipulate safety message header or content to provide false information. The destination region can also be reduced, leading to fewer vehicles informed about the event. Similarly, the destination region can be enlarged that causes increased network load and overhead. Another way of service attacking is holding on a message and postponing it to a later time to lose its efficiency. A related method is to forward misbehavior, where a node can illegitimately forward a fake safety message when not desired. The nodes can also forge false messages. At the MAC layer, nodes can behave selfishly by not abiding to channel access protocols, and aggressively get access to the medium to propagate false messages. Finally, at the physical layer, signal jamming can be performed to disrupt communication.

Any VANET based system must comply with basic security objectives before deployment. Some of these requirements are authentication, authorization, privacy and data integrity. Maintaining these goals is a very challenging mission. Most of the nodes are strangers to each other. There is no security infrastructure available when working in Inter-VANET manner. The nodes are mobile and encounter unknown nodes frequently. The nodes cannot rely on the other nodes to provide complete and accurate information about their security. Yet, it is necessary to ensure that safety information is not tempered by malicious nodes. Some of the security problems highlighted in this study previously can be addressed by digital signatures [116].

Also, a public key infrastructure can be installed in each vehicle to provide a public and private key pair. Every safety message is signed with a private key. A safety message is sent along with a certificate in order to verify the integrity of the message [116] [88] [86] [82].

2.2.7 Simulation

Before a VANET protocol or application is put into operation in ITS, it must be tested. One can test the performance in a real environment, on a test bed, or in a simulation environment. Because of the cost and complexity of the two former options, simulation is the best and most widely used procedure for validating any protocol. Different simulation toolkits have been anticipated for this purpose. Some of these tools are open source, while others are proposed for commercial purposes. These tools can also be classified based on their scalability features, for example the number of nodes supported for simulation. The following sections discuss two types of network simulators: generalized network simulators and simulators that are precisely proposed for VANET simulations. In addition, there are several supporting tools for VANET simulation that are discussed at the end of this section.

2.2.7.1 Generalized Network Simulators

Different simulation toolkits have been proposed for analyzing the behavior and the performance of various architectures and protocols for networks that are operated in wireless ad hoc manner. Some of these simulators are:

- **NS-2 and NS-3:** Network Simulator (NS-2) is one of the most widely utilized software packages for simulating wireless networks [55]. It is a discrete event simulator having packages for simulation of TCP, UDP, ad hoc networking, routing, and multicasting over wireless ad hoc network. Network Simulator (NS-3) is another discrete event simulator that aims at providing a solid and well-documented simulation core for research and educational purpose [67]. It includes models for Wi-Fi, WiMAX, or LTE and implementation of several ad hoc network routing protocols (such as AODV, OLSR). In integration with them, various mobility models and specialized tools for simulation of VANET have also been proposed for NS-2 and NS-3.
- **GlomoSim:** Global Mobile System Simulator (GlomoSim) is the second most widely used network simulator after NS-2 [8]. The distinctive feature of this simulator is scalability. The tool has been developed in Parallel Computing Laboratory at University of California (UCLA), and can run on Symmetric Multiprocessor (SMP). Thus, the simulation can be divided into separate modules that can run as a distinct process. The simulator is claimed to support millions of nodes in a single simulation.
- **OMNet++:** Objective Modular Network (OMnet++) is a C++ simulator, provides features for simulation of different types of networks such as wired, wireless, on-chip,

and queuing networks [130]. There are model frameworks for simulation of sensor, ad hoc and other types of networks. In addition, there are models for development in other programming languages like Java and C#.

2.2.7.2 VANET Simulators

There are few specialized VANET simulators presently available and some of these simulators are as follows:

- **Trans:** Traffic and network simulator environment (Trans) is a Java-based simulator. It has a visualizer to graphically view any VANET simulation [112]. It can also be incorporated with SUMO and NS-2. The simulator can support up to 3000 nodes. Mobility traces can be imported from the Topologically Integrated Geographic Encoding and Referencing system (TIGER) database. In addition, a vector map can also be used.
- **NCTUns:** National Chiao Tung University Network Simulator (NCTUns) integrates the simulation of traffic and network [131]. It enables the testing of ITS by providing implementation of various protocols (802.11a, 802.11b, 802.11 g and 802.11). The tool supports SHARPE-format map file for road information. The simulator also provides implementation of directional, bidirectional, and omnidirectional antennas. The only drawback of this tool is that it can only support up to 4096 nodes.
- **GrooveNet:** GrooveNet is a modular, discrete event simulator that facilitates construction of hybrid simulation environment comprising real and simulate vehicles [98]. For this purpose, real-street map topography can be used to enable in-vehicle deployment. The simulator provides support for GPS messages, multiple network interfaces, and simulation of thousands of vehicles. In addition, there are several significant supplementary tools such as trace files generator and traffic simulator available for VANET. Well-known and widely used tools with high level of realism are as follows:

2.2.7.3 Mobility Models

To produce realistic simulations, VANET has a need for a mobility model that can be used to create and mimic realistic vehicles' environment. In addition to network simulators, there are several significant supplementary tools such as trace files generator and traffic simulator available for VANET. In the literature, various types of mobility models have been proposed. Aamir et al. classified these models in a survey view as event-driven (based

on the traces), software-based (generated using software), and synthetic model (based on mathematical equations) [65].

2.2.7.3.1 Individual Mobility Models The movement of nodes in these models is independent in each node. Some of the popular mobility models in this category are: random walk mobility in which nodes move with a random speed and direction, random way point mobility in which nodes move towards a random target, city section mobility in which nodes are confined to street (grid) with limited node movement and speed, and Manhattan mobility model, which is a probabilistic version of city section mobility model [32].

2.2.7.3.2 Group-Based Mobility Models In these types of mobility models, nodes movements are represented in the form of groups. An example is the reference point group mobility model, in which there are a group of nodes and each one of them has a leader [32]. The leader follows the random way point mobility, while the other nodes follow their leader. Similarly, the nodes in column mobility model compose a line and travel onward to the particular direction [32] [15].

2.2.7.3.3 Mobility Generators There are several independent tools that have been proposed recently for the purpose of generating mobility patterns. These tools can use real world maps from any database or manual topology generation. One of these tools is Street Random Waypoint (STRAW) model that extracts its topology from TIGER database [38]. In addition, the tool also provides micro-mobility support. The distinctive feature of this tool is the use of traffic lights and signals for intersection management. Well-known and widely used tools with high level of realism are as follows:

- **VANET MobiSim:** The tool simulates two ways of communication: *car-to-car* and *car-to-infrastructure* communications [64]. Different types of databases such as TIGER, GDF are supported in the favor of obtaining the maps. The simulation also incorporates stop signs, traffic lights, and other macro-mobility aspects.
- **SUMO:** Simulation of Urban Mobility (SUMO) is an open source, large scale, and macroscopic traffic simulation package [77]. The tool supports vehicles movement based on space and time, and simulation of lanes and traffic rules. The tool is portable and can import network behaviors in different formats.

Table 2.3: Types of messages in VANET

Type	Description	Examples
Warnings	Information about accidents, traffic signal violations, or stop sign violations	Accidents, emergency vehicles approaching, collision warning, or pre/post-crash notification
Alerts	Different types of less-critical warnings are exchanged among vehicles.	Road conditions, or extreme weather conditions
Information	Various types of informative messages for traffic management and improved driving experience can be exchanged.	Information about traffic signal violations, or stop sign violations
Inquiries	Vehicles can inquire about various services.	Parking lot availability, current weather, or infotainment application
Contents	Based on inquired request for services or for sharing and downloading	Videos, or files

2.3 Summary

Intelligent Transportation System (ITS) has become the most viable approach to tackle traffic management problems. In this chapter, an overview of ITS, its architecture, services, and various issues are highlighted. Before its complete realization, several challenges have to be addressed, as discussed in issues sections. Therefore, ongoing realistic tests such as FleetNet and vGrid are expected in future [56] [6]. There are various types of ITS system currently available and this chapter discussed ITS in general and highlights some of these systems. Chapter 3 specifically talks about vehicular ad hoc network that uses inter-vehicle communication for solving traffic problems. The chapter introduces its readers to the concept of VANET, presents various challenges over VANET, and addresses several issues in different aspects. Vehicular ad hoc network is discussed along with its properties, communication details, research issues, and existing solutions. In this chapter, the major contributions were a novel classification of communication messages, routing protocols, simulation tools, the identification of various types of issues, and mobility models in VANET.

Chapter 3

Releated Works

Information dissemination is defined as the delivery of data to the intended vehicles in the network, complying with different QoS requirements such as delay and reliability. Geographical Broadcast, well known by the term Geocast, is the delivery of information to a specific and pre-determined geographical region. It is the preferred approach for dissemination of safety messages in vehicular ad hoc network (which is the main topic of research for this study). Hence, in the rest of the study, we consider only geocasting routing protocols for the goal of efficient data dissemination for further discussion.

3.1 Data Dissemination

The objective of data dissemination is to improve passengers' safety, time, distance, and comfort. For instances, drivers can be informed of traffic jams, and emergency notifications can be provided to vehicles (about weather or accidents) to avoid collisions. Information dissemination in VANET comprises the following steps [108] [78]:

- **Acquisition:** Obtaining data locally to satiate the application needs is a very important requirement (yet often neglected) for any information dissemination protocol. The choice of the parameters to be measured depends on specific objectives of application as well as other protocol design parameters. The data is often acquired from sensors equipped in vehicle as well as external sensors [108].
- **Transport:** Most of the approaches proposed in the literature are focused on the delivery of acquired data to interested vehicles. Some of these approaches are based on broadcasting, publish-subscribe model, client-server approach, and the use of underlying routing protocol for dissemination of information [134] [122].

- **Summarization:** It is defined as the process of semantically combining same information from different sources to produce single known information. Normally, the sensor values are averaged considering the time stamp information and road segments [91].
- **Aggregation:** Aggregation is similar to summarization but it produces coarse grained information of vehicles over large areas. The information from vehicles can be aggregated in various ways [66]. For example, a subset of information from a vehicle can be considered. This approach reduces the volume of data. Clusters of vehicles can also be formed to further limit the magnitude of information.
- **Information assurance:** Because of the network size, speed, dynamism, and absence of any trust among vehicles, assurance of information becomes a taxing task, and has attracted research attention in past few years. Some of the challenges under investigation are authorization, privacy, data validation, and isolation [78].

A data dissemination scheme can be based on broadcast or geocast techniques. The first one is based on propagation of information to neighboring vehicles within the network. As wireless networks are broadcasters in nature, the broadcasting does not incur or cost any additional effort. The broadcasting can be performed in two ways, single- or multi-hops [107]. In single-hop broadcasting, data are not immediately flooded further to vehicles but stored in the temporary database of the vehicle. Then, vehicles sporadically choose a subset of stored data to disseminate to neighbors. The philosophy is that as vehicles move, they acquire information from each received broadcast and this process is repeated only when the vehicles enter a new area in the next period. The second approach in broadcasting is multi-hop broadcasting where packets are disseminated via flooding style by utilizing intermediate nodes. When the broadcasted packet is received by surrounding nodes, those surrounding nodes become intermediate relay nodes and rebroadcast the packet. Unlike broadcasting, in geocasting, the destination of packet is a specific region to receive the packet as discussed in the previous section. Geocasting is the most feasible approach for data dissemination in VANET because of the following reasons:

- **Region of interest:** A disseminated message in VANET is of interest to a particular region. For example, if a node wants to find parking place, then dissemination of message should only be limited to the parking region and sending this message to other regions has no value.
- **Location-based dissemination:** A multicasting algorithm requires every node to be registered to a multicast group. On the contrary, geocast does not impose any

such constraints. In addition, geocast does not require a destination address to disseminate message. Instead, the destination location obtained from the Global Position Information (GPS) is used to perform routing of the message.

- **No overhead (of discovery and maintenance):** due to location-based dissemination concept, there is no overhead of route discovery and maintenance cost within the geocast area. The information is always disseminated based on up-to-date information. Furthermore, procedures like address resolution and topology management are not required for geocasting. Data dissemination can run in two manners, infrastructure-based or Infrastructure-less data dissemination manner. Figure 3.1 categorizes the routing protocols over VANET and illustrates some examples for each category.

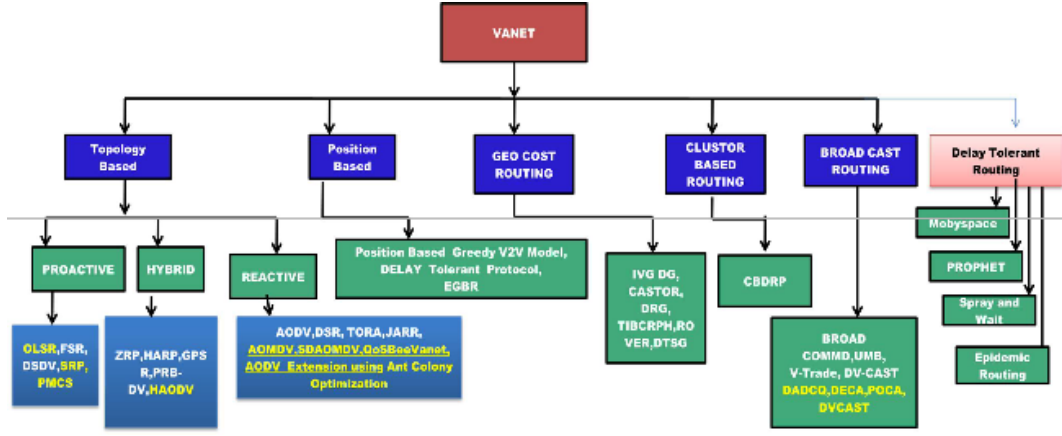


Figure 3.1: Classification of routing protocols over VANET [59]

3.1.1 Infrastructure-based data dissemination schemes

There has been plenty of research done on information dissemination in ITS since data dissemination almost serves almost all of ITS applications. In this research, infrastructure-based techniques are not used. Therefore, in this section, only information dissemination scheme that makes use of infrastructure is briefly discussed. According to Pratibha *et al.*, infrastructure data dissemination schemes are categorized as push-based and pull-based schemes [126]. In the former approach, the data is periodically broadcast from Road Side Units (RSUs) and sometimes RSUs use vehicles, to deliver the data to out-ranged vehicles. The pull-based approaches are based on a request-response model, where vehicles can request the data required and data can be retrieved from infrastructure and routed back to the requester. From another perspective, infrastructure data dissemination schemes

can be categorized based on the kind of infrastructure resources used. For instance, some approaches have used road side deployed units, while others used the parking lot resources for data dissemination [143] [61] [22]. A number of hybrid schemes are also proposed. These hybrid schemes can be further classified as those that utilize a combination of vehicle and road side units [135], and those schemes that only use sensor nodes for performing data dissemination [92]. Recently, a number of approaches are planned in order to determine the best placement for extremely expensive infrastructural units. These existing approaches fall in one of the following directions:

3.1.1.1 Probabilistic Approaches:

In [89], a Markov model-based approach to data dissemination is proposed. In a Markov model, the current state is dependent on the previous state. Intersections of ranges between vehicles and road side units are formed as Markov chain; road network is formed as undirected graph, and depth first algorithm is used to find an optimal placement for road side units [21]. In another approach, the randomness of vehicle traffic and communication channel characteristics are analyzed and exploited [2]. A probabilistic model is proposed to determine the maximum distance between road side units.

3.1.1.2 Trajectory-Based Approaches:

In some of the approaches, the trajectories of the vehicles are exploited for deciding the infrastructure placement. In [136], the analysis of path number between two vehicles is evaluated to get the trajectory of vehicles, which is then used for RSUs' placements.

3.1.1.3 Cooperative Road Side Units-Based Approaches:

In high-volume networks, road side units can suffer from heavy loads leading to high deadline miss-rates. Therefore, the concept of cooperative road side units has been proposed [3]. The units can work in cooperation to transfer some delay tolerant requests from heavy load units to other units [110] [28].

3.1.1.4 Road Configuration-Based Approaches:

In these approaches, the radial configuration of roads is utilized. In [54], a hexagonal cell-based data dissemination scheme is proposed. The road configuration is exploited for communication infrastructure where data and queries can be stored.

3.1.2 Infrastructure-Less Data Dissemination Schemes

There are number of ways that are used to connect vehicles and Figure 3.2 shows some of these ways. Following are some of the representative schemes that are proposed in the literature for information dissemination without the existence of infrastructural resources:

3.1.2.1 Flooding:

Messages are broadcast to neighbors that repetitively rebroadcast them; following such way all nodes in the network are expected to receive the message. They are useful for applications demanding near real-time delivery of information. In addition, it is ideally suitable for low-density (sparse or fragmented) networks. The major drawbacks are the high overhead of message dissemination, contention, and collision which eventually lead to broadcast storm problem [128]. In addition, flooding protocols perform poorly in high density networks such as urban areas or at the time of traffic congestion.

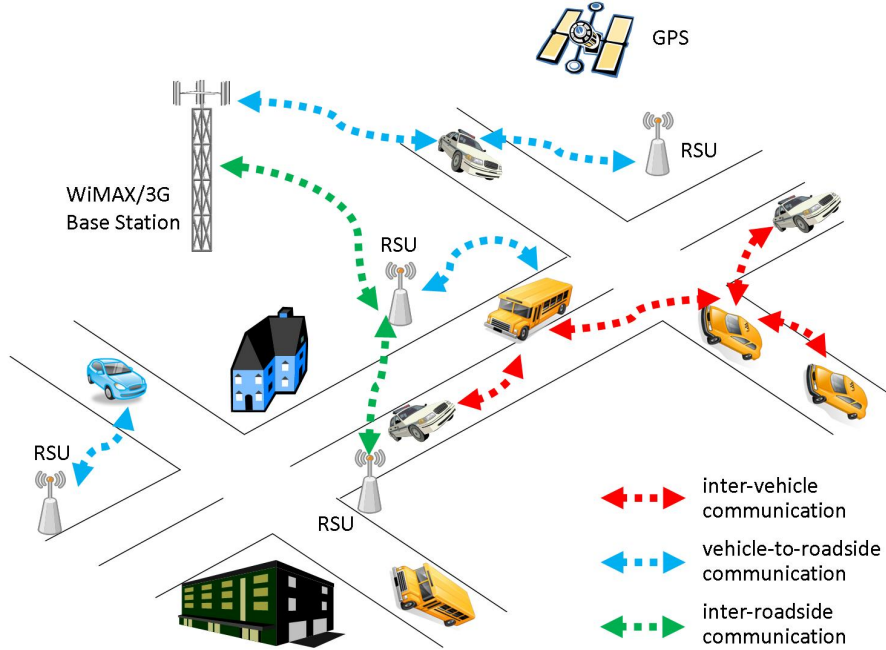


Figure 3.2: Different data communication schemes [77]

3.1.2.2 Relaying:

In this approach, a relay node is selected for further dissemination of information. The contention is less and overhead is low compared to flooding. Therefore, this approach

provides more scalability and is useful for dense networks [126].

3.1.2.3 Opportunistic Dissemination:

Another approach is opportunistic dissemination, in which a vehicle disseminates the information as soon as it encounters another node [143]. The messages are therefore stored at intermediate nodes and forwarded to other nodes to reach the destination.

3.1.2.4 Geocasting:

Due to continuously changing topology and the mobility of nodes, it is viable to use geocasting that delivers a message to several nodes in geographical area [4]. Geocasting is discussed in detail in section 3.2.

3.1.2.5 Peer-to-Peer Dissemination:

These approaches focus on providing Peer-to-Peer (P2P) content distribution for data such as music and videos over the VANET and are handy for delay tolerant application [94].

3.1.2.6 Cluster-Based Dissemination:

The nodes are arranged in the form of clusters. Then, few elected nodes in each cluster are responsible for aggregating the data in their cluster, with the possibility of sending them to the next cluster. The clustering of data ensures better delivery ratio, reduced propagation and avoids broadcast storms, as a message is relayed by a small number of intermediate nodes [91]. Unlike conventional networks, it is not viable to use flooding, on-demand data consumption, or multicasting [104]. The nodes are mobile and the network suffers from frequent disconnection and partitioning. The data cannot be disseminated to a group address like in MANETs [10] [50] [30]. There is no infrastructure, prior planning or address assignments that can be done. For this reason, the message is disseminated to a particular region, where the location of nodes determines the group of recipients. The rest of the chapter, therefore, focuses on geocast routing protocols on VANET. Finally, data dissemination in VANETs is also linked to underlying link layer and network layer protocols. Additionally, infrastructure support and data accumulation or aggregation strategies can be exploited for efficient data dissemination in VANET.

3.2 Geocast Protocols for Data Dissemination over VANET

Geocast, also called and derived from the term Geographical broadcast, is the delivery of information to a definite geographical region [9]. In the literature, various geocasting approaches have been presented. The following paragraphs discuss few of the recent approaches, providing some examples on each category. Further, an analysis and a comparison between these protocols are drawn.

3.2.1 Geometric Approaches

Geometric approaches are based on exploiting geometric properties of area or zones in order to broadcast the message in the geocast region [19]. Hsu *et al.* presented a geometric geocasting approach based on the concept of Fermat point region [68]. It is defined as a region in a triangle, such that the aggregated distance from triangle's vertices to this region is the minimum [81]. These regions serve as routing regions and forward data packets to the geocast area using the greedy approach. Another geometric approach has been cited by Allalet *al.* The roads are represented by two dimensional Euclidean spaces. Different shapes, circle, triangle, or quadrilateral of Zone of Relevance (ZOR) are defined [4]. Different ZORs for an event are computed by a competent authority. A vision angle routing technique is proposed to disseminate messages to vehicles in different ZORs. The distances between source and ZORs are computed and then if the nearest zone is in the same direction as other zones, a single message is broadcast.

3.2.2 Trajectory-Based Approaches

Another distinctive direction of research is based on exploiting vehicle trajectories in furtherance of geocasting messages. According to the authors of [70], geocast faces several challenges due to the large scale dynamic network topology and random mobility of vehicles in the network. These challenges can be addressed by exploiting the trajectories of vehicles. They presented the pioneered work on exploiting the trajectories of vehicles to determine vehicle's coverage before geocasting is performed. A trajectory is defined as the sequence of road segments traversed by vehicles. This information can be obtained from navigation systems that are already able to provide suggestions to drivers based on traffic conditions and distance. The coverage graph of vehicle is updated based on its trajectory and encounters with other vehicles. Based on the coverage's graph, the routing algorithms

can be designed to achieve the highest packet delivery ratio and the lowest delay[20]. Another trajectory-based approach is for GEOcast routing based on SPatial Information (GeoSPIN) proposed by Celes *et al.* [35]. The trajectories of vehicles here are computed based on daily movement of vehicles via the GPS device. By applying clustering, relevant information from these trajectories are identified. The second phase of algorithm is to forward messages by employing an opportunistic approach. When two vehicles encounter each other, they exchange the list of messages with each other. If a vehicle realizes that it has a higher probability of delivery with small distance, it can request other vehicles to store this message locally for the sake of forwarding it to the source.

3.2.3 Path Sharing and Splitting-Based Approach

Zone-Based Forwarding (ZBF) is proposed as a scheme for disseminating emergency messages to vehicles. ZBF transmits alert messages to vehicles within a certain area to avoid chain collisions. The total area for transmitting messages is divided into several segments equal to radio transmission range of each vehicle. For each sector there would be three types of vehicles: (1) a forwarder for each segment, responsible for forwarding messages to other vehicles in certain intervals, (2) receivers, all the vehicles in a sector who receive messages from the forwarder, and (3) a relay, the next expected forwarder vehicle, that is approaching border of a sector and performing an election of being the next forwarder. The vehicle that is predictable to be in a sector for the longest time is elected as the relay forwarder. SmartGeocast by Zhang *et al.* [141] uses path sharing in order to geocast the message to multiple ZORs. The protocol comprises two phases: geocasting initialization and geocasting maintenance. In the first phase, the concept of path sharing is utilized to where multiple messages through multiple paths are aggregated into a single message and delivered through a single path, leading to reduced bandwidth utilization. The concept of path splitting is also utilized to split a message into several copies transmitted to a vehicle closest to the target region. In the maintenance phase, rebroadcasts are performed by a node based on the concept of regional autonomy. A small area is cut in each target region, thus reduces the message redundancy and maintenance cost.

3.2.4 Beacon-Based Approach

There have been several methods that operate periodic beaconing before or during geocasting the message. Most of the protocols in this direction consider a structure such as a tree or mesh for the information dissemination. A structure-less approach for dissemination is adopted by Cuckov *et al.* [43]. The proposed approach creates a layered vision about the

road conditions in which the number of layered decreases with the increase in distance. The proposed approach comprises three phases. The beaconing service is utilized to create an immediate view on each vehicle's surroundings. In the second phase, the immediate view is exchanged in a single-hop manner to neighbors in order to create a local view of surroundings. In the final phase, local views are transmitted using a geocasting protocol. Intermediate vehicles keep on broadcasting the information, until they arrive at the point of aggregation. This is achieved when the originator of the geocasted frame is not in its local view or the nodes mentioned in geocasted frame are not in its immediate view.

Ibrahim *et al.* also proposed a probabilistic Inter-Vehicular Geocast (p-IVG) that is basically beacon-based approach [69]. The scheme initially uses the traffic density of the surrounding vehicles before starting the data dissemination. This conventional inter-vehicular geocast approach selects the farthest vehicles, within transmission range, for further dissemination of the message. P-IVG proposes a solution for the spatial broadcast storm problem by considering the vehicle density information computed using a lightweight utility running on every node, which rises when more than a node has an equivalent distance and starts the same timer. The utility periodically sends beacon messages every two seconds to neighbors. This information is used to sense the local topology and the density of vehicles. Then, the probability function makes a decision of either starting a timer or not; based on the density of surrounding vehicles.

Zarza *et al.* proposed a Context Aware Geocast Forwarding Protocol (CAGFP) that disseminates a safety message using the control channel in beaconing within the IEEE 1609 standard [140]. To mitigate the spatial broadcast storm problem, a topology sensing algorithm is proposed based on periodic transmission of beacon messages. Every node maintains a list of neighbors as an output of these beacon messages. Whenever a safety message is received, the node sorts the recent list of neighbors maintained. Then, the node at the top of the list is assumed as the next forwarder node. The node will instantly rebroadcast the message. A relevancy function is defined based on GPS information of every node to check if it is within the 600-meter range of the accident.

Oh *et al.* proposed a Zero-Coordination Opportunistic Routing protocol (ZCOR) for the delivery of Life Safety Messages (LSM) over VANET [105]. The algorithm uses slot reservation mechanism for delivery of LSM based on slotted Abramson's Logic of Hiring Access (slotted-ALOHA). The forward/relay nodes are selected using a coordination-free opportunistic approach. Each packet contains coordination information for the next relaying nodes. For coordination, a circle of trust is maintained by every node. The only overhead of this protocol is the use of periodic beacon messages that are normally part of most of VANET protocols.

Another protocol based on beaconing technique by exchanging Hello and Response packets is vehicular Ad-hoc networks Context-Aware Routing Protocol (VCARP) [123]. This protocol is built on three forms of packets: Geocast, Hello, and Response packets. The nodes exchange Hello and Response packets to update the surrounding nodes tables. This table contains context information about neighbors. The Geocast messages are to be relayed by nodes moving earlier toward the specified geocast region. To select this relay node, each node checks its neighbor table for a forwarding node that is closet to the destination or, in other words, approaches the destination sooner. If such node is not discovered, the node caches the packet and waits for any new neighbor meeting these criteria. The protocol exploits the trajectories of the node to determine if it is approaching the destination or not. Finally, the concept of shared cache is utilized. If a node cache is full and receives a geocast, it searches for a neighbor with free cache slot and closer to destination. The packet is relayed to that destination with a packet header indicating the node to cache.

3.2.5 Time Stable Geocast

A time stable geocast protocol aims at keeping the message alive for a specific amount of time inside the geocast region. Rahbare *et al.* and Kheawchaoom *et al.* proposed two versions of Dynamic Time-Stable Geocast protocol (DTGS) [114] [75]. The protocol dynamically modifies the wait time and guarantees message delivery with a low cost. In the first version, DTGS comprises two phases: a pre-stable period and a stable period. The pre-stable phase intends to disseminate the message within the geocast area [114]. Upon encountering a critical event, the source node immediately broadcasts an alarm message. It keeps on broadcasting the message after specific intervals until one helping vehicle, which lies in the opposite side, delivers the same message to the source. One leader vehicle is elected, the farthest one, for further relaying based on a timer. In the stable period, the message is kept alive for the desired time within the region. For this purpose, an extra length region is defined as a few meters outside the geocast area. The vehicle keeps on broadcasting the message in the extra length region until one of the nodes in the opposite lane receives the message. Kheawchaoom *et al.* extends this approach further by proposing a second version of DTSG [75]. The length of the extra region in this version is dynamically set up and adjusted based on density. In addition, the approach also solves the broadcast storm problem that are arising in some situations in [114].

3.2.6 Abiding Geocast

Abiding Geocast is designed to transmit messages to vehicles positioned in a specific location for a specified duration of time, which is established by authors of [84]. Three basic working approaches are proposed, server-based approach, election-based approach, and neighbors approach. The last one is developed in most of the protocols that use abiding geocast concept in order to keep the message alive for a specified time and deliver messages to all vehicles within the specified geographic location. For delivering messages both unicasting and single-hop broadcasting are used. Unicasting is used to deliver the new message to the specified location utilizing infrastructures while broadcasting is used to disseminate the message within the specified location. Whenever an elected node is about to leave the region, it hands over the responsibility to the other suitable vehicle. The election is made based on the longest possible existence of vehicles within the region. The vehicle near the center of the region with lower velocity is the most suitable candidate. This proposal does not guarantee the delivery in low-density scenarios and therefore is not suitable for safety applications. Yu *et al.* [139] proposed another safety abiding geocast protocol that was the first to make use of the opposite side vehicles and provides higher reliability than the approach in [84]. In this protocol, vehicles on the opposite lanes are selected as relays since they are faster than the same lane vehicles to warn about dangerous situations ahead. This selection of vehicles on opposite lanes is claimed to diminish the occurrence of the broadcast storm problem. The notion of effect area is introduced and is modeled based on Poisson distribution. In addition, the wait time of vehicles can be adjusted dynamically for the next broadcast, thus avoiding unnecessary broadcast. If a relay vehicle receives broadcast message from another vehicle, it can postpone its broadcast until the vehicle moves out of the effect area. To avoid issues like network fragmentation, relay vehicles that are in the opposite lane are given the responsibility to frequently broadcast the warning. The broadcasting frequency should be such that that no vehicle in the opposite lane moves into, passes, or leaves the transmission range without receiving the broadcast. Lim *et al.* proposed an abiding geocast protocol for delivering a commercial advertisement to all vehicles within a geocast region for a particular duration of time [84]. The dissemination starts by road side units, and then forwarders are selected for dissemination of messages. The concept of a timer whose value is based on the distance from the roadside unit to the vehicle is used to select the forwarder. Another timer (based on speed, location, and distance from center of destination region) is used to keep the message alive in the region.

3.3 A Comparison between Geocast Protocols for Data Dissemination over VANET

When disseminating a message using a geocast technique, three different aspects should be considered: determining the geocast area, delivering the message to the geocast region, and disseminating the message within the geocast region. In this section, we compare and analyze existing geocast protocols from these three aspects. By doing so, this is going to pave the path for designing an effective geocast protocol for data dissemination over VANET.

There is a number of comparative studies and surveys performed in the literature on geocast over VANET. Most of these studies were precisely focused on geocast protocols [113] [95] [4] while some were generalized studies on different routing protocols. Maihofer *et al.* provided a comparison between various geocast protocols [95]. He categorized these protocols as flooding, directed flooding, and no-flooding approaches. Besides the qualitative comparison, the protocols were quantitatively analyzed by a simulation in NS-2. However, the protocols considered in this study were proposed before 2004 and considered both infrastructure-based and infrastructure-less networks. Similar work has been done in [60], where various types of geocast protocols have been classified as flooding, directed flooding, and no flooding. These protocols are compared based on the simulation scenarios and the performance of the delivery ratio without performing any implementation. Authors concluded that none of these protocols are suitable for both city and highway scenarios. In [85], various types of geographic routing protocols, i.e. unicasting, broadcasting, and geocasting were discussed. The authors then talked about few geocasting protocols such as inter-vehicle geocast, cached geocast, and abiding geocast. However, no classification of geocasting protocols is provided. The authors analyzed the complexities involved and concluded that real world implementation of protocols are required in multiple scenarios to obtain realistic results. Rahbar [113] discussed various types of routing protocols over MANET and VANET such as inter-vehicular geocast, cached geocast, and LBM. The protocols were compared based on the resources required (GPS, RSU, OBU), transmission strategies, beaconing, and their delay tolerance capabilities. Allal *et al.* discussed various types of geocasting protocols for VANET [4]. They classified these geocast schemes as those based on beaconing and those operated without the need of beaconing. The selected geocasting approaches were compared based on different criteria such as strategies for forwarding, route maintenance, and time constraints. Table 3.1 presented the summary of various surveys and comparative studies.

3.3.1 Qualitative Comparison between Geocast Protocols over VANET

In most of the approaches such as Rahbar *et al.* and Kheawchaoom *et al.* [114] [75], the geocast area is defined as an area of few meters around the point of incidence (accident, congestion, or bad road condition). While in other works, the geocast area is determined based on relevancy function such as in Zarza *et al.* [140]. In Singh *et al.*, the geocasting areas is a particular road segment called zone [122]. Yu *et al.* have used the notion of effect area, a region in which a message remains active [139]. In Allal *et al.*, the geocast area determination is delegated to a third party, that based on event and other information, determines the zone of relevance and its shape [5]. In Zhang *et al.*, the concepts of buoys have been used to determine the geocast area [141].

In some of the approaches, the role of opposite lane vehicles is greatly emphasized such as in [140] [128] [75]. These vehicles are natural candidate for dissemination of information to coming vehicles, as they can inform coming vehicles after crossing the event location. In Yu *et al.*, the problem of network fragmentation has been addressed using the help of opposite lane vehicles [139]. For this purpose, a relay vehicle keeps on informing opposite lane vehicles fast enough that no passing by vehicles misses the information. Similarly, Jiang *et al.* and Celes *et al.* have used an opportunistic approach in which opposite lane vehicles are informed and information can be exchanged based on certain conditions [70] [35]. A time stable geocasting keeps the message alive in a region for a specific period of time. A dynamic protocol can adjust the time based on current context. Some of the geocasting protocols proposed in the literature claim to possess these two properties. For example, Rahbar *et al.* and Kheawchaoom *et al.* keep on disseminating message after exiting the geocasting area for a specific distance [114] [75]. The protocol is dynamic as the dynamic time calculation is on network density and vehicle speed. Several forwarding approaches have been proposed. One of the approaches is that the nodes in geocast area keeps on broadcasting periodically (after certain interval) until it receives same message from other nodes [140] [114] and [75]. In [122], a forwarder is elected that is responsible for message dissemination in that zone. In [68], the concept of Fermat point region is introduced and messages are forwarded based on the closest Fermat point region. In [70], the messages are disseminated in an opportunistic way using coverage graphs. In some of the approaches such as [114], the node keeps on broadcasting for an extra length region to keep the message alive. In [75], the extra length region is dynamic and adjusted based on vehicle density. While in other approaches (such as [122] and [68]), no such details are provided.

Beaconing is the process of periodic exchange of messages among nodes to maintain

neighborhood information. In some of the protocols, beaconing has been used to exchange additional information such as the location and speed of vehicle. Based on these information, relay nodes are selected (such as in [69], [140], [43], [105], [123]).

In Lim *et al.*, the geocasting protocol gets support from infrastructure for dissemination of information [84]. In Cuckov *et al.*, besides dissemination of message, data aggregation is also performed to get summarized information as the distance increases [43]. A few geocasting approaches are proposed for special types of messages. For instance, Zarza *et al.* and Oh *et al.* have been proposed for safety applications, while Lim *et al.* have been proposed for commercial applications [140] [105] [84]. As far as the contents of the message are concerned, sender's ID, location of the event, and vehicle details are the information exchanged during geocasting. Packet delivery ratio and the message overhead are the parameters considered for the evaluation of geocasting approaches. Some schemes have assumed geometrical properties for regions. For example, Hsu *et al.* defines Fermat regions, Allal *et al.* and Singh *et al.* divide the regions into zones [68] [5] [122].

Based on the above, following observations can be drawn as directions for our design:

- **Approaches addressing network fragmentation:** It is found out that only a small number of approaches address network fragmentation after happening in VANET and most approaches consider this issue in the design phase; which means no solving methods are provided after the occurrence of network fragmentation. However, VANET suffers from frequent network fragmentation due to high mobility and dynamic nature of VANET
- **Time stable geocasting:** A geocasted message should remain in the network for desired number of times, such that arriving vehicles could be informed about the network event. Only few approaches have addressed this problem. More approaches are required in this direction
- **Multiple region geocasting:** There is only a small number of approaches that allow geocasting to multiple regions. Normally, an event in VANET is required to be disseminated to multiple regions. Hence, future work should also be pursued in this direction.
- **Aggregation:** Most of the geocasting approaches only focus on transmission of a message to a specific region and not on the aggregation of information. The aggregation of this message as the message moves away from the source is required to reduce network overhead. Future work in this direction is also required.

Table 3.1: The summary of various surveys and comparative studies

Author/s	Criteria	Protocols	Conclusion	Type
Maihofer <i>et al.</i> [95]	Forwarding Technique and Structure of the Network	Flooding, LBM, Voronori, Mesh, GeoGrid, URAD, GeoN- ode, GeoTora	No protocol provides guaranteed delivery. Protocols have sig- nificantly different abilities depending upon their strategy.	Quantitative and Qualita- tive
Ghafoor <i>et al.</i> [60]	Forwarding Technique and The suitability for city and highway	Simple flooding, LBM, GeoNode, Abiding Geocast	None of the proto- cols is operated in both city and highway. Geocast protocols are not suitable for city scenarios.	Qualitative
Rahbar [113]	Resources, strategies, delay tolerant, bea- coning, system model, performance metrics, simulation scenario	LBM, Flooding, IVG, Cached geocast, TORA	Few number of proto- cols are able to keep the message alive in the geocast region for the specefied time.	Qualitative
Allal <i>et al.</i> [4]	Strategies for bea- coning, forwarding, route maintenance, overhead, and other constraints	Inter-vehicle geocast, cached geocast, abid- ing geocast, DRG, ROVER, DGCastoR, Mo- bicast DTSG, Constrained Geocast, Geo- cache	Zone of relevance in most of the schemes are circular. If ZOR can be decided based on location, traffic rules, and other fac- tors, overhead can be reduced.	Qualitative

Table 3.2: Qualitative Comparison between Geocast Protocols -1

Protocol	Geocast Area Determination	Opposite Lane	Time Stable	Dynamic	Avoid Fragmentation	Forwarding Technique	Beconing
Geomatic Approaches: 1- [68], 2- [4] and 3- [81]							
1	✗	✗	✗	✗	✗	Nearest	✗
2	Other	✗	✗	✗	✗	Nearest	✗
3	circles	✗	✗	✗	✗	Greedy and Flooding	✗
Trajectory Based Approaches: 1- [70] and 2- [35]							
1	✗	✓	✗	✗	✗	Coverage Graphs	✗
2	✗	✗	✗	✓	✗	Distance and Probability	✗
Path-Sharing: 1- [141]							
1	Concept of Buoys	✗	✓	✗	✗	Zones	✗
Beacon Based Approaches: 1- [43], 2- [69], 3- [140] and 4- [123]							
1	✗	✗	✗	✓	✗	Local View	✓
2	✗	✗	✗	✓	✗	Probabilistic	✗
3	Relevancy Function	✓	✗	✗	✗	Timer	✓
4	✗	✗	✗	✗	✗	Hops and store-forward	✓
Time Stable Approaches: 1- [114] and 2- [75]							
1	Mostly Fixed	✓	✓	✓	✗	Timer	✗
2	Mostly Fixed	✗	✗	✓	✗	Timer	✓
Abiding Approaches: 1- [139] and 2- [84]							
1	Mostly Fixed	✓	✓	✓	✓	Opposit Lane	✗
2	✗	✗	✗	✓	✓	Timer	✓

Table 3.3: Qualitative Comparison between Geocast Protocols -2

Protocol	Infrastructure Support	Applications (saftey or Commercial)	Optimization Parameters	Number of Regions
Geomatic Approaches: 1- [68], 2- [4] and 3- [81]				
1	✗	both	Throughput	Single
2	✗	both	Overhead	Multi
3	✗	both	Delivery to Multiple	Multi
Trajectory Based Approaches: 1- [70] and 2- [35]				
1	✗	both	Delivery Ratio and Delay	Single
2	✗	both	Delivery Ratio and Delay	Single
Path-Sharing: 1- [141]				
1	✗	both	Overhead	Multi
Beacon Based Approaches: 1- [43], 2- [69], 3- [140] and 4- [123]				
1	✗	both	Visibility of Information	Single
2	✗	both	Delivery Ratio	Single
3	✗	both	Delivery Ratio and Overhead	Single
4	✗	both	Delivery Ratio, Overhead, and Delay	Single
Time Stable Approaches: 1- [114] and 2- [75]				
1	✗	both	Delivery Ratio and Overhead	Single
2	✗	both	Delivery Ratio and Overhead	Single
Abiding Approaches: 1- [139] and 2- [84]				
1	✗	Safety	Overhead	Single
2	✓	Commercial	Delivery Ratio	Single

3.4 Summary

This chapter starts with a discussion on information dissemination in VANET, various issues, and approaches. A survey on various geocasting protocols is provided. The major contribution of this chapter is providing a comprehensive comparison and classification of existing geocasting protocol over VANET in order to draw directions for designing a potential protocol.

Chapter 4

Semantic and Self-Decision Geocast Protocol for Data Dissemination over VANET (SAS-GP)

When disseminating a message using a geocast technique, three different aspects should be considered: determining the geocast area, the way of delivering the message to the geocast region, and disseminating the message within the geocast region. In this chapter, we present a geocast routing protocol for reliable and effective dissemination of safety and non-safety information between the intended vehicles. The protocol utilizes the available resources in the medium, the traffic information system, and the digital map. It principally employs timer-based techniques in order to avoid overhead and achieve high delivery ratio and low delay; nonetheless, novel factors are enhanced to calculate the timer's values. The proposed protocol is named Semantic and Self-Decision Geocast Protocol for Data Dissemination over VANET (SAS-GP).

4.1 Determining the Geocast Area

In determining the geocast area, most approaches define the geocast area as a rectangle whereas in some other approaches it is defined as a circle or a polygon [69] [96] [139] [84] [128]. In some other approaches such as Rahbar *et al.* and Kheawchaoom *et al.*, the geocast area is defined as an area of few meters around the point of incidence (accident, congestion, or bad road condition) [128] [75]. While in other works, the geocast area is determined based on relevancy function such as in the proposal of Zarza *et al.* [140]. In Singh *et al.*, the geocasting areas is a particular road segment called zone [122]. Yu *et al.* have used the

notion of effect area, a region in which a message remains active, and determines it as a fixed length [139]. In Allal *et al.*, the geocast area determination is delegated to a third party, that based on event and other information, determines the zone of relevance and its shape [5]. In Zhang *et al.*, the concepts of buoys have been used to determine the geocast area [142]. Jochle *et al.* compare these methods of determining the geocast area and conclude that circular geocast area performed better in most of the scenarios they used; in this study we locally define a semantic geocast area on the receiver side to optimally overcome the overhead that polygon approaches cause when encoding points (latitude and longitude) [71].

4.1.1 The Algorithm for Determining Semantic Geocast Domain

Although Jochle *et al.* conclude that circular geocast area performed better in most of the scenarios they used, we locally define a semantic geocast area on the receiver side to optimally overcome the overhead that polygon approaches cause when encoding points (latitude and longitude) [71]. The term “Semantic Geocast” is not new and has been introduced in the literature in many different ways [92]. Here, we signify the Semantic Geocast Domain (SGD) by the possibility of being affected by the event and define the geocast area by all the possible paths that can lead to the event location during the lifetime of the event, which is a new way in defining the geocast area. Consequently, the geocast area is not defined and sent along with the disseminated data as a geometric shape in SAS-GP. Similar to every timer-based approach, a source vehicle upon encountering an accident prepares a warning message (w_m) and broadcasts this message on the network. The source vehicle is the one that has faced the accident and is the initiator of the warning message w_m . It is also possible to initiate w_m by vehicles with authority for all possible applications. Table 4.1 shows the content of w_m and these contents do not exceed the standard size of a packet that is supposed to be sent in a single transmission. Moreover, it allows more data to be attached to the packet if needed by the application.

Table 4.1: Warning message contents

Message ID	Event Location	Lifetime of the Event
Event Time	Sender Location	Lifetime of Spread & Assurance Phases
Update Sequence	Free Space	

As seen in Table 4.1, the initiator vehicle needs to run ASG before starting to broadcast as well in order to attach the lifetime of the spread and assurance phases to w_m using 4.1. The lifetime of the spread and assurance phases is based on the longest path L_p in meters that a vehicle can travel during the event time in the semantic area without considering the traffic information and divided by doubled value of the transmission range R as

$$T_s = T_a = \frac{L_p}{2 \times R} \quad (4.1)$$

As seen in 4.1, the distance is not divided by the speed of light in order to reflect the associated delays in the both the sender and the receiver. Algorithm 1 shows the detailed Algorithm for determining the Semantic Geocast Area (ASG). ASG takes the location of the event (E_{loc}) and the desired amount of time to settle the event, which is the Lifetime of the Event (T_{ev}), as inputs and attach them to w_m . From the digital map, the algorithm obtains all possible paths that lead to E_{loc} during T_{ev} considering the current traffic information. Thus, the algorithm determines how far w_m should go, which is principally the semantic geocast domain. The outputs of the algorithm are all possible paths formed in points for each start point that leads up to E_{loc} and these paths are locally stored. Hence, the complexity of ASG is $O(n)$ whereas n is the number of intersections and exits in SGD. Each vehicle periodically repeats running the semantic algorithm with the most updated traffic information and the remaining T_{ev} . Consequently, much semantic geocast area determination is achieved. SGD is a monotonic function to the traffic information. Thus, the semantic geocast area is mostly decreased if there is no change in the traffic information since T_{ev} is always decreasing but this repetition of applying ASG is stopped when the longest path in each border of SGD is equal to the double of the transmission range ($2R$). This is due to the fact that choosing a smaller area has very little impact on reducing the overhead of the network since many vehicles outside the geocast area would receive w_m if the longest path was less than $2R$. There are two sub-functions that are run after computing these end points: (1) maximum number of vehicles (N) that can be inside SGD, and (2) the longest path (L_p) in SGD (Algorithm 1). These functions are performed in order to prepare information that is needed in determining the lifetime of the three phases and some other parameters that are used to calculate the wait time (WT), which each vehicle waits before rebroadcasting w_m .

4.2 Data Dissemination Scheme in (SAS-GP)

Any vehicle receiving w_m becomes a potential candidate for further dissemination of this message to other vehicles. However, only one vehicle from the set of received vehicles within

Algorithm 1 Semantic geocast area determination

```
1: Require by all except the Initiator: Receive  $w_m$ ;
2: Take the opposite direction of the event location  $E_{loc}$ ;
3: for all same direction paths do
4:   set  $EP_i = E_{loc}$ ; //  $P_s$ 
5: end for
6: for all opposite direction paths do
7:   set  $SP_0 = E_{loc}$ ; //  $P_{opp}$ 
8: end for
9: while  $T_i \leq T_{ev}$  do
10:    $T_i = \frac{d_i}{S_{i-traffic}}$ ; // ( $S_{i-traffic}$  Max speed associated with the traffic level in edge i ( $E_i$ )
11:   if ( $E_i$  is not visited in  $P_s$  and  $P_{opp}$ ) then
12:     if (Direction of  $E_i$  to  $P_s \neq NULL$ ) then
13:       Add  $E_i[d_i, T_i, SP_i, EP_i]$  To  $P_s$ ; //  $SP_i$ : Start point of  $E_i$  and  $EP_i$ : End
        point of  $E_i$ 
14:     else(Direction of  $E_i$  from  $P_s \neq NULL$ )
15:       Add  $E_i[d_i, T_i, SP_i, EP_i]$  To  $P_{opp}$ ;
16:     end if
17:   end if
18:    $T_{i+1} = T_i + T_{i-1}$ ;
19:   if ( $E_i$  is connected to an Edge) then
20:     go back to the beginning of while;
21:   end if
22: end while

23: function LONGESTPATH( $P_s$ )
    //First sub function
24:    $L_{sp} = P_s-0$ ;
25:   while  $P_{sj} \neq NULL$  do
26:     while  $E_i \neq NULL$  do
27:        $L_{sj} = (d_j) + L_{sp}$ ;
28:        $j++$ ;
29:     end while
30:     if ( $L_{sj} \leq L_{s(i-1)}$ ) then
31:        $L_{sp} = L_{si}$ ;
32:     end if
33:      $i++$ ;
34:   end while
35:   return  $L_{sp}$ 
36: end function

37: function MAXNUMOFVEH( $P_s$ )
    //Second sub function
38:   while  $P_{sj} \neq NULL$  do
39:      $N_i = (P_{sj} \rightarrow SUM(d_s) \times \text{width of } E_i$ ;
        // width of  $E_i$  is the size of a vehicle in the
        road
40:      $N = N_i + N$ 
41:   end while
42:   return  $N$ ;
43: end function
```

R is selected as a relay vehicle. The philosophy is that the vehicle at the boundary of the transmission range is the natural candidate for relaying the message. As a result, vehicles at this boundary should have a shorter waiting time and start broadcasting earlier. Rest of the vehicles will cancel and reset their timer when the same message is received from another vehicle. When a vehicle receives w_m for the first time, it runs ASG for the purpose of determining SGD, L_p , and N. Then, based on the current time, it sets a Waiting Time (WT) for its next retransmitting. Moreover, each vehicle repeatedly runs ASG whenever it receives or before it sends w_m . WT is the time period that every vehicle should wait before it undertakes its role as the broadcaster vehicle. The value of WT is in inverse ratio to the distance between the sender and the receiver. Any vehicle receiving the message is a potential candidate for further dissemination of this message to other vehicles. However, only one vehicle from the set of received vehicles within the transmission range is selected as the relay vehicle. The vehicle at the boundary of the transmission range is the natural candidate for relaying of the message. Therefore, vehicles at the boundary of the senders' transmission range should have a shorter WT and start broadcasting earlier. Rest of the nodes will cancel its timer when the same message is received from another vehicle. SAS-GP has three phases: Spread, Preserve, and Assurance. Every receiver calculates and sets a waiting time (WT) using the equation for WT of its phase. Upon expiration of this timer without receiving the same w_m , the vehicle takes a place of relaying w_m . If a vehicle receives w_m while it is in the waiting state, it resets WT based on the location of the new sender, which has already taken the charge of relaying. Once a relay vehicle is selected, it keeps on resetting the waiting time, until another relay vehicle is denoted. In the latter case, any vehicle might start relaying w_m by having the smallest WT among the vehicles within its transmission range. The lifetime of the event (T_{ev}) is divided into three slots assigned for each phase. The first and the last slots are reserved for the first and the last phases respectively while the second slot is for the second phase. The lifetime of Spread and Assurance phases are the same and its value is attached to w_m by the initiator. Based on the current time, each vehicle is able to determine in which phase of the three following phases it should comply.

4.2.1 Spread Phase

Spread phase occurs at the beginning of the protocol in order to deliver w_m up to the borders of the semantic geocast area. The lifetime of spread phase (T_s) and the lifetime of assurance (T_a) are the same and are calculated by the source vehicle and attached to w_m as mentioned earlier. If the time of receiving w_m is less than ($T_{ev} + T_s$), the vehicle that received w_m runs in the Spread phase and calculate its WT as

$$WT_{sp} = 2 \times \left[\left(\frac{m}{c_{min}} \right) + \left(\frac{R}{c} \right) \right] \times \frac{N}{d} \quad (4.2)$$

The wait time in spreading phase (WT_{sp}) for each vehicle is calculated based on the size of w_m (m) in bytes, the distance between the sender and receiver (d) in term of the length of the path; not by using the distance formula between two points, and the maximum number of vehicles that can be inside the semantic area (N). In case this N is unknown, it can be replaced with 1 and the equation still performs the same curve. Also, the minimum channel capacity (c_{min}) and the speed of light (c) are used in calculating WT_{sp} such that all of nodes in transmission range receive w_m . Equation (4.2) ensures that all vehicles within R receive w_m and then let the vehicle that is farthest from the source be the earliest to retransmit w_m .

4.2.1.1 Derivation of Equation 4.2

The philosophy of the waiting time (WT) concept in this phase is that vehicles wait for a period of time that is enough for the source vehicle to transmit w_m to all vehicles within its range. Then, the equation allows the vehicle at the edge of the transmission range to be the earliest optimal vehicle for rebroadcasting w_m . As a result, if we consider the relation between the sender's and receivers' distance, then WT can be basically calculated as

$$WT = \frac{1}{d} \quad (4.3)$$

On the sender side, waiting time can be calculated by the total of needed time for propagating and transmitting w_m . Thus,

$$WT = T_{pro} + T_{trans}. \quad (4.4)$$

The First factor in 4.4 can be calculated considering the size of w_m and the minimum channel capacity as

$$T_{pro.} = \frac{m}{c_{min}} \quad (4.5)$$

whereas the second factor can be calculated considering the location of the farthest node by being at the edge of the transmission range and the speed of light using

$$T_{trans.} = \frac{R}{c}. \quad (4.6)$$

By substituting the value from 4.5 and 4.7 into equation 4.4, the WT can be expressed as

$$WT = \frac{m}{c_{\min}} + \frac{R}{c}. \quad (4.7)$$

In order to reflect the distance between the sender and all the receivers, the value is multiplied by $1/R$ and also multiplied by 2 to reflect the delay on both sides (sender and receiver). Furthermore, the contention factor is set to N and this factor can be set to one in case the N is impossible to compute.

4.2.2 Preserve Phase

The objective of this phase is to maintain w_m and keep notifying all the vehicles that are entering SGD during the lifetime of the event. The lifetime of Preserve phase (T_p) is the time between the Spread phase and the Assurance phase and is calculated using the following equation

$$T_p = T_{ev} - (2 \times T_s) \quad (4.8)$$

If the time of receiving w_m is greater than $(T_{ev} + T_s)$, the vehicle that received w_m runs in the Preserve phase. In order to notify all the vehicles newly entering the geocast region, most approaches state that a vehicle should not wait for a long time that permits another vehicle to enter and leave its transmission range without rebroadcasting w_m . This is assumed to be achieved by using 4.9. In 4.9, the expected receiver is presumed to have the maximum allowed speed ($S_{\max}$), which is the worst case, while (S_{self}) represents the current speed of the receiver.

$$WT = \frac{2 \times R}{(S_{\max} + S_{\text{self}})} \quad (4.9)$$

However, this equation does not take into account the propagation and the transmission delays that are very small but should be considered in case the expected receiver is moving at the maximum speed or when sending a large amount of data. Therefore, the message delivery time (T_{del}) is proposed in SAS-GP only based on the size of the warning message (m) and then is normalized using the maximum allowed speed. This means that all vehicles will calculate the same T_{del} regardless of the distance between the sender and the receiver. Thus, T_{del} will not affect the farthest vehicle of having the smallest waiting time.

$$T_{\text{del}} = \frac{\ln\left(\frac{m \times c}{c_{\min}}\right)}{S_{\max}} \quad (4.10)$$

We use the natural logarithm in order to increase the waiting time when the number of bytes is increasing and in Appendix A we proved that this equation is true even in sending one byte. Although, this increase is a slight increase but it is correspondent with the time needed to deliver the message. In addition, we chose to normalize the value by the maximum speed in lieu of the speed of light that the message is travelling at in order to show the effect of the increase number of bytes; in this way also the noise is considered.

So, the waiting time for each vehicle receiving w_m in Preserve phase (WT_p) is calculated using

$$WT_p = \frac{(R + d)}{(S_{max} + S_{self})} - T_{del} \quad (4.11)$$

4.2.3 Assurance Phase

Assurance phase arises at the end of the protocol in order to guarantee delivering w_m to all the vehicles inside SGD. The lifetime of this phase is equal to the lifetime of the first phase (T_s). It also computes the waiting time using 4.2 the same way as in the Spread phase (WT_{sp}). This phase addresses the case when the relay vehicle that is expected to be the earliest in sending w_m is in a waiting state and will not be able to send before the expiration of the event's lifetime and also aims at assuring the delivery of w_m to all the vehicles in SGD in very short period of time.

4.3 Characteristics of SAS-GP

SAS-GP has four main characteristics: Context-Aware, Time Stable, Self-Decision, and Dynamic at the same time.

4.3.1 Context-Awareness

The Semantic Geocast Area Determination algorithm allows SAS-GP to be sensible to the map and the real-time traffic situation. The network overhead is accordingly controlled taking into consideration these two pieces of information when setting up the value of waiting time. SAS-GP is also aware of how bad the event is and this is perceived and reflected by the value of the event lifetime. Furthermore, SAS-GP is adaptable to the changes in the environment and the event situation during its running. In short, SAS-GP is aware of all available information like location, traffic, identity, activity and time.

4.3.2 Time-Stable

SAS-GP is a time-stable protocol during the lifetime of the event. This means, that w_m will remain alive in the network and all vehicles within the geocast area will receive w_m during this lifetime. The three phases and the other three characteristics of SAS-GP allow w_m to remain alive during the lifetime of the event. In case the lifetime of the event should be increased or decreased, only two fields will be updated: *Lifetime of the Event* and *Update Sequence*.

4.3.3 Self-Decision

In the three phases, each vehicle checks its location when receiving w_m and setting a WT. If the vehicle is estimated to be outside SGD after waiting for WT and no one has sent w_m , it only waits for an estimated time to be in a distance of R from the border of geocast region, $R/2$, $R/3$, or $R/4$ etc., which is respectively applicable. On the other hand, when a vehicle outside SGD receives w_m , it has to run the ASG and then be able to determine if it falls inside SGD or not. If not, then it sets a timer for an estimated value of being inside SGD when applicable. Upon the expiration of this timer, it checks again if it is inside SGD or not. If yes, then it acts as a receiver who received w_m from a vehicle that is away from the sender by R . For vehicles that are leaving the SGD, they keep relying the w_m for a distance of R outside SGD if they do not receive w_m from any other node while being inside SGD for a distance of $2R$ from any border of SGD. This will help in keeping w_m alive in low-density cases during T_{ev} . In addition, SAS-GP has the ability of updating the contents of w_m with a minimum cost. A vehicle that has an authority will increase the update sequence number by one and attach the updated data to w_m . Thus, SAS-GP is going to run in the spread phase and each vehicle that receives w_m will understand that the message with the greatest updating sequence number is the most updated version of w_m .

4.3.4 Dynamic

SAS-GP is dynamically adapted and suitable to be operated both in town and on highway. ASG is capable of determining SGD in both scenarios. Furthermore, each vehicle dynamically sets up the value of WT for each phase. In term of updating w_m , SAS-GP has the ability of updating the content of w_m dynamically with a minimum cost. A vehicle that has an authority will increase the update sequence number by one and attach the updated data to w_m . Thus, SAS-GP is going to run in the spread phase and each vehicle

that receives w_m will recognize that the message that has the greatest updating sequence number is the most updated version of w_m .

4.4 Qualitative Comparison between SAS-GP and Existing Geocast Protocols

Table 4.2 and Table 4.3 show a qualitative comparison between SAS-GP and all the geocast protocols that have been discussed in Chapter 3 and summarized in Table 3.2 and Table 3.3. 12 attributes are chosen to compare all the protocols and as shown SAS-GP is treated as a separated technique because it mixes between the categorization parameters. SAS-GP does not use any beaconing or infrastructure and it utilizes vehicles on the opposite lane. It is also time-stable and dynamically updatable. The value of timers are set dynamically too. The only attribute that SAS-GP does not meet is to geocast in multiple regions. This is because we do not see this applicable in the applications we target but there is a possibility of extending SAS-GP to provide such service as it will be discussed in the last chapter 6. In the next chapter 5, the quantities metrics will be analyzed.

Table 4.2: Qualitative Comparison between Geocast Protocols -1

Protocol	Geocast Area Determination	Opposite Lane	Time Stable	Dynamic	Avoid Fragmentation	Forwarding Technique	Beconing
SAS-GP	Dynamic	✓	✓	✓	✓	Dynamci Timers	✗
Geomatric Approaches: 1- [68], 2- [4] and 3- [81]							
1	✗	✗	✗	✗	✗	Nearest	✗
2	Other	✗	✗	✗	✗	Nearest	✗
3	circles	✗	✗	✗	✗	Greedy and Flooding	✗
Trajectory Based Approaches: 1- [70] and 2- [35]							
1	✗	✓	✗	✗	✗	Coverage Graphs	✗
2	✗	✗	✗	✓	✗	Distance and Probability	✗
Path-Sharing: 1- [141]							
1	Concept of Buoys	✗	✓	✗	✗	Zones	✗
Beacon Based Approaches: 1- [43], 2- [69], 3- [140] and 4- [123]							
1	✗	✗	✗	✓	✗	Local View	✓
2	✗	✗	✗	✓	✗	Probabilistic	✗
3	Relevancy Function	✓	✗	✗	✗	Timer	✓
4	✗	✗	✗	✗	✗	Hops and store-forward	✓
Time Stable Approaches: 1- [114] and 2- [75]							
1	Mostly Fixed	✓	✓	✓	✗	Timer	✗
2	Mostly Fixed	✗	✗	✓	✗	Timer	✓
Abiding Approaches: 1- [139] and 2- [84]							
1	Mostly Fixed	✓	✓	✓	✓	Opposit Lane	✗
2	✗	✗	✗	✓	✓	Timer	✓

Table 4.3: Qualitative Comparison between Geocast Protocols -2

Protocol	Infrastructure Support	Applications (saftey or Commercial)	Optimization Parameters	Number of Regions
SAS-GP	✗	both	Delivery Ratio, Overhead, and Geocast Delay and Distance	Single
Geometric Approaches: 1- [68], 2- [4] and 3- [81]				
1	✗	both	Throughput	Single
2	✗	both	Overhead	Multi
3	✗	both	Delivery to Multiple	Multi
Trajectory Based Approaches: 1- [70] and 2- [35]				
1	✗	both	Delivery Ratio and Delay	Single
2	✗	both	Delivery Ratio and Delay	Single
Path-Sharing: 1- [141]				
1	✗	both	Overhead	Multi
Beacon Based Approaches: 1- [43], 2- [69], 3- [140] and 4- [123]				
1	✗	both	Visibility of Information	Single
2	✗	both	Delivery Ratio	Single
3	✗	both	Delivery Ratio and Overhead	Single
4	✗	both	Delivery Ratio, Overhead, and Delay	Single
Time Stable Approaches: 1- [114] and 2- [75]				
1	✗	both	Delivery Ratio and Overhead	Single
2	✗	both	Delivery Ratio and Overhead	Single
Abiding Approaches: 1- [139] and 2- [84]				
1	✗	Safety	Overhead	Single
2	✓	Commercial	Delivery Ratio	Single

4.5 Summary

In this chapter, a semantic and self-decision geocast routing protocol for disseminating safety and non-safety information over VANET (SAS-GP) is presented. It explains three approaches that we used: the algorithm of determining the geocast area, data dissemination and the characteristics of the protocol. SAS-GP disseminates the information in three phases: Spread, Preserve, and Assurance, and the three phases utilize the traffic information system and the digital map. Novel factors are enhanced to calculate the timer's values in each phase.

Chapter 5

Simulation and Results

The proposed protocol is implemented in the Network Simulator (NS-2.35) [55]. We used a mobility generator in order to evaluate SAS-GP in high scale scenarios. Furthermore, we used Simulator of Urban Mobility (SUMO 0.19.0) in order to evaluate SAS-GP in realistic scenarios [77]. In safety application, it is very important to achieve the minimum possible delay and the highest possible delivery ratio.

5.1 Simulation Setup

SAS-GP has been implemented in a discrete event wireless network simulator NS-2.35 [99]. Additionally, a mobility model generator and SUMO 0.19.0 are used to evaluate the protocol in high scale and realistic mobility scenarios respectively 5.1 [77]. 32 highway scenarios are generated using the mobility generator and 24 urban scenarios are generated using SUMO, achieving 95% confidence interval (Table 5.1).

Table 5.1: Minimum and maximum values that achieve 95% confidence interval

Metrics	SAS-GP		DTSG		Abiding	
	Min	Max	Min	Max	Min	Max
Geocast Delay	0.4309	1.3719	0.73134	2.1814	2.6795	6.5825
Transmission Delay	0.000973	0.00105	0.001001	0.00106	0.001095	0.00112

A realistic map for Ottawa city is obtained and plugged to SUMO from OpenStreetMap [62]. Those 52 scenarios have different levels of density. Table 5.1 shows various parameters of

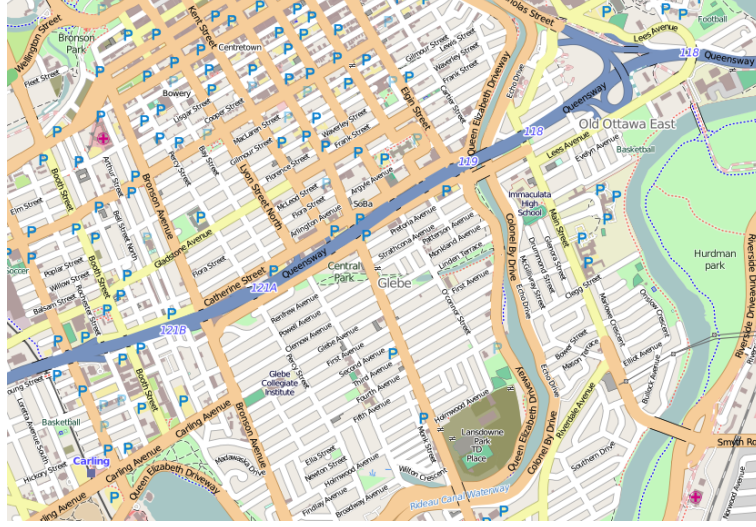


Figure 5.1: Realistic highway scenario (Queensway, Ottawa, Canada) [77]

simulation. The first 10 minutes of the simulation is used to set up the traffic information and allow all vehicles to obtain the digital map. At the 600th second, the source runs the semantic algorithm and then broadcasts w_m . Then, the source sets the lifetime of the event to 10 minutes. This time can be decreased or increased in different cities based on the average police response time that police takes to reach the event. It also can be different in different places of the cities according to the response time. In addition, the lifetime of the event in commercial applications can be set to reflect the duration that the advertisements should remain on. For simplicity, we assume that the area for each vehicle is 25 m^2 when calculating N .

5.2 Simulation Results

Each plotted point in the mobility generators figures represents the mean of 32 scenarios (Figure 5.2, Figure 5.4, Figure 5.6, Figure 5.8, and Figure 5.10) while it represents the mean of 24 scenarios in SUMO scenarios (Figure 5.3, Figure 5.5, Figure 5.7, Figure 5.9, and Figure 5.11). The packet size (m) in SAS-GP is less compared to DTSG and Abiding; as seeing in Figure 5.10 and Figure 5.11, SAS-GP requires sending less number of packets than DTSG and accomplishing higher delivery ratios in all scenarios. Naturally, a larger amount of data can be attached to the packet if it is required by the application that uses SAS-GP like applications for video advertisements. Although Abiding sends less number of

Table 5.2: Simulation parameters

Parameter	Mobility Model	
	Mobility Generator	SUMO
Simulation Time	1200 seconds	
MAC layer	802.11 standard	
Transmission Range	250 meters	
Enivornemt Area	12000 * 30 m^2	2600 * 3000 m^2
Density	25 ~ 600 (vehicle/km)	50 ~ 300 (vehicle/km)
Total Number of Vehicles	300 ~ 2000	400 ~ 1000
Max Speed	45 meter/second	25 meter/second

packets and accordingly has less number of false warnings than SAS-GP, the delivery ratio and the speed of notification it reaches is not acceptable in safety applications. Moreover, SAS-GP reached the highest delivery ratio just in a few seconds and exactly at the end of the spread phase while it takes a few minutes for both other protocols to reach their highest delivery ratio. The geocast delay and distance are smaller by 50% than the other two protocols in the worst cases. In SUMO scenarios, DTSG and Abiding did not have a high delivery ratio compared to their performance in mobility scenarios because both protocols only take into consideration vehicles entering the geocast area from two points (Figure 1.1). Abiding also failed to maintain w_m alive in low-density scenarios. By tracing those vehicles that did not receive w_m in SAS-GP, it turned out that these vehicles did not pass by any vehicle that was already notified about w_m . DTSG performs the worst in terms of the number of false warnings and this is due to the nature of the protocol in blindly sending the warning message when entering the extra region that the protocol defines (Figure 1.1).

Five metrics are chosen to evaluate SAS-GP and to compare it with DTSG [114] and Abiding [139]. These metrics are: Geocast Delay, Geocast Distance, Packet Delivery Ratio, False Warnings Ratio, Average Number of Sent and Received Packets.

5.2.1 Geocast Delay

Geocast delay is the time between entering the geocast area and receiving the first w_m ; hence, it represents how fast vehicles are notified after entering SGD (Figure 5.2 and Figure 5.3). The End-To-End delay is not considered in the analysis of SAS-GP because it does not reflect in the context of these types of applications. In Abiding, the delay is high because the protocol focuses more on reducing the overhead by having a large amount of time between two sendings and limits the number of relays causing this high delay. On the other hand, DTSG provides a better delay than Abiding since all vehicles always send the warning message when they reach the extra region that is at the border of the geocast area. However, the value of the geocast delay is higher when using realistic scenarios as a result of only considering two entering points for the geocast region and not considering inter-connected roads and bridges (Figure 5.3). In SAS-GP, the value of

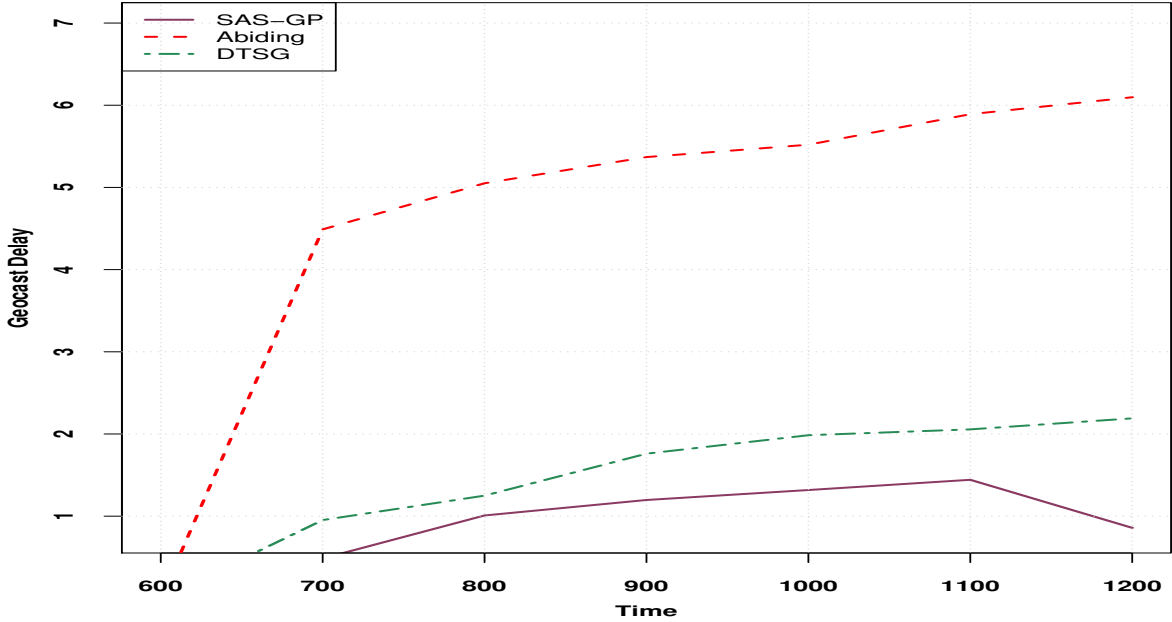


Figure 5.2: Average geocast delay vs time (Mobility Generator)

delay is performing the best and is the smallest during the Spread Phase as a result of calculating the waiting time in a concept that allows all vehicles within the 2R receive w_m and then let the vehicle that is farthest from the source be the earliest to retransmit w_m . In the Preserve Phase, we maintain the value of geocast delay to approximately two seconds as an average in SUMO scenarios by using appropriate waiting time that takes into consideration the delivery time and by using the self-decision technique. The geocast

delay is reduced again in the Assurance Phase following by utilizing the waiting time of the Spread Phase and the self-decision technique from the Preserve Phase.

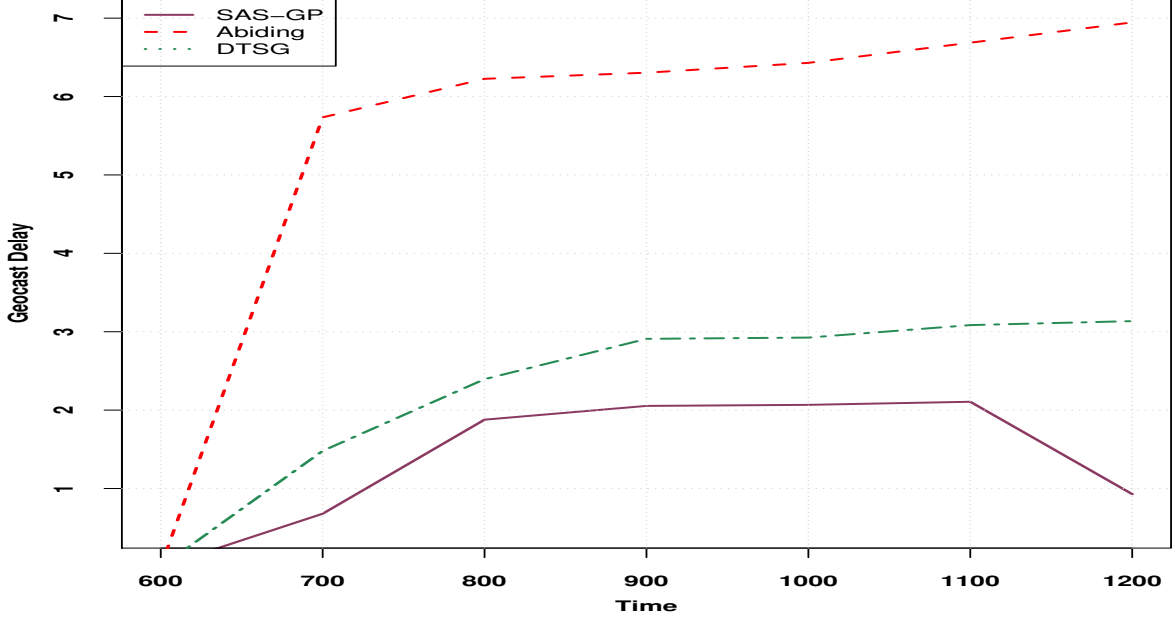


Figure 5.3: Average geocast delay vs time (SUMO scenarios)

5.2.2 Geocast Distance

Geocast Distance is the distance between the location of the first receiving of w_m and the location of the incident and it represents how fast in distance vehicles are notified after entering SGD (Figure 5.4 and Figure 5.5). In other words, it is the same as the first metric 5.2.1 but in terms of meters in lieu of seconds.

Abiding performs the worst in terms of the geocast distance, DTSG performs better than Abiding but in less efficiency in SUMO scenarios (Figure 5.5), and SAS-GP performs the best as seen in Figure 5.4 and Figure 5.5.

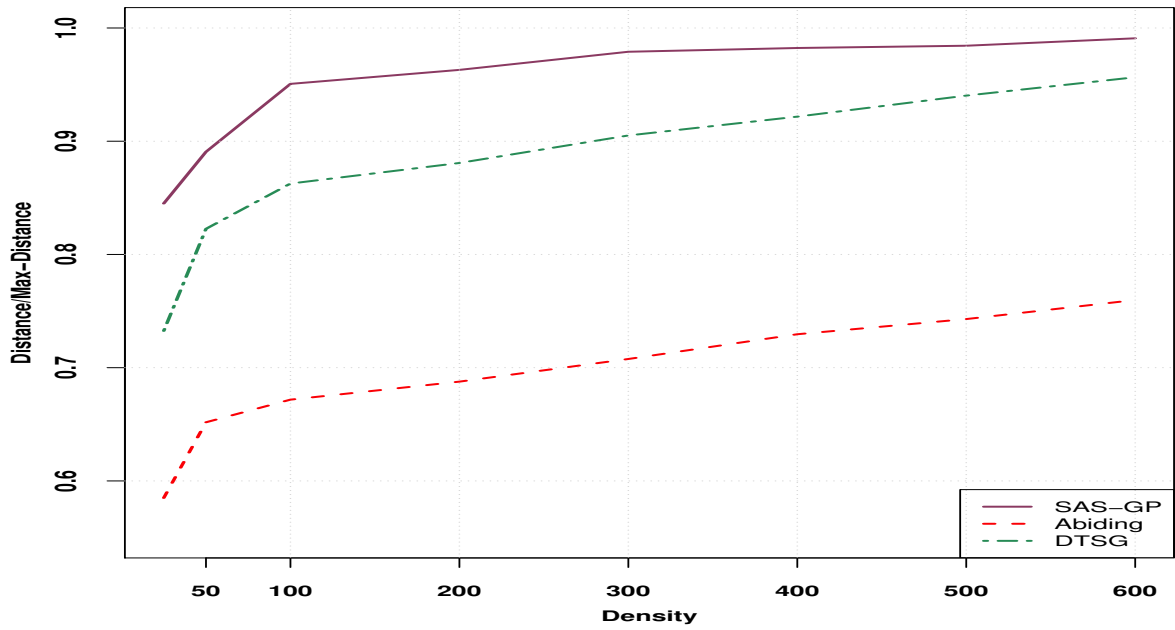


Figure 5.4: Average warning distance vs density (Mobility Generator)

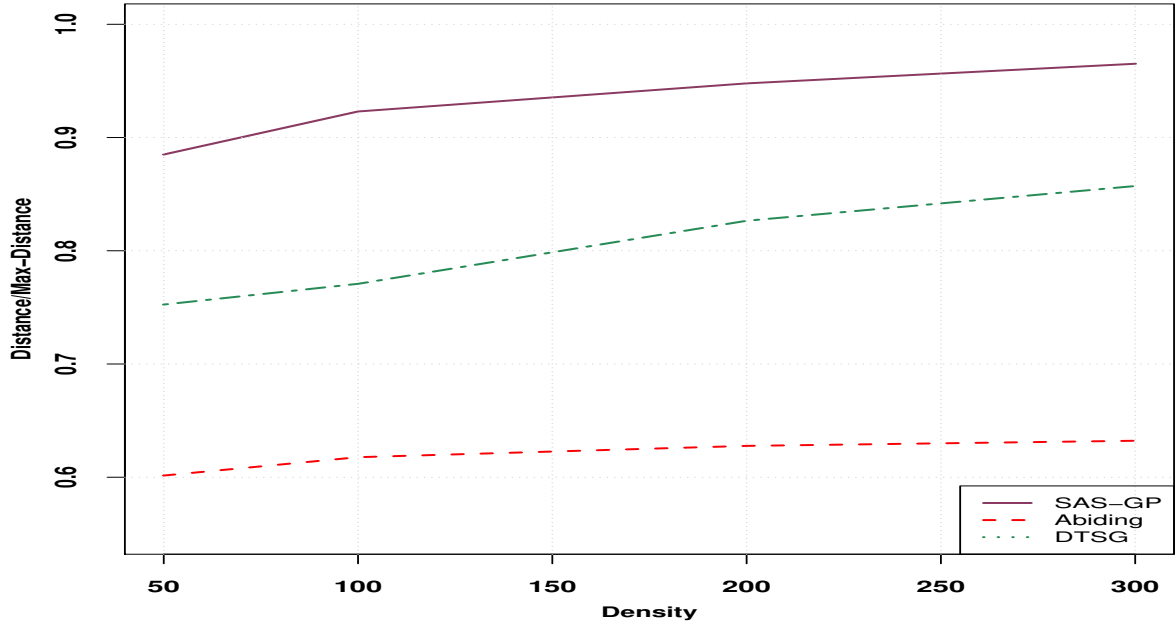


Figure 5.5: Average warning distance vs density (SUMO scenarios)

5.2.3 Packet Delivery Ratio

Packet Delivery Ratio is the number of vehicles received w_m to the total number of vehicles participated in the geocast domain. Figure 5.6 and Figure 5.7 show the delivery ratio with different levels of density. SAS-GP reached the highest delivery ratio just in a few seconds and exactly at the end of the Spread Phase while it takes a few minutes for both other protocols to reach their highest delivery ratio. In SUMO scenarios, DTSG and Abiding did not have a high delivery ratio compared to their performance in mobility scenarios because both protocols only take into consideration vehicles entering the geocast area from two points. Abiding also failed to maintain w_m alive in low-density scenarios. By tracing those vehicles that did not receive w_m in SAS-GP, it turned out that these vehicles did not pass by any vehicle that is already was notified about w_m .

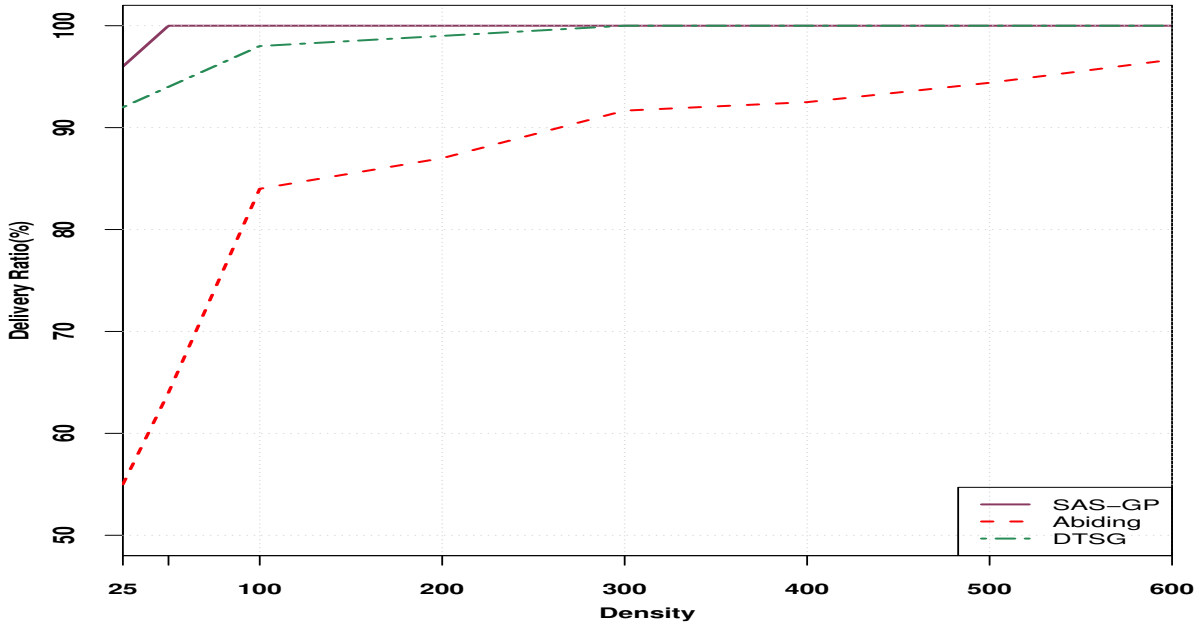


Figure 5.6: Average delivery ratio (%) vs density (Mobility Generator)

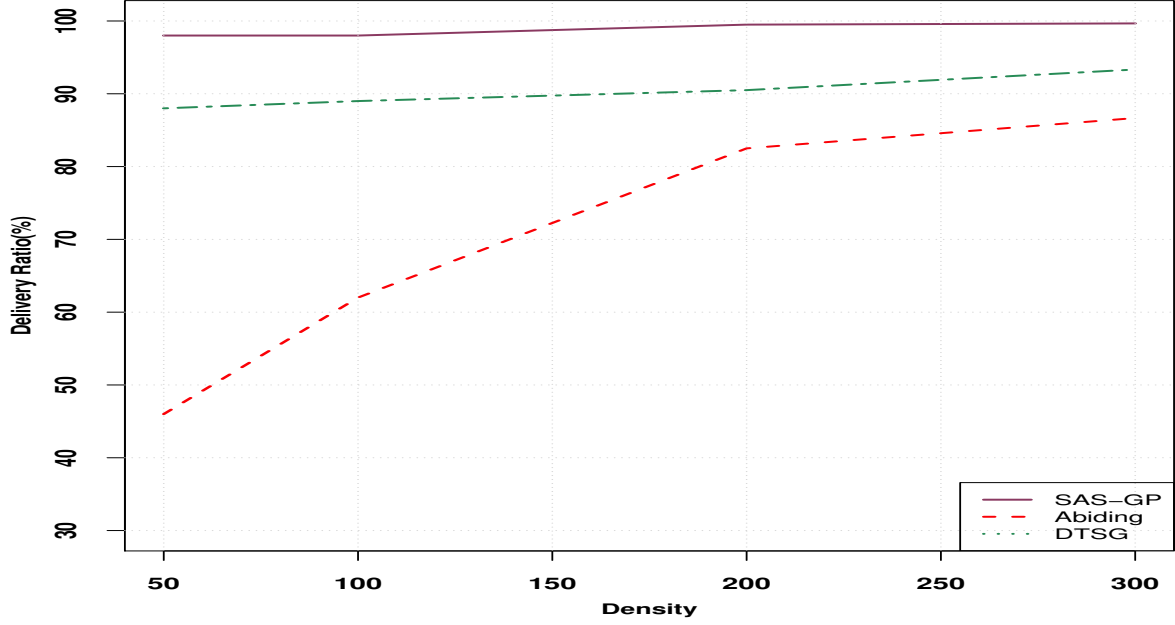


Figure 5.7: Average delivery ratio (%) vs density (SUMO scenarios)

5.2.4 False Warnings Ratio

False Warnings Ratio is the number of messages received by vehicles outside SGD over the total number of received packets. Figure 5.8 and Figure 5.9 show the False Warnings Ratio with different levels of density. When a vehicle receives w_m and the vehicle is outside the geocast domain, it means the resources of the vehicle and VANET are consumed. This shows the importance of well-defining and determining the geocast area. For example, DTSG performs the worst in terms of the number of false warnings and this is due to the nature of the protocol in blindly sending the warning message when entering the extra region that the protocol defines. In Figure 5.8 Abiding has the least number of false warning messages in highway scenarios but the delivery ratio and the speed of notification it achieves is not acceptable in safety applications. On the other hand, SAS-GP fulfils a balance in this issue and performs better in SUMO scenarios because such an issue has been taken into consideration when designing it and concurrently puts a higher priority for achieving the highest delivery ratio.

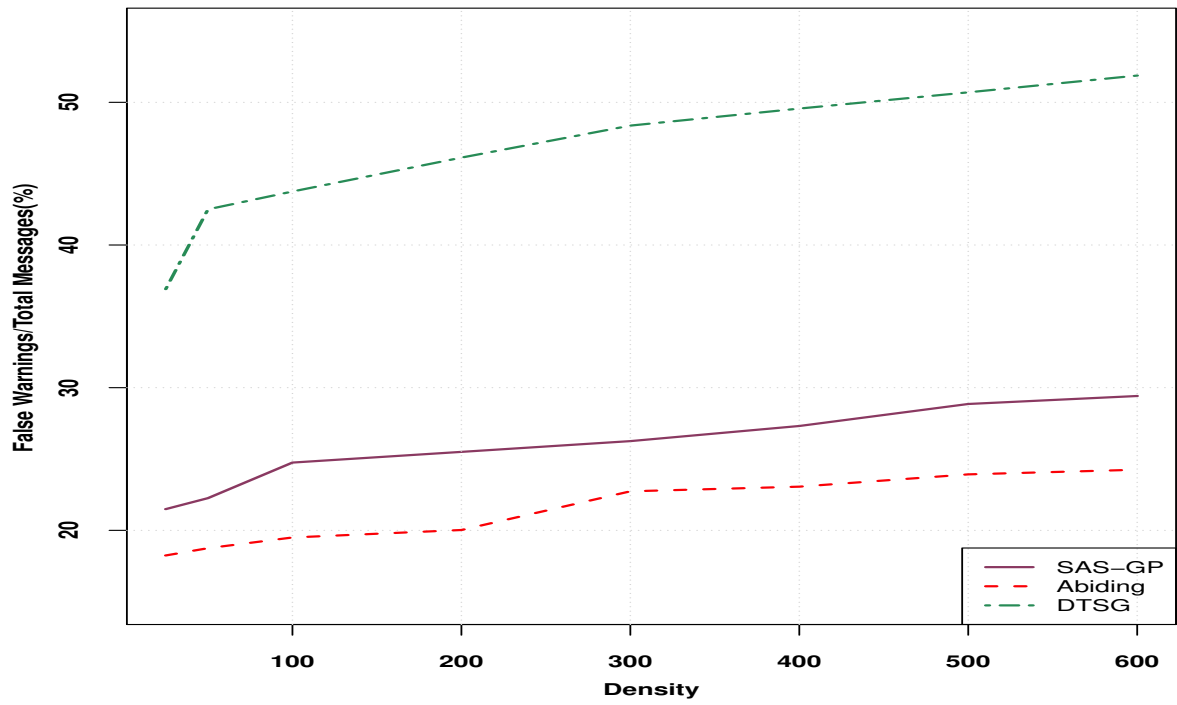


Figure 5.8: Average number of false warning vs density (Mobility Generator)

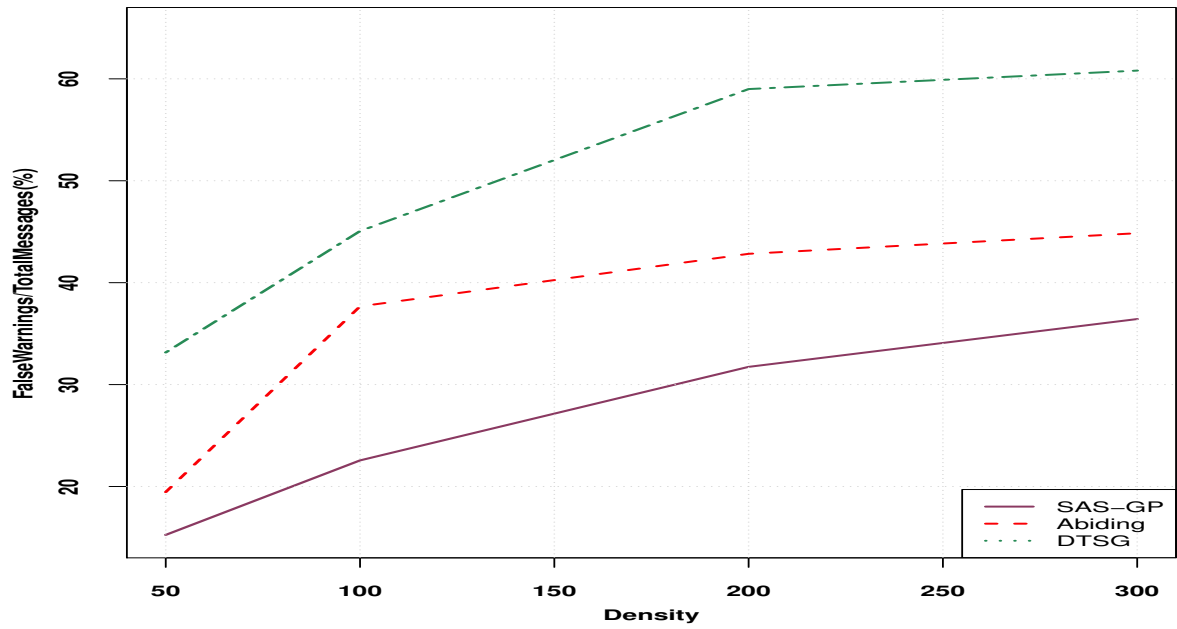


Figure 5.9: Average number of false warning vs density (SUMO scenarios)

5.2.5 Average Number of Sent and Received Packets

Figure 5.10 and Figure 5.11 show Average Number of Sent and Received Packets with Time. In Figure 5.10 and Figure 5.11, Abiding sends less number of packets and accordingly has less number of false warnings than SAS-GP but the delivery ratio and the speed of notification it reaches is not acceptable in safety applications. DTSG performs the worst in terms of the number of sent and received packets and this is due to the nature of the protocol in blindly sending the warning message when entering the extra region that the protocol defines. When all the related vehicles receive w_m by sending and receiving the minimum number of messages, it means the resources of vehicles and VANET are efficiently operated. Furthermore, accomplishing high delivery ratio and low delay is a mandatory objective in safety applications. The packet size (m) in SAS-GP is less compared to DTSG and Abiding. SAS-GP requires sending less number of packets than DTSG and accomplishing higher delivery ratios in all scenarios. Thus, a larger amount of data can be attached to the packet if it is required by the application that uses SAS-GP like applications for video advertisements. SAS-GP achieves these goals by effectively employing and balancing the resources.

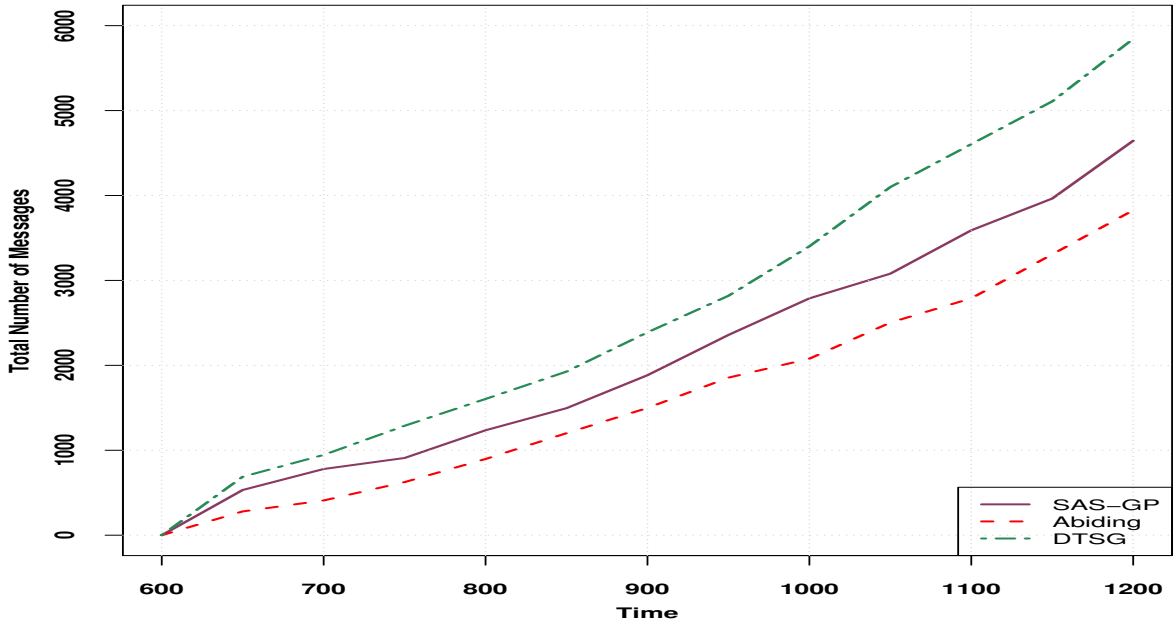


Figure 5.10: Average number of sent and received packets vs time (Mobility Generator)

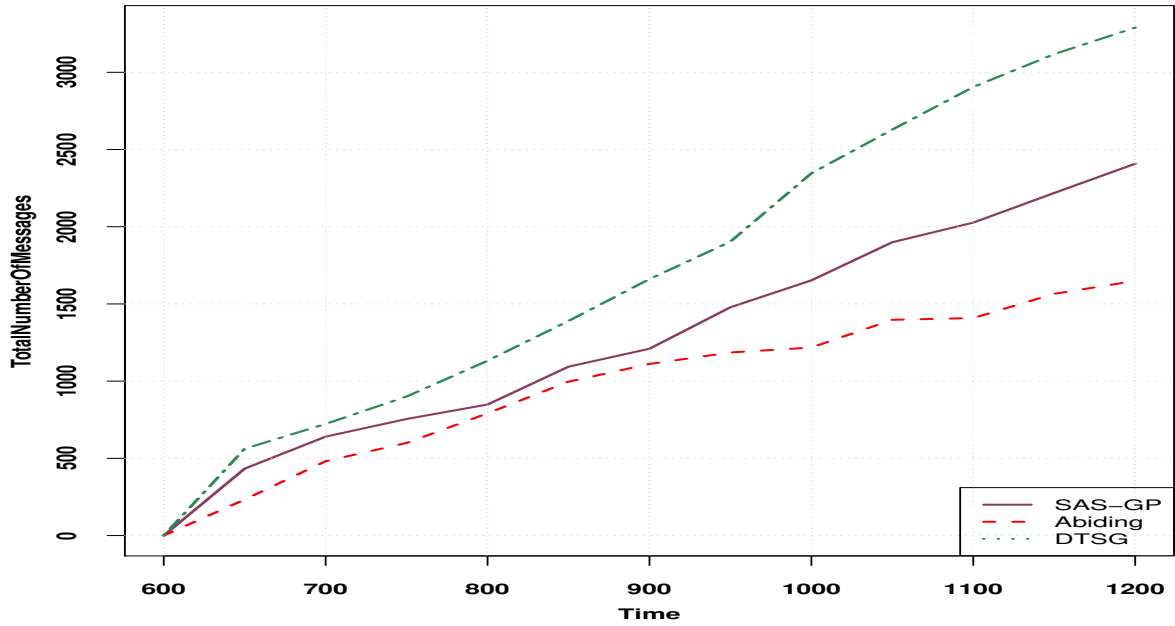


Figure 5.11: Average number of sent and received packets vs time (SUMO scenarios)

5.3 Summary

In this chapter, SAS-GP is tested in a high scale and realistic scenarios. Five metrics are chosen to evaluate the performance of SAS-GP: Geocast Delay, Geocast Distance, Packet Delivery Ratio, False Warnings Ratio, and Average Number of Sent and Received Packets. SAS-GP attains its goals in these five metrics by effectively employing and balancing the resources and performs better when compared with two existing protocols.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

Intelligent Transportation System (ITS) integrates various ICT technologies for solving transportation problems. Different standards have been proposed providing guidelines for implementation of ITS systems. It can be concluded that a good standard must specify logical and physical components of the system, underlying data flows, stakeholders, and different types of services provided by an ITS system. In addition, convergence and interoperability of these systems is also an open challenge. Different types of messages are exchanged to realize various ITS services. This thesis classifies them as alert, warnings, information, inquiry, and content. Among the different approaches, VANET is becoming the most viable alternative for realization of ITS system as it requires no prior infrastructure for their operation. However, VANET requires addressing different types of research issues. Some of these research issues such as physical and MAC layer protocols, routing, security, simulation, mobility models, and information dissemination are discussed. DSRC (or its variants) has been identified as the widely used standard for short range communication among vehicles. For medium access, random access protocols are suitable as they do not require any infrastructure for its operation. Different types of routing protocols are proposed in the literature. This thesis classifies them as unicasting, multicasting, position-based routing, broadcasting, and geocasting protocols. Each of them is useful for accomplishing various objectives. We conclude that geocasting is the preferred approach for dissemination of safety and non-safety information. Security in VANET is a very critical requirement, specifically for safety applications. There can be malicious, selfish, and prankster entities that can compromise the messages. This can lead to loss of lives, money, and time and can cause inconvenience. Different security solutions such as intrusion detection and digital signatures can be used for this purpose. In order for

real-time deployment of any VANET solution, it must be validated. For this purpose, test beds or simulation tools can be used. There are generalized network simulators such as NS-2, GlomoSim, and OMnet++ available. While, specific tools for VANET are also available. This includes Trans, NCTUuns, and GrooveNet. In addition, supporting tools for simulation such as VANETMobiSim and SUMO are also available. These tools can generate traces and traffic simulation, and can be integrated with other simulators. An issue relevant to simulation is generation of realistic mobility patterns. Mobility models are used for this purpose. A mobility model can generate independent mobility patterns for individual nodes or it can generate patterns for over all groups. Group mobility models are considered more suitable for VANET as the nodes on the roads are influenced by mobility of other nodes. An important issue of VANET is information dissemination. Disseminating information to relevant nodes in VANET, like the nodes that are informed about different events and current situation, requires taking care of several challenges. Some of these challenges are mobility, heterogeneity, scalability, message differentiation, frequent disconnection, and trust management. Different approaches to data dissemination have been discussed in the literature. Among them, we identify geocasting as one of the most prominent approaches. This is because information dissemination requires transmitting a message only in a specific region similar to geocasting. This leads to very low overhead and doesn't require route discovery and maintenance procedures. Various approaches to geocasting in the literature have been discussed. These approaches exploit various properties such as geometry of region, trajectories of nodes, path sharing, and local beaconing for geocasting. There are few approaches that provide dynamic time-stable geocasting such that a message remains in the region for the desired amount of time. In addition, Abiding Geocast, Zone-Based Forwarding, and Stored Geocasting are also presented and analyzed. A novel taxonomy of these approaches and their comparison have been provided in this thesis. Employing this qualitative comparison as a guideline for designing a reliable protocol, we observed a demand for an algorithm for determining the geocast area. Therefore, the semantic geocast algorithm is proposed. This algorithm overcomes all the drawbacks that were realized in the literature. The proposed approach disseminates the warning information effectively by consuming less amount of data in terms of the size of the packet and the overhead in the network. SAS-GP disseminates the information in three phases: Spread, Preserve, and Assurance, which utilize the traffic information system and the digital map information. SAS-GP principally employs timer-based techniques in order to avoid overhead and broadcast storm problems; nonetheless, novel factors are enhanced to calculate the timer's values in each phase. SAS-GP is a distinctive protocol by being time-stable, context-aware, self-decided, and dynamic at the same time. Quantity comparison shows that SAS-GP conquers existing protocols in all the parameters except that it is not sup-

porting geocast for multiple regions. Simulation results demonstrate effective and reliable dissemination in terms of delivery ratio and the number of false warnings compared to the existing protocols when evaluated in high scale and low realistic scenarios. Furthermore, SAS-GP performs faster in notifying vehicles resulting a higher geocast distance before approaching the location of the event.

6.2 Future Work

The proposed approach can be extended to dynamically increase the transmission range based on the traffic information. Moreover, congestion window information and current available resources in the channel can be taken into account in calculating WT in order to tolerate resources' balancing with other applications. Vehicles with no access or lost access to digital maps and traffic information can use the disseminated data in order to participate in SAS-GP. Moreover, disseminated data, especially in the first phase (spread phase), can be used to notify any police vehicle that is within the geocast area about the accident instead of using the traditional method of calling 911. In addition, the criticality of the accident can be added to (w_m) to assist the police to take more proper actions like calling for ambulance.

In geocast protocols, there are three aspects to consider: delivering (w_m) to the geocast area, determining the geocast area, and disseminating (w_m) within the geocast area. In this work, originating (w_m) from a source that is outside the geocast area and delivering (w_m) to the geocast area is not discussed and is a possible direction to improve SAS-GP. This can be done by declaring a new phase prior to the three phases that have been declared in SAS-GP whereas the source vehicle can receive acknowledgment from receivers inside the geocast area to confirm that (w_m) has been delivered. A key point in this direction is to investigate the WT for the Spread Phase in order to observe the performance of it in this aspect.

Another valuable area of research is vehicular clouds in which a set of vehicles establish a cloud between a set of vehicles on the road to provide different types of cloud services (storage, bandwidth, computing, and sensing) [52]. More work is required in addressing legal and privacy issues, standardization, and novel market penetration strategies. As far as future of ITS is concerned, an evolution of fully automated, adaptable, and integrated solutions addressing natural disaster and climate change is expected. In addition, the concept of VANET can be merged with CyberCars and CityMobile concepts to establish a new generation of such concepts [58] [41]. Novel applications such as office on wheels and P2P file sharing are now partially achieved and foreseen in the near future [57]. The scenario

of new generation warfare can be completely revolutionized comprising an autonomous ground [119].

It is also feasible to improve the SAS-GP in the direction of automatically broadcasting the traffic information around the clock or in the direction of freeing a lane for vehicles with authority like police or ambulance. Such improvements require only modifying the definition of the geocast domain in SGA. In addition, It is attainable to send video messages using SAS-GP since it only requires a very small amount of data (around 50 bytes that can be reduced by using coding techniques) during its operation which represents a small portion of the packet size.

In addition, security in such protocol is a must and is achievable by deploying encryption, digital signature, and context aware security techniques.

Appendix A

Proof of Corectness for Wating Time Equations

A.0.1 Proof of Equation 4.2

The (WT_{sp}) is calculated when the size of the packet is 1, 50 or 1500 bytes while the number of nodes is 1, 300, or 1000 nodes and the distance between the sender and the receiver is 1 or 250 meters.

$$WT_{sp} = 2 \times \left[\left(\frac{1}{c_{min}} \right) + \left(\frac{c}{R} \right) \right] \times \frac{300}{250} = 0.0000936seconds \quad (A.1)$$

$$WT_{sp} = 2 \times \left[\left(\frac{1500}{c_{min}} \right) + \left(\frac{c}{R} \right) \right] \times \frac{300}{250} = 0.0137seconds \quad (A.2)$$

$$WT_{sp} = 2 \times \left[\left(\frac{50}{c_{min}} \right) + \left(\frac{c}{R} \right) \right] \times \frac{300}{250} = 0.00051seconds \quad (A.3)$$

$$WT_{sp} = 2 \times \left[\left(\frac{1}{c_{min}} \right) + \left(\frac{c}{R} \right) \right] \times \frac{1000}{250} = 0.0000372seconds \quad (A.4)$$

$$WT_{sp} = 2 \times \left[\left(\frac{1500}{c_{min}} \right) + \left(\frac{c}{R} \right) \right] \times \frac{1000}{250} = 0.04578seconds \quad (A.5)$$

$$WT_{sp} = 2 \times \left[\left(\frac{50}{c_{min}} \right) + \left(\frac{c}{R} \right) \right] \times \frac{1000}{250} = 0.001685seconds \quad (A.6)$$

$$WT_{sp} = 2 \times \left[\left(\frac{1500}{c_{min}} \right) + \left(\frac{c}{R} \right) \right] \times 1000 = 11.44seconds \quad (A.7)$$

$$WT_{sp} = 2 \times \left[\left(\frac{1}{c_{\min}} \right) + \left(\frac{c}{R} \right) \right] \times 1000 = 0.009 \text{seconds} \quad (\text{A.8})$$

$$WT_{sp} = 2 \times \left[\left(\frac{50}{c_{\min}} \right) + \left(\frac{c}{R} \right) \right] \times 1000 = 0.383 \text{seconds} \quad (\text{A.9})$$

$$WT_{sp} = 2 \times \left[\left(\frac{1500}{c_{\min}} \right) + \left(\frac{c}{R} \right) \right] \times 1 = 0.011446 \text{seconds} \quad (\text{A.10})$$

$$WT_{sp} = 2 \times \left[\left(\frac{1}{c_{\min}} \right) + \left(\frac{c}{R} \right) \right] \times 1 = 0.009297 \text{seconds} \quad (\text{A.11})$$

$$WT_{sp} = 2 \times \left[\left(\frac{50}{c_{\min}} \right) + \left(\frac{c}{R} \right) \right] \times 1 = 0.000383 \text{seconds} \quad (\text{A.12})$$

A.0.2 Proof of Equation 4.9

In order to prove this equation, the value of size should be equal or greater than one. This is because the behavior of this equation is to decrease with the decrease in size. Figure A.1 shows the domain of the equation when maximum speed is set to 45 meter/second and the size of the packet varies from 1 to 1500 bytes.

$$T_{\text{del}} = \frac{\ln \left(\frac{m \times 8 \times 299792458}{2097152} \right)}{50} \geq 1. \quad (\text{A.13})$$

$$m \geq 0.00699 \text{bits}. \quad (\text{A.14})$$

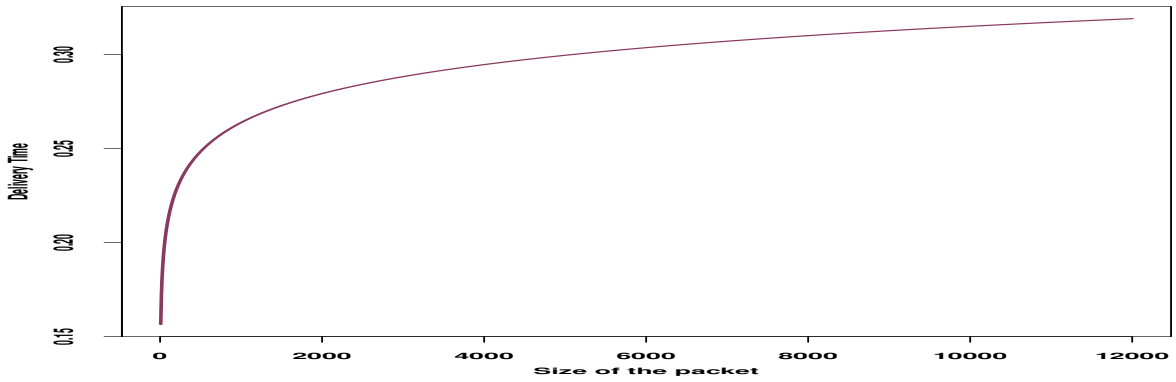


Figure A.1: The domain of equation 4.9 with different sizes

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